*Proceedings of the 2010 Winter Simulation Conference*
*B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, eds.*

# FLIGHT ASSIGNMENT PLAN FOR AN AIR CARGO INBOUND TERMINAL

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## ABSTRACT

The paper studies the modeling and optimization for the flight assignment plan for an air cargo inbound terminal. A multi-objective Mixed Integer Programming (MIP) model is formulated to determine this plan. A set of non-dominated solutions are obtained by solving this multi-objective model and they are further analyzed by a simulation model to identify the best one.

## 1 INTRODUCTION

This research is motivated by a study at an air cargo terminal which handles the inbound and transshipment cargos for a top tier international airline at its hub airport. The basic layout of the inbound cargo terminal can be illustrated by the graph below in Figure 1. It primarily consists of ramp zone facilities, PCHS system (material handling and storage system), and break-bulk workstation areas.

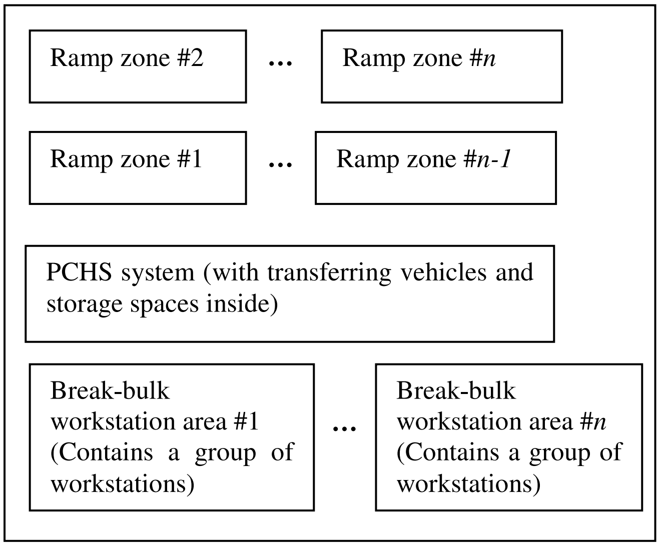

Figure 1: A simple illustration of the basic layout for a terminal

To handle the huge volume of cargos daily, the terminal is equipped with various facilities and equipments, including ramps, storage spaces and break-bulk stations, as seen in Figure 1. Currently, the terminal operator assigns the resources according to the flight number, i.e., for the cargo which comes from the same flight number, it will go through the same resources/equipments. The quality of this assignment greatly affects the overall efficiency of the terminal operations. It is observed that there are various problems or inefficiency caused by the existing assignment plan used by the terminal operator. First of all, many transshipment cargos have to travel through a much longer way to the outbound terminal although there are shorter paths available. In addition, imbalanced workload at the different stations causes congestion to the cargo flow.

Hence, the main motivation of this study is to reduce the flow time and congestion by finding an optimal flight-to-ramp-to-workstation assignment. Related works are summarized as follows.

Nozick and Morlok (1997) presented a model for the planning of operations of an inter-model truck-rail server and the fixed schedule used is similar to what we use. Although our objective is to improve operations of an air cargo, it is very similar to the tactical design for a container terminal. The assignment problem itself is tackled in Bish (2003) and its heuristic algorithm approach used to solve the NP-Hard problem also gives implications for our problem modeling of flow time, which is in turn covered in Vis and Koster (2003). Improvements like increasing throughput and decreasing turnaround time, as well as allocating space to effectively assigning operations to reduce traveling and delivery cost, are motivated by Preston and Kozan (2001) and Kim and Park (2003) respectively. A decision support system for the operations management of an inter-modal container was presented in Gambardella et al. (1998) whereas Macro and Samli (2002) and Yun and Choi (1999) covered application of simulation tools to efficiently allocate resources. Similar strategic planning problems have been studied extensively and most of them focused on the reduction of traveling cost and handling cost within the system. Tsui and Chang (1990) proposed a bilinear programming model and a straightforward solution method for a local optimal solution to a freight terminal assignment problem and later Tsui and Chang (1992) improved solution time by using another heuristics approach to solve this same problem. Meanwhile, Gue (1999) researched about reducing material flow cost for a long term planning problem whereas Bartholdi et al. (2000) described a set of models that guided a local search routine to generate a layout to minimize total cost. These works investigated the possible causes of congestion, with the help of queuing theory. That motivates our study to place extra emphasis on both the traveling and waiting time.

The rise of Toyota Production Systems, Kanban Systems and Just-in-time emphasized the important of balancing the workload among facilities during each time window. Houghton and Protougal (1997) created a dynamic programming model which has multiple objectives and constraints. Berrada and Stecke (1986) modeled their problems with the Integer Programming approach and solved it with Branch and Bound method before Wilson (1992) modified the objectives and solved it with a heuristic algorithm. Subsequently, Khouja and Conrad (1995) tried to assign the customer groups to employees, hoping to minimize the deviation of the processing time of different groups from an employee point of view. A more complicated models is Sawik (2002)'s integrated formulation for both the scheduling and balancing of an assembly line system which took into account task precedence information, time limitations and other important information.

From these literatures, it can be seen that similar problems have been addressed before. However, these papers alone are not sufficient in solving our problem efficiently. Although simulation is a good method because we can make less assumption as compared with MIP, it is too time consuming to enumerate all possible cases. Furthermore, the lack of measurement for congestion effects was common in all the above mentioned works regarding container operations. Therefore, our paper will look into the possibility of combining the MIP model with a simulation model to cover for each others' shortcomings.

A mixed integer programming model is formulated for our problem to improve the assignment plan because it is not practical to formulate it as a pure LP/IP model. In addition, the model is formulated as a multi-objective model because it is not possible to formulate it as a single objective problem.

Although much less time-consuming than simulation, our MIP model cannot capture some factors such as queuing time and congestion effects directly. Hence, three performance measures are proposed to capture the objective of improving the quality of cargo assignment to reduce congestion caused by imbalanced workload without compromising, or even improving, the flow time.

Firstly, average flow time of ULD is used as a straightforward measure of system efficiency. It is made up of movement, processing and queuing time but excludes storage time because it might be caused by other reasons. Next, Capacity Ratio (CR), which is defined as the ratio of the current assignment workload at the equipment to the nominal processing capacity of the equipment during a fixed time period, is actually the measure of utilization of each facility and is used to estimate the degree of workload congestion. CR is usually less than 1 but in this case it is calculated in a relaxed manner by including work in queue and therefore can go above 1 in this case. Finally, the exceeding value of the capacity ratio over 1 is used to model over-utilization. However, these performance measures can only estimate these factors to a certain extent and more importantly, the flow time obtained through solving the MIP does not include the waiting time. Hence, a set of non-dominated solutions are obtained from the MIP and they are fed into a simulation model to identify the best solution from this pool of solutions. With the simulation model, we hope to test the non-dominated solutions obtained from the multi-objective MIP under relaxed assumptions and arrive at a more accurate solution to the problem.

Although this paper is based on a particular real life problem, it should offer some useful information for future related researches. It provides a novel and comprehensive approach to address the assignment problem and offers an MIP model that can evenly allocate the cargo workload to the equipments and improve the overall movement efficiency. In addition, it proposes an applicable hybrid framework to work on air cargo terminals with both optimization and simulation techniques whereby simulation is used to further test the non-dominated solution obtained from MIP. Finally, this approach extends the planning problem from daily operations to the weekly tactical plan and thus gives assistance in the mid to long term business process reengineering of similar problems. Hopefully this research would provide a useful foundation for future researches. The rest of this paper is organized as follows. The MIP model will be presented in Section 2. In Section 3, we will describe our simulation model. Solution and results will be presented in Section 4. Finally we will give the conclusion and future research in Section 5.

## 2 PROBLEM DEFINITION

A mixed-integer programming model, with multi objectives based on three performance measures, is used to solve the flight to ramp zone and break-bulk area assignment problem. The three objectives of the model are minimizing overall flow time for all cargos in movement, balancing workload and reducing cargo overloading at facilities respectively.

Time horizon is set to be one week and the facility's natural processing capacity is in terms of the number of cargos processed within a given time interval that is set to be 5 minutes and 1 hour for the one-day and one-week problems respectively. The various times, workload coefficients, processing and arrival rates are all estimated statistically based on actual data collected coupled with equipment specifications.

The computation experiments are implemented using solution package ILOG CPLEX 8.0, on a PC Pentium IV 2.60 GHz platform with 512 MB build-in memory.

### 2.1 Assumptions

Various assumptions are made to control the size of the problem, namely:

1. "Towing and unloading time" between arrival of flights at the airport and the arrival or cargos at the cargo terminal is ignored.
2. We assume that there is no interaction between the cargo arrivals from different flights to facilitate estimation of the cargo arrival behavior and workload profile.
3. Arrival process of cargos at the ramp is assumed to be constant.
4. Processing rate of cargos at the facilities is assumed to be constant.
5. We assume that ramp zones and workstation areas have unlimited resources.
6. The processing rate for freighter flights is twice as that of passenger flights at breakbulk workstation area. However, processing rate at ramp zone is the same.

## 2.2 Notations

In this section, the objectives, constraints, and variables are stated.

*Set notations and indices*

| | |
|---|---|
| $I^p$ | the set of all incoming passenger flights; |
| $I^f$ | the set of all incoming freighter flights; |
| $J$ | the set of ramp zones; |
| $K$ | the set of break-bulk workstation areas; |
| $T$ | the set of time intervals; |
| $i^p$ | an incoming passenger flight, $i^p \in I^p$ ; |
| $i^f$ | an incoming freighter flight, $i^f \in I^f$ ; |
| $j$ | a ramp zone, $j \in J$ ; |
| $k$ | a break bulk workstation area, $k \in K$ ; |
| $t$ | a time interval (time unit) in one week, $t \in T$ ; |

*Variables*

| | |
|---|---|
| $x_{i^p jk}$ | = 1, if the passenger flight $i^p$ is processed at ramp zone $j$, and then goes to workstation area $k$ for break bulk; 0 otherwise; |
| $y_{i^f jk}$ | = 1, if the freighter flight $i^f$ is processed at ramp zone $j$, and then goes to workstation area $k$ for break bulk under parallel processing by double workforce; 0 otherwise; |
| $CR_j^t$ | the capacity ratio for ramp zone $j$ during time interval $t$, which denotes the ratio of actual work load to the nominal processing capacity of a ramp zone; |
| $CR_k^t$ | the capacity ratio for workstation area $k$ during time interval $t$, which denotes the ratio of actual workload to the nominal processing capacity of a workstation area; |
| $a_j^t$ | the exceeding value of $CR_j^t$ over 1, if $CR_j^t$ is greater than 1; 0 otherwise. It is an auxiliary variable which denotes the exceeding value of the capacity ratio of real workload over the processing capacity of a ramp zone; |
| $b_k^t$ | the exceeding value of $CR_k^t$ over 1, if $CR_k^t$ is greater than 1; 0 otherwise. It is an auxiliary variable which denotes the exceeding value of the capacity ratio of real workload over the processing capacity of a workstation area; |

*Input parameters*

| | |
|---|---|
| $U^{i^p}$ | the number of ULDs on passenger flight $i^p$ ; |
| $U^{i^f}$ | the number of ULDs on freighter flight $i^f$ ; |
| $T_{jk}$ | equipment transferring time from ramp zone $j$ to workstation area $k$ ; |
| $C_j$ | the processing capacity of ramp $j$ ; |
| $C_k$ | the processing capacity of workstation area $k$ ; |
| $m_{i^p jk}^t$ | the workload at ramp zone $j$ in terms of the number of ULDs during interval $t$ for a passenger flight $i^p$, which is assigned to ramp zone $j$, and workstation area $k$ ; |

| | |
|---|---|
| $m^t_{i^f jk}$ | the workload at ramp zone $j$ in terms of the number of ULDs during interval $t$ for a freighter flight $i^f$, which is assigned to ramp zone $j$, and workstation area $k$; |
| $n^t_{i^p jk}$ | the workload at workstation area $k$ in terms of the number of ULDs during interval $t$ for a passenger flight $i^p$, which is assigned to ramp zone $j$, and workstation area $k$; these ULD are under processing by one checking team; |
| $n^t_{i^f jk}$ | the workload at workstation area $k$ in terms of the number of ULDs during interval $t$ for a freighter flight $i^f$, which is assigned to ramp zone $j$, and workstation area $k$; these ULD are under processing by two checking teams; |

### 2.3 Model formulation

Objectives Type I (minimize the overall flow time):

$$\text{Minimize} \quad \sum_{i^p \in I^p} \sum_{j \in J} \sum_{k \in K} U^{i^p} T_{jk} x_{i^p jk} + \sum_{i^f \in I^f} \sum_{j \in J} \sum_{k \in K} U^{i^f} T_{jk} y_{i^f jk} \tag{1}$$

Objectives Type II (minimize the maximal pair-wise difference of workload):

$$\text{Minimize} \quad CR_{\max\_r}, \tag{2}$$

$$\text{Minimize} \quad CR_{\max\_b}, \tag{3}$$

Objectives Type III (minimize the overall exceeding value of workload):

$$\text{Minimize} \quad \sum_{j \in J} \sum_{t \in T} a_j^t, \tag{4}$$

$$\text{Minimize} \quad \sum_{k \in K} \sum_{t \in T} b_k^t, \tag{5}$$

*Subject to:*

Assignment constraint:

$$\sum_{j \in J} \sum_{k \in K} x_{i^p jk} = 1, \qquad \text{for } \forall i^p \in I^p \tag{6}$$

$$\sum_{j \in J} \sum_{k \in K} y_{i^f jk} = 1, \qquad \text{for } \forall i^f \in I^f \tag{7}$$

Capacity Ratio constraint for each ramp zones / workstation area:

$$\sum_{i^p \in I^p} \sum_{k \in K} x_{i^p jk} m^t_{i^p jk} + \sum_{i^f \in I^f} \sum_{k \in K} y_{i^f jk} m^t_{i^f jk} = CR_j^t C_j, \qquad \text{for } \forall t \in T, \forall j \in J, \tag{8}$$

$$\sum_{i^p \in I^p} \sum_{j \in J} x_{i^p jk} n^t_{i^p jk} + \sum_{i^f \in I^f} \sum_{j \in J} y_{i^f jk} n^t_{i^f jk} = CR_k^t C_k, \qquad \text{for } \forall t \in T, \forall k \in K, \tag{9}$$

The additional constraints for $CR_{\max\_r}$ and $CR_{\max\_b}$:

$$CR^t_{j_1} - CR^t_{j_2} \le CR_{\max\_r}, \qquad \text{for } \forall t \in T, \forall j_1 \in J, \forall j_2 \in J, \tag{10}$$

$$CR^t_{k_1} - CR^t_{k_2} \le CR_{\max\_b}, \qquad \text{for } \forall t \in T, \forall k_1 \in K, \forall k_2 \in K, \tag{11}$$

Additional constraint for Objective Type III:

$$CR_j^t - 1 \le a_j^t, \quad \text{for } \forall t \in T, \qquad \forall j \in J, \tag{12}$$

$$CR_k^t - 1 \le b_k^t, \quad \text{for } \forall t \in T, \qquad \forall k \in K, \tag{13}$$

Integrality and non-negativity constraint:

$$x_{ijk} \in \{0,1\},\ y_{i^f jk} \in \{0,1\},\ CR_j^t \ge 0, CR_k^t \ge 0, a_j^t \ge 0,\ b_k^t \ge 0 \tag{14}$$

The overall flow time of all ULDs is the most important measurement for evaluating the system efficiency. The expression (1) captures the pure movement time for each flight but the waiting and intermediate storage times are not directly captured in the linear model. However, it is indirectly captured by the capacity ratio. Objectives (2) and (3) aim at minimizing the maximal pair-wise differences of workload at ramp zones and break-bulk areas so as to balance the workload. Objectives (4) and (5) are meant to minimize over-utilization so that the utilization ratio of equipment will be maintained at an ideal rate.

Constraint (6) and (7) ensure that only one ramp zone and one break-bulk area are assigned for one passenger flight and vice versa. Constraints (8) and (9) capture the workload at the ramp zone and break-bulk area during each time window. It is not difficult to see that, the left-hand-side of the above equation gives the workload assigned to a given facility at a given time interval. The right-hand-side is the product of the capacity ratio (for this facility during a given time interval) and the facility's capacity. The workload coefficients are estimated from real data, assuming a uniform distribution for the workload within any specific period of time.

Constraints (10) to (11) are meant to capture the maximum pair-difference of each two capacity ratios. By reducing $CR_{\max\_r}$ and $CR_{\max\_b}$, the difference between any two facilities could be lessen, and the workload would be distributed more evenly. Constraints (12) and (13) are the additional constraints to capture over-utilization at each facility. If the capacity ratio is greater than 1, the facility is over utilized and the exceeding value $a_j^t$ or $b_k^t$ will be greater than 0. Finally, Constraint (14) is the integrality and non-negativity constraint for all variables.

## 3 SIMULATION MODELING

The major framework of the simulation model is shown in Figure 2 below.

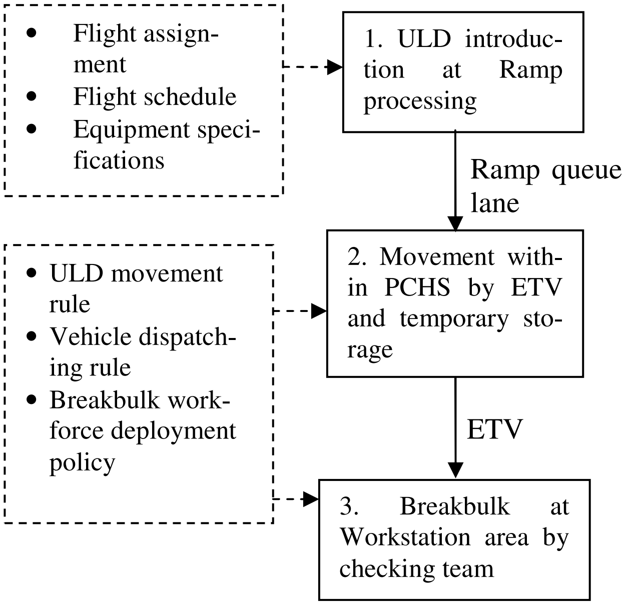

Figure 2: the simulation model framework

The three solid boxes are the major physical flows in the simulation model. As seen in Figure 2, the first process of cargo flow starts from ULD introduction process at the ramp zone. Subsequently the ULDs are moved by the ramp queue lane onto ETV (Transfer Vehicle) which will then transfer them to the PCHS for temporary storage. This process is performed in simulation based on the direction of the flight assignment plan, the flight arrival schedule, and the equipment specifications.

The second step of ULD movement is represented in the simulation by various movement procedures performed on ETVs in the PCHS. In this process, the ULD movement rule and the vehicle dispatching rule together control the movement mechanism of ULDs within PCHS.

Finally, the ULD is transferred to breakbulk workstation areas via the ETV. The break-bulk process is performed by the checking teams at the workstations. Hence, at this stage, the ULD movement rule and the break-bulk workforce deployment rule dictate the processing at workstation areas.

The dashed box at the top-left of Figure 2 indicates the inputs information such as flight assignments, arrival times, aircraft types, and equipment specifications for the simulation. These inputs are used to decide the times, paths, and quantities for the ULD movements and the accuracy of these input parameters will affect the quality of the simulation output.

Finally, the dashed box at the top-right includes the various rules and policies for ULD movements, vehicle dispatching, and checking team deployment that we have used for the simulation model. Firstly, vehicles are scheduled according to a first in first out rule according to the ULD request sequence. Secondly, the ULD will move from its origin to its destination via the shortest possible path. Finally, checking team is assigned to a flight in advance and the ULD will stay in the buffer inside PCHS until that team is available.

Subsequently, the simulation model is implemented using AutoMod. There are primarily three types of systems included in the model design for our problem using AutoMod, namely the processing system, the conveyor system, and the path mover system.

The process system in this model represents the air cargo movement processes, such as the hoist movement process, the break-bulk process at break-bulk workstation area, etc. Similarly, the ramp queue lanes at the ground level of the cargo terminal are defined as the conveyor system in the simulation model. Finally, the path mover system is employed to represent the movement of the ETV within the PCHS system, in which the ETV moves between the loading points and unloading points for the ULD to pick-up and drop-off.

## 4 SOLUTIONS AND RESULT PRESENTATION

As stated in the previous chapters, a set of non-dominated solutions are obtained by the MIP model before they are measured against one another through simulation to see which one provides the shortest overall flow time.

A ε-constraint approach, which minimizes one objective while transforming others to constraints, is used to explore the efficient solutions for the multi-objective MIP problem. The $\varepsilon$ serves as the reference value which is determined by the Decision Maker (DM), offering him the flexibility to adjust the right-hand-side of the secondary constraint values to adapt to his aspiration level. Without loss of generality, fine-tuning the value of $\varepsilon$ could improve the values of the objective-turned-constraints.

For our problem, several sets of the values of $\varepsilon$ were set according to their respective most desirable values, obtained from solving the single objective MIP without considering other objectives. The different levels of $\varepsilon$ for objectives (2), (3), (4) and (5) are summarized below.

Table 1: Experiment designs

| Objective sets | Adjustable ranges |
|---|---|
| Objective (2), Objective (3) | 110%, 150%, 200% |
| Objective (4), Objective (5) | 150%, 200% |

Next, the primary objective is maintained as the unique objective function for optimization while the four respective ε values are varied so as to obtain all the different combinations of them, and hence the non-dominated solutions of the different models. Computation procedures are deployed using solution package ILOG® CPLEX 8.0, on a PC Pentium IV 2.60 GHz platform, with 512 MB build-in.

Among all the solutions obtained, there are 13 distinguished efficient solutions as shown in Table 2.

Table 2: The 13 distinguished efficient solutions from the multi-objective MIP model

| Design | Obj (1) | Obj (2) | Obj (3) | Obj (4) | Obj (5) |
|---|---|---|---|---|---|
| 1 | 1719.81 | 2 | 1.2 | 17.2 | 6.4 |
| 2 | 1740.86 | 2 | 1.2 | 17 | 4.8 |
| 3 | 1741.58 | 2 | 1 | 17.2 | 5.4 |
| 4 | 1742.56 | 2 | 1 | 17.2 | 5.4 |
| 5 | 1756.07 | 2 | 1 | 17.2 | 4.6 |
| 6 | 1757.51 | 2 | 1.2 | 16.8 | 4.4 |
| 7 | 1831.54 | 2 | 1.2 | 12.8 | 6.4 |
| 8 | 1831.54 | 2 | 1.4 | 12.8 | 6.4 |
| 9 | 1831.74 | 2 | 1.2 | 12.8 | 6 |
| 10 | 1831.79 | 2 | 1.4 | 12.8 | 6.4 |
| 11 | 1831.94 | 2 | 1.4 | 12.8 | 6.4 |
| 12 | 1837.52 | 2 | 1 | 12.8 | 5.6 |
| 13 | 1845.53 | 2 | 1.2 | 12.8 | 4.8 |

All these distinguished efficient solutions are then tested with our simulation model with the appropriate warm-up period, run length and number of replications,. Table 3 shows the results from the simulation runs.

Table 3: The average flow time for the 13 distinguished efficient solutions from multi-objective MIP model

| Design | Average Flow time |
|---|---|
| 1 | 6077.2 ± 5.9 |
| 2 | 5849.9 ± 5.9 |
| 3 | 6063.9 ± 5.8 |
| 4 | 5890.5 ± 5.7 |
| 5 | 6173.7 ± 6.4 |
| 6 | 5939.1 ± 6.0 |
| 7 | 5879.2 ± 5.6 |
| 8 | 5832.1 ± 5.7 |
| 9 | 5879.5 ± 5.9 |
| 10 | 6164.5 ± 6.2 |
| 11 | 5887.2 ± 5.7 |
| 12 | 5859.9 ± 5.8 |
| 13 | 5833.7 ± 6.0 |
| Original plan | 6841.0 ± 6.9 |

The simulation results indicate the design 8 is the best solution. Moreover, compared to the original assignment plan adopted by the terminal operator, there is a reduction of 14.7% decline in the overall flow time.

Another observation is that design #8 did not have the shortest traveling time in the MIP model and this discrepancy is probably caused by the congestion effect that is not directly modeled in the MIP. This is reiterated by the fact that it has the smallest value for objective (2) and (3) and second smallest value for objective (4) and (5).

## 5 CONCLUSIONS

The paper studies the modeling and optimization for an air cargo inbound terminal. Many factors affect the operation performances but the only factors investigated in this paper are cargo flow time, workload balancing and congestion effects.

A Mixed Integer Programming model is formulated to improve the assignment plan because it is impractical to formulate it as a pure LP/IP model. In addition, the model is formulated as a multi-objective model because it is not possible to formulate it as a single-objective problem. From this model, a set of non-dominated solutions are obtained and further analyzed by a simulation model to identify the best one.

Many assumptions are made to simplify the problem and only the significant factors are modeled. Although some accuracy is sacrificed, it helps to control the size of the model. To ensure that these assumptions would not greatly affect the quality of the solutions obtained, simulation is used to test these solutions under relaxed assumptions.

There are some aspects for future improvements on this research work because of some practical constraints. First of all, it would be better if the MIP can produce more efficient solutions. Secondly, it would be more realistic if the simulation model could cover the entire cargo terminal. Thirdly, the manpower planning problem can be covered in this problem to give a more complete view. Finally, priorities and human interventions can be included in future researches.

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