Developing a Mathematical Model for Scheduling of Turnaround Operations (Low Cost Airline as a Case Study)

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Abstract: On-time departure performance is important for airlines that seek the highest satisfaction of their passengers. The main component of achieving on-time departure is being able to complete the turnaround operations of an aircraft within the scheduled time. To address this problem, the present paper examined planning and scheduling of turnaround operations in the low cost airline industry. A mathematical model, named 'TurnOper_LP' was developed for a low-cost Turkish airline to identify the critical path of turnaround operations and the optimal turnaround time. The results of the model in terms of optimised turnaround times are then analysed and an example of schedule of turnaround operations is presented.

Key Words: Turnaround operations, low cost airlines, mathematical modelling, flight types

1.   Introduction

From the airline business point of view, turnaround operations are one of the most important processes in the Airline Industry. Therefore, many airline companies especially Low Cost Airlines (LCAs) have been working on improving the efficiency of the turnaround process with an objective to reduce turnaround time. This can be considered as one of the serious challenges that decision makers face in planning and scheduling turnaround operations with the view to achieving minimum cost and most efficient performance. Hence, a proper planning and scheduling of turnaround operations for LCA companies is very important since every second on the ground make these companies loose potential profit. In this sense, most LCA companies have problems in completing turnaround operations on time which leads to delays. For this reason, such companies strive to optimally schedule their turnaround operations by using most up-to-date data collected from their hub airports.

Scheduling of turnaround operations have been investigated by a number of researchers including, but not limited to, Wu and Caves (2004) who develop a stochastic mathematical model for optimising aircraft turnaround time at an airport. Sanz de Vicente (2010) analyses different scenarios in ground handling operations of low-cost and conventional carrier according to their parking positions (apron or terminal). Kunze, Oreschko and Fricke (2012) model the randomness of turnaround operations for each fight considering the operational and strategic information. Mao, Roos and Salden (2009) introduce a stochastic programming model to schedule aircraft ground operations within high uncertainty environment. Han, Chung and Liang (2006) propose a fuzzy critical path method for planning of the airport cargo-ground operations. Vidosavljević and Tošić (2010) present an aircraft turnaround model using Petri Nets (PN). The model includes all turnaround operations such as air-bridge positioning/removal, passengers' disembarking/boarding, potable water loading, catering, lavatory services, baggage loading/unloading and fuelling. Gomez and Scholz's (2009) suggest a direct cost method for improving turnaround operations for a low cost airline.

However, previous research focuses on achieving optimal schedules of turnaround operations for different types of flights. These types include arrivals from a domestic destination to the hub airport turning around to a departure to another domestic destination, arrival from a domestic airport turning to a departure to an international destination, arrival from an international origin airport and departure to a domestic airport, and finally arrival from an international airport departing to another international destination. The main advantage of considering the above different types of arrival-departure turnaround pairs in the proposed optimisation model 'TurnOper_LP' of turnaround operations is that it includes turnaround operations/ times that are different from

one flight type to another and hence, a realistic schedule of turnaround operations taking into consideration the different flight types is produced. Ultimately, the main aim of this study is to generate an optimised schedules profile of turnaround operations of different flight types for a low-cost airline while achieving the minimum completion time.

2. Methodology

2.1 Data Collection

In the data collection phase, the non-participant observation technique is selected. According to the non-participant observation type of data collection, the observer does not intervene with the participants. The data is mainly collected by observing the system from a distance while taking notes. Observations are performed over a 3-day site visit to the hub airport of the low-cost company. At the airport, the sequence of the operations, number of resources used and the starting and finishing time of each operation involved in the turnaround process are observed and recorded on a specific research instrument paper that was prepared prior to the observation process.

Since there is more than one flight type; *domestic-domestic*, *domestic-international*, *international-domestic*, and *international-international*, the data are collected by dividing the flight types into 4 different clusters/groups and hence, cluster sampling is decided to be used as a data collection technique. Cluster sampling is a type of sampling method which divides the population into different group of samples (Saunders et al. 2009).

2.2 Process Mapping

The most used list of turnaround operations is in (Sanchez, 2009). However, in order to model the turnaround operations of low-cost airlines and to identify constraints, a process-mapping technique is used. For each turnaround operation inputs, outputs, constraints and resources are identified. The parent process-map diagram of the turnaround operations is shown in figure 1
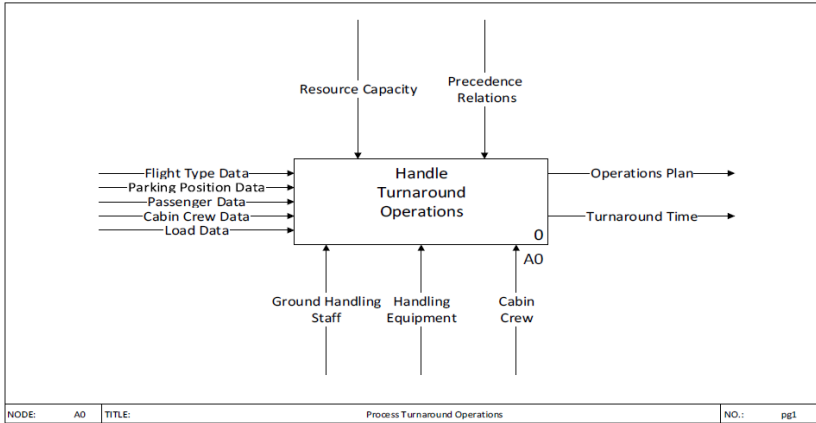

Figure 1: Process Map Level 1 (Parent Diagram)

The process map presented in figure 1 is called 'Parent Box' and has an ID as 0 with a sub-diagram ID node number/ index equal to A0. In this diagram, the inputs to the handling activity of the turnaround are flight type data, parking position information, passenger data, cabin crew data and load data which contains the information about the amount of fuel, clean water and baggage is needed for or expected at that flight type. The outputs of this process are schedule(s) of turnaround operations and the optimal turnaround time. There are some constraints that would control/ restrict the turnaround activity including precedence relationship of operations and resource capacities. Resources which are used during this process, are ground handling/ turnaround operations staff, handling equipment and cabin crew.

The turnaround operations module presented in figure 1 is then decomposed into a child diagram that involves a number of detailed turnaround operations. A detailed process map of DomInt and IntDom flight types is presented in figure 2.
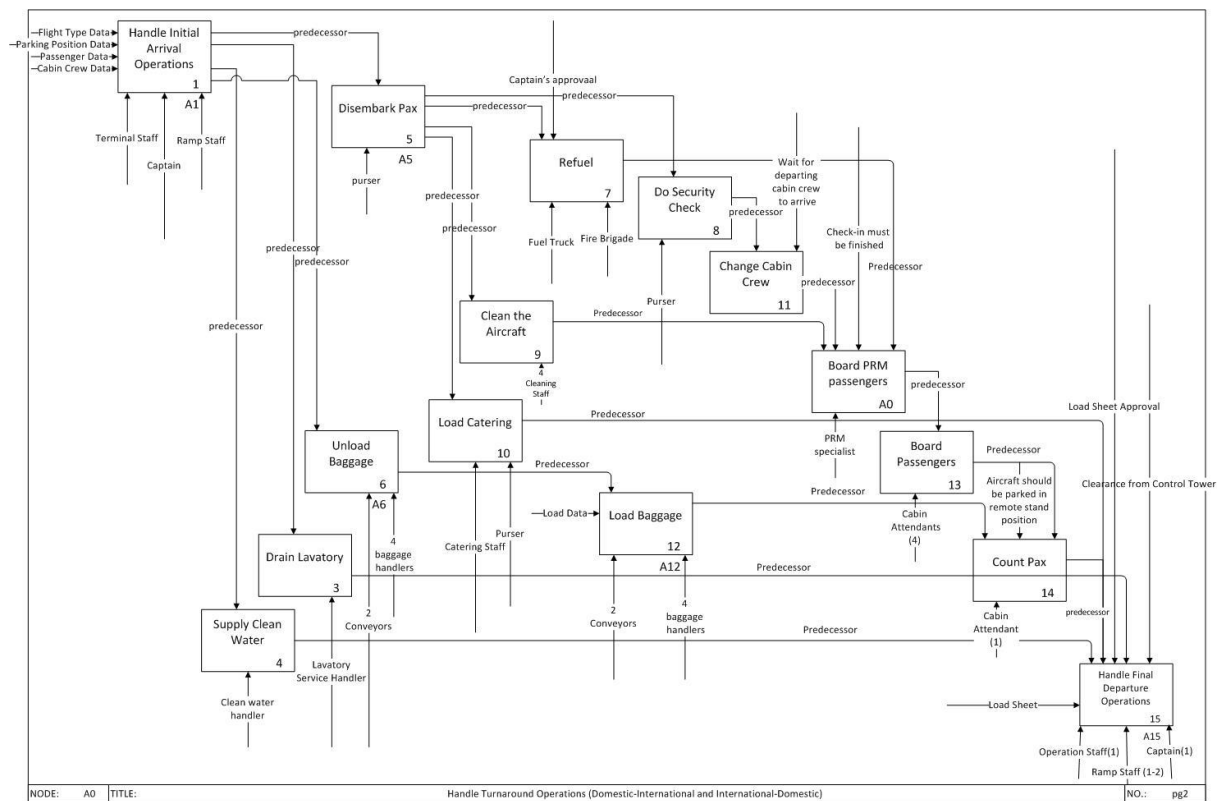

Figure 2: Turnaround Processes of DomInt and IntDom flight types (Child Diagram)

In figure 2, the process map begins with the initial arrival operations with inputs of flight type data, parking position, passenger and cabin crew information. Terminal staff, captain and ramp staff are involved as resources in this process. After disembarking of all passengers; baggage unloading and lavatory and potable water services operations begin.

The process of passengers disembarking is a predecessor of many other processes such as refuelling, security checks, aircraft cleaning and catering. In order to start the refuelling process another constraint has to be satisfied, the captain's approval on the amount of fuel to be lifted. Catering loading is handled by catering staff often with participation by the flight pursuer. Another output of passenger disembarking is considered as a constraint that would restrict security checks where the cabin crew checks inside the aircraft in case someone left their stuff. The output of aircraft cleaning is a predecessor to boarding of PRM passengers. Waiting for the departing crew to arrive is another constraint that would restrict the "change cabin crew" process. The output of this process is a constraint to the passengers boarding process because passengers cannot be boarded unless the new crew are onboard the aircraft. The baggage unloading process is the constraint for baggage loading process. After boarding PRM passengers by a PRM specialist, passenger boarding starts. Passenger boarding process is handled by cabin attendants as well. The output of this process is constraint of counting the passengers. Another constraint of this process is baggage loading and aircraft should be parked in remote stand position. As a final step, the final departure operation is handled by operation staff, ramp staff and captain. Input of this process is the load sheet approval. The constraints of this process are predecessors from the drain lavatory, supply clean water, load catering operations beside other constraints including load sheet approval and clearance from the control tower.

2.3 Development of the Mathematical Model

The first step of developing a mathematical optimisation model involves setting a number of assumptions. The next sub-sections will reflect the step-by-step stages of the model development starting from the modelling assumptions.

2.3.1 Modelling Assumptions

Managing turnaround operations is a complex process with many variables. For this reason, a number of assumptions are set in order to make the problem solvable in a polynomial time.

These assumptions are:

- The following operations are considered necessary in every flight:
  - Cabin Crew change
  - Fuelling
  - Lavatory Service
  - Water Service
  - Boarding and disembarking PRM passengers
- All equipment and other vehicles are ready in the parking area before aircraft arrives
- There is no restriction on the number of resources required for each operation.

2.3.2 Model Indices & Decision Variables

- Model Indices

Here, j and k are the turnaround operations and they belong to a set where j or k starts from 1 to total number of operations in the system.

The parameters used in this model are:

- p_j which, is the processing time of job j
- $M = \Sigma_{j=1}^{n} p_j$ is the upper bound on the total duration of operations.

- Decision Variables

The decision variables used in the developed mathematical model are:

C_{max} = Completion time of the last job,
S_j = Start time of job j,
$y_{jk} = \begin{cases} 1, if\ job\ j\ is\ proccessed\ before\ job\ k \\ 0, otherwise \end{cases}$

2.3.3 Development of the Linear Programming Model

The developed mathematical model 'TurnOper_LP' based on the aforementioned assumptions is as below:

$$\text{Minimize } C_{\max} \hspace{4cm} (1)$$

subject to

$$S_k \geq S_j + p_j \hspace{2cm} \forall_{j \to k} \in A \hspace{1cm} (2)$$

$$C_{\max} \geq S_j + p_j \hspace{2cm} \forall_j \in J \hspace{1cm} (3)$$

$$S_k \geq S_j + p_j - M\left(1 - y_{jk}\right) \hspace{1cm} \forall_{j,k} \in B \mid j \neq k \hspace{1cm} (4)$$

$$S_j \geq S_k + p_k - M\ y_{jk} \hspace{1cm} \forall_{j,k} \in B \mid j \neq k \hspace{1cm} (5)$$

$$S_j, C_{\max} \geq 0\ ,\ y_{jk} \in \{0,1\} \hspace{1cm} \forall_{j,k} \in J \hspace{1cm} (6)$$

The objective function (1) will find the minimum completion time of the final job taking into account the following constraints:

Constraint (2) ensures that the turnaround operations must be scheduled taking into account the precedence relationships of these operations. For example, refuelling needs to be finished before the passenger boarding can start. This constraint does not allow the model to schedule these two operations in parallel. It forces to assign the boarding to start after the finish time of the refuelling.

Constraint (3) makes sure that the completion time of any operation is the sum of start time and processing time of that operation. For example, if the start time of operation j=1 is at time 0, and if the processing time of that operation is 5 minutes, then the completion time of the operation will be at time 5.

Constraint (4) and (5) are the disjunctive constraints which do not allow these operations to be handled simultaneously (either j will precede k or k will precede j). An example to these two operations can be given as; loading the PRM passengers while the aircraft is on the remote parking stand cannot be handled at the same time while loading the Catering from the front door. Both uses the same door (space) hence with this constraint, it is not allowed for both operations to be handled simultaneously. The final constraint (6) ensures that Non-negativity is achieved and y_{jk} is binary.

After running this model, the start time of each operation will be generated and all the turnaround operations will be scheduled taking into consideration constraints (2-6). Hence the critical path can be identified after the start time of the operation is provided by the model, so that turnaround operations that will increase/ decrease the turnaround time will be identified if the time of these operations is increased/ decreased (such as passenger boarding).

3.   Case Study and Model Implementation

One of the Turkish low-cost airline companies is considered as a case study. This company is the most rapidly growing airline in Europe started its flight schedule in (2005). Fight network of the company has reached to 76 locations since then 31 domestic flights and 45 international in almost 30 countries. The company's hub airport is located in the first biggest city in Turkey. There are two airports in the city and the hub airport of the company is located in the smaller one, which has 3,500,000 passenger capacity per year and 8,760 aircraft per year. The hub airport of the low cost carrier has only 1 runway and the carrier uses 70% capacity of the airport.

In this case study, 5 same aircraft types are observed for 4 different inbound-outbound flight combination scenarios (DomDom, DomInt, IntDom, IntInt). In total, 20 observations are recorded. A number of on-site visits are performed in addition to other historical data collection including turnaround operations logic, their sequence and number of resources used in each process.

In addition, 4 different types of boarding and disembarking styles/ options in the turnaround process being investigated are considered including:
   ▪ Disembarking and boarding passengers via pax stairs.
   ▪ Disembarking and boarding passengers via airbridge.
   ▪ Disembarking passengers from airbridge and boarding from pax stairs.
   ▪ Disembarking passengers from pax stairs and boarding them via airbridge.

In order to run the developed model 'TurnOper_LP', data on the processing times of each operation are collected (operation times of each flight type and boarding and disembarking style are confidential and unauthorised to be published in this paper). After the data have been collected, durations of each operation are gathered and an average duration for each operation is calculated. Four different sets of inputs each representing a different flight type can then be individually fed into the developed model (referred as "coefficients" such as the processing time (p) of every operation (j)) to generate the required flight type schedule. 16 different schedules for 4 different flight types along with 4 different disembarking and boarding styles are generated.

The third style of boarding and disembarking of passengers for the DomInt flight type is presented in this work and will be discussed in the next sections. The developed mathematical optimisation model is translated to CPLEX software format.

3.1 Result Analysis and Discussion

The third style of disembarking and boarding passengers is considered before running the developed model in section 2.3. Results reveal that the total turnaround time is equal to 3180 seconds (53 minutes). A schedule for DomInt flight type is presented in Figure 3.
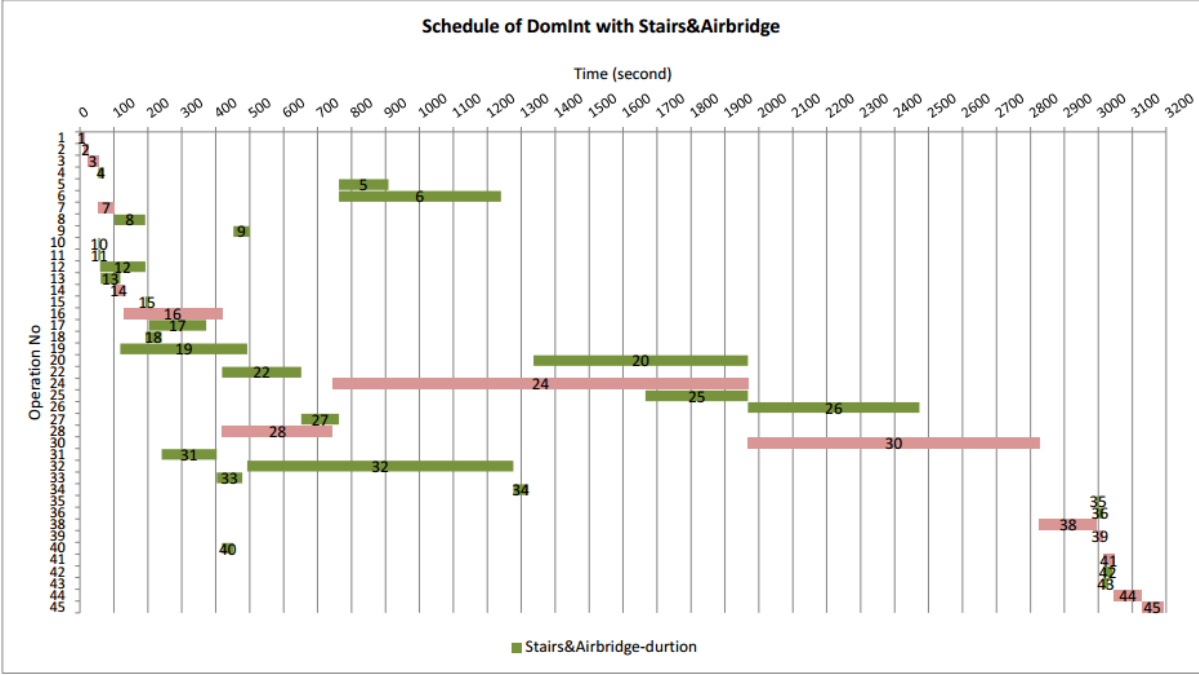

Figure 3: Schedule of Domestic to International Turnaround Operations using during Pax Stairs Deboarding and Airbridge during boarding of Pax

Critical operations are identified and highlighted in red in the Gantt chart provided in figure 3. Table 1 shows common turnaround operations in the critical path are the first and last operations, i.e. placing/ removing front and rear aircraft wheel blocks.

Table 1 shows the critical turnaround operations for DomInt flight type along with the third style of boarding and disembarking passengers.

Table 1: Critical operations for DomInt with Pax Stair & Airbridge

Operation No	Name of the Operation
1	Place front chocks
2	Stop engines
3	Place rear chocks
7	Position pax stairs (forward)
14	Open front pax doors and ask purser if there are any PRM pax
16	Disembark pax from the forward door
28	Disembark wheelchair pax via truck
24	Cleaning
30	Pax boarding
38	Hand in the Load Sheet and get Captain's approval
39	Close pax doors
41	Remove airbridge
44	Push-back connection
45	Remove rear chocks

Table 1 shows the most critical turnaround operations involved in the DomInt flight type. Some benefits of focusing on these critical operations are identified. For example, in table 1, it is evident that, the passenger

boarding (operation no 30) is in a critical path during the turnaround process and hence applying efficiency interventions on the passenger boarding style could assist in improving the overall turnaround time,

As an overall comparison, the turnaround time and schedule of the third disembarking /boarding style for DomInt flight type was presented. Schedules were generated by applying 4 disembarking and boarding styles along with 4 flight types and then compared with regards to total turnaround times. It was concluded that, using passenger stairs for disembarking and airbridge for boarding results in minimum turnaround time for each flight type. For DomDom flight type, the minimum turnaround time is equal to 40 minutes, for both DomInt and IntDom 53minutes and 41 minutes for IntInt flight type.
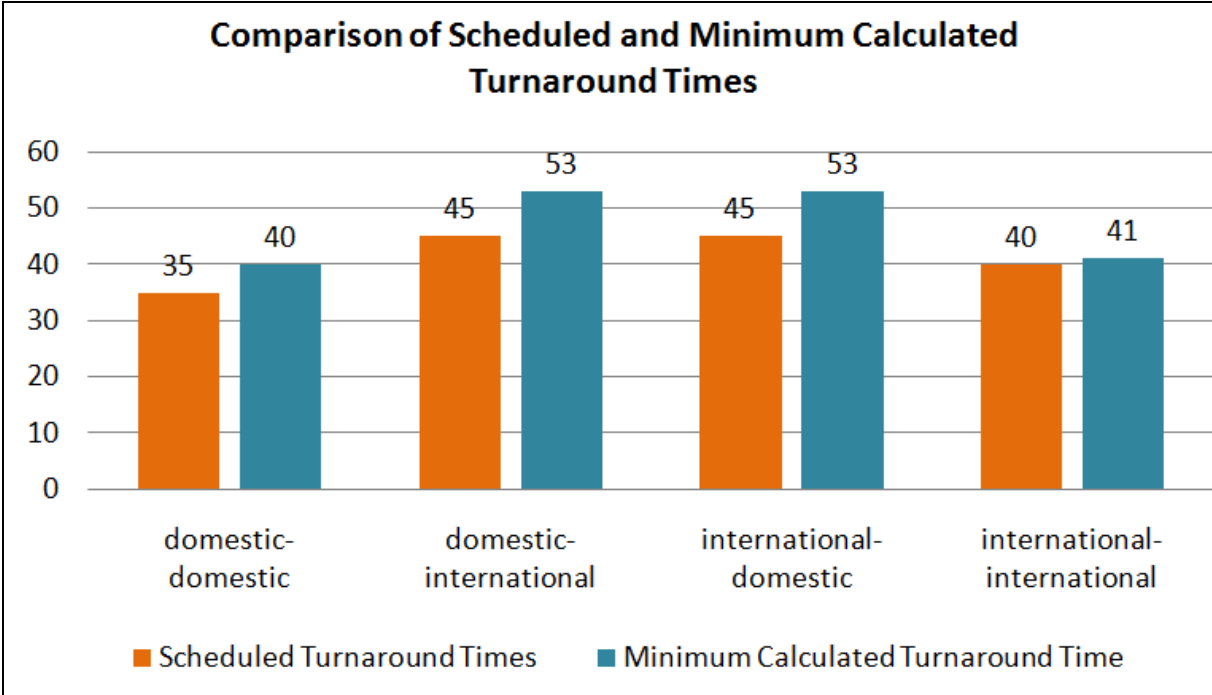

Figure 4: The planned and optimised turnaround times

Figure 4 shows that the planned/ scheduled turnaround times generated by the company are lower than the optimised turnaround times generated by applying the 'TurnOper_LP' model. In fact, based on these results, the optimised turnaround times should be 5,8,8, and 1 minutes less respectively than the planned/ scheduled turnaround operations for each flight type. This is possible when passenger stairs are used for disembarking and airbridge used for boarding and which is why the company being investigated are experiences delays, as it used to adopt overlay optimistic turnaround times. However, by adopting the optimised turnaround times and schedule provided by the 'TurnOper_Lp' mathematical optimisation model, the company is expected to achieve a higher on-time departure performance and almost no delays occurring from the turnaround time point of view.

The optimised turnaround times based on different styles of disembarking and boarding passengers for different flight types are calculated and presented in figure 5.
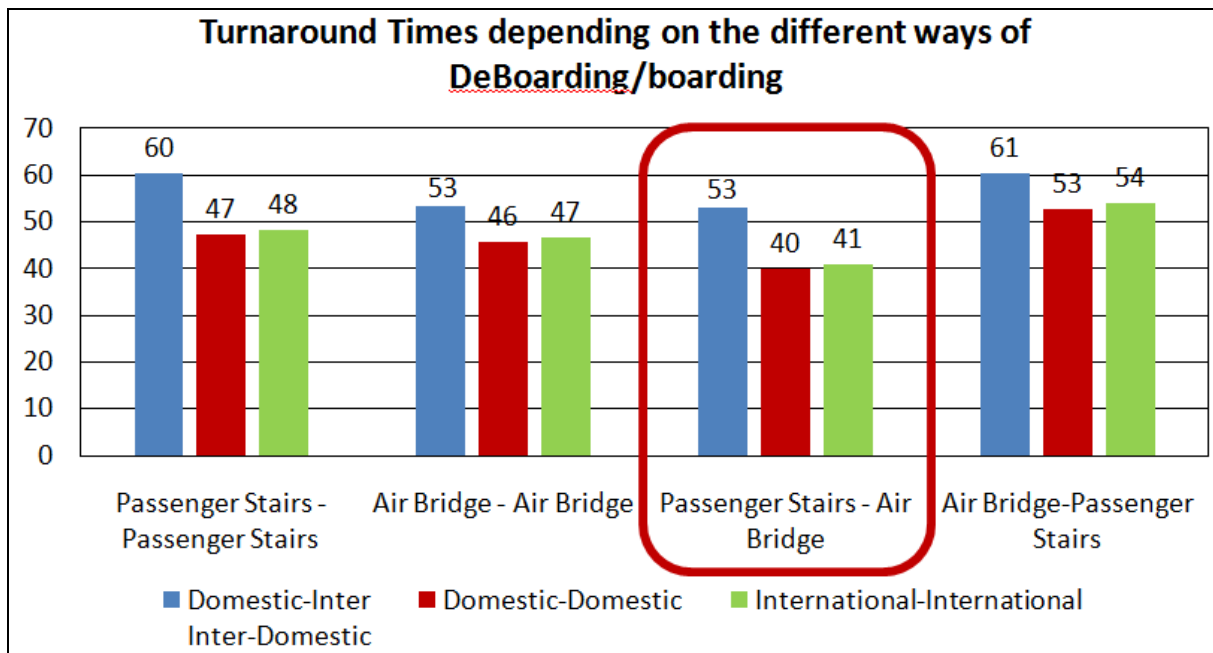
Figure 5: The optimised turnaround times based on different deboarding and boarding passenger

Figure 5 shows that for each flight type, minimum ground handling operation time have been achieved by using passenger stairs for disembarking and airbridge for boarding, which always gives the minimum time for each flight type. The second best scenario is to use airbridge for both disembarking and boarding of passengers for every flight type.

4.   Conclusions & Recommendation

4.1 Conclusion

This research has successfully addressed the problem of scheduling turnaround operations taking into consideration different inbound-outbound flight combination scenarios, and successfully provided the optimal schedule with minimum turnaround time for each flight type.

The developed integer programming model; 'TurnOper_LP' has assisted in solving this problem. This was possible by introducing a number of constraints that ensured the precedence relationships of turnaround operations while the scheduling process takes place. From the model outputs, it was evident that, using passenger stairs for disembarking and airbridge for boarding scenario resulted in minimum turnaround time for each flight type. In addition, the minimum turnaround time was achieved for the DomDom flight type compared with other types of flights.

4.2 Recommendation

As multi-skilled resource allocation in the context of turnaround operations scheduling for different inbound-outbound flight combination scenarios has not yet received enough consideration, and hence, it is recommended that more mathematical optimisation models in this area of research is required to generate more realistic scheduling plans of turnaround operations under different resources allocation scenarios. In addition, Constrained Programming (CP) can be used to solve the complexity inherited in modelling such combinatorial scheduling problems.

Acknowledgements

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