MASTER OF SCIENCE BY RESEARCH

Scheduling of aircraft turnaround operations using mathematical modelling
Turkish low-cost airline as a case study

Gok, Yagmur Simge

Award date:
2014

Awarding institution:
Coventry University

SCHEDULING OF AIRCRAFT TURNAROUND OPERATIONS USING MATHEMATICAL MODELLING: TURKISH LOW-COST AIRLINE AS A CASE STUDY

A Dissertation Submitted By

Yagmur Simge Gok

In Partial Fulfilment of the Requirements for the Degree of

Master of Science

In

Air Transport Management

at

Coventry University

Supervised by: Dr. Ammar Al-Bazi

September, 2014

ABSTRACT

In recent years, with the phenomenal growth of many low-cost airlines, competitiveness has increased significantly. Within this competition, to achieve an on-time departure performance is a momentous factor; thus providing those airlines with on-time departure performance with a foremost competitive advantage. On-time departure performance is important for airlines to satisfy passengers by departing on adequate scheduled time of departure (STD). The main component of achieving on time departure is being able to complete the turnaround time of an aircraft within its scheduled time. By considering this problem, optimally scheduling of turnaround time was studied in this thesis as a real case of a low-cost company.

One of the Turkish airline companies was facing many delays occurring because of subjective scheduling of turnaround operations. In order to solve this problem a number of on-site visits were conducted and data was collected from the turnaround operations of Boeing 737-800 type of aircrafts from the hub airport of the company. A mathematical model is then developed to find an optimal schedule of operations for four different flight types considering arrival from a domestic or international port and departing to a domestic or international port. The objective of the modelling is to minimise the completion time of the last operation. There are other studies in the literature which were interested to schedule turnaround operations with heuristic approaches and simulation. This study fills the gap of optimisation with integer linear programming (ILP) since there is no other papers used ILP to schedule turnaround operations. The problem was solved using mathematical modelling approach and an optimisation solver (IBM ILOG OPL) to get the results for different scenarios.

The results of the model are then interpreted and Gantt charts of schedules for different flight types are generated. In addition to these, models were also run for different disembarking/boarding styles and the fastest completion time of turnaround time was determined. It was concluded that the minimum time of turnaround operations are in domestic-domestic flight type with using passenger stair for disembarking and airbridge for boarding. Finally, critical path in each schedule were listed to indicate the critical operations needed to be focused.

This dissertation is dedicated to the memory of my aunt ***Süreyya Eronat*** *who as a teacher has the biggest effort on me to come to this point and have always believed in me.*

ACKNOWLEDGMENTS

First of all, I would like to express my deepest gratitude to my academic supervisor Dr. Ammar Al-Bazi for all his invaluable guidance, eternal patience and infinite insight during my dissertation. Very special thanks to my unofficial advisor; Dr. Cemalettin Ozturk for his continues encouragement and belief in me who has always given a priceless effort and his precious time to guide me.

Another special thank goes to the Ground Operations personnel in the airline where case study has been conducted, for their help during the observation in the airport and taking their time to answer all my questions. Especially, many thanks to Okan Samur, Murat Demirbilek and Boğaç Uğurluteğin for giving me the opportunity to work with them and to experience the aviation environment from a very close point.

I would also like to thank to my lecturers of Air Transport Management course especially Roxani Athousaki, Gordon McJannett, Jenni Fernando and Illias Panagopoulos for sharing their valuable knowledge in the field of aviation.

From a moral support perspective, I would like to thank two people who are the centre of my life; my mother Mehtap Gök and my father Cumhur Gök for motivating and encouraging me during my master study in the UK. Many thanks to my dear friends Hazal Girgin, Efecan Çınarlı, Yeşim D. Özkan, Anouck Helbois, Hardeep Kumar, Rohit Kshirsagar, Mahesh Nagarkar, John Mankit Lee and many others who were always there for me with their love, humour, support and best wishes.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 - INTRODUCTION

1.1. Introduction

For the business, turnaround operations are one of the most important processes in the Airline Industry. Therefore, many airline companies especially Low Cost Airlines (LCA) have recently working on the improvements on how to reduce the turnaround time and hence reduce the time that the aircraft is spending on the ground. This is an important challenge for Airlines decision makers to make a decision about planning the turnaround time with a minimum cost and most efficient and quick way. In this chapter, the LCA and the turnaround operations are explained in detailed to give a broad knowledge on turnaround operations and the strategies of LCA using to schedule the operations and reduce turnaround time.

The structure of this thesis is organised as follow: the problem which has been discussed and solved in this study has been defined briefly. Aims, objectives and methodologies are explained and indicated. Research questions are stated related with the objectives and the scope of the research has been specified. Finally, with the thesis structure, all chapters were introduced regarding to their content.

1.2. Airline Industrial Background

Airline industry is a very huge and complex industry which deals with operational problems from different areas. Airlines are firmly committed to providing and maintaining a safe and healthy working environment. There are two types of Commercial Air Transportation services which are passenger and cargo transportations. Passenger airlines carry passengers and some of them additionally carry small cargo. On the other hand cargo airlines are the airlines which are specifically established to carry only cargo. That’s why the aircrafts are different from the passenger airlines’. There are no seats inside the aircraft and no passengers allowed into the cargo aircrafts. Since, the problem discussed in this thesis belongs to passenger airlines, the information related to turnaround operations were explained considering only passenger airlines because the turnaround processes are different.

Airlines always try to minimise their costs and increase their revenue as most other industries also do. In this context, airlines gave a lot of importance on reducing the turnaround times by having an efficient operational flow. Aircrafts bring revenue to the airlines as they are in the air. However, turnaround processes are taking a lot of time which means spending a lot of time on the ground. That's why it is important for airlines to efficiently plan their turnaround operations and keep the time minimum (Bazargan, 2010).

General Description of the Turnaround Operations

To begin with the explanation of turnaround time in an Airline industry, it is the time starts with the arrival of the aircraft until the next departure of the same aircraft. During this time, aircraft needs to be prepared for the next flight and some operations such as refuelling, baggage loading and unloading, cleaning, catering and passenger boarding/deboarding are needed to be done. These operations are called as "Turnaround Operations" or can also be called "Ground Handling Processes" or "Ground Operations". The most used list of turnaround operations are stated below (Sanchez, 2009):

- Chocks on/off
- GPU connection
- Passenger boarding/deboarding
- Baggage loading/unloading
- Catering
- Cleaning/Tidy-up
- Lavatory Service
- Portable water service
- Routine maintenance check
- Fuelling
- De-icing

These operations are handled when the aircraft arrives. However they do not necessarily have to be done in every turnaround. There are different approaches to the turnaround operations by low-cost carriers and full service carriers. In the following part, these operations are explained in detailed and which operations are handled by which carrier are explained.

1. Chocks on/off

When the aircraft lands to an airport and goes to its pre-assigned parking position, first step is to place chocks in front of and back of the tires. The reason is that holding the breaks during the turnaround procedure is something damaging for the aircraft and that's why as soon as the chocks are placed, the captain should leave the breaks. Hence, the aircraft is kept stable and safe during the turnaround process. Before the aircraft moves to leave the parking position, chocks are need to be taken out. No matter the airline is low-cost or full service, this process is handled in every turnaround of the aircraft.

2. GPU Connection

After placing chocks, another important process is to connect Ground Power Unit (GPU) to the aircraft. GPU is an external power supply which helps the aircraft to use the electrical equipment inside the aircraft while staying in the parking position (during the turnaround process) since the aircraft shuts down its engines. Depending on the parking position, power either can be supplied with a cable from the airbridge or if the aircraft is parked in remote stand position, then the handling agents bring a portable GPU and connect it to the aircraft.

3. Passenger Boarding/Deboarding

Passenger deboarding and boarding can be seen in two different ways depending on the parking position of the aircraft. If the aircraft is parked on the remote stand, then passengers are deboard and board to the aircraft via passenger(pax) stairs and they are brought in front of the aircraft or to the terminal building via shuttle buses. On the other hand, if aircraft is parked in front of the terminal building, then there are two options again, to board/deboard via pax stairs or via airbridge. Most of the low-cost airlines avoid using airbridge since it is more costly. They prefer pax stairs instead or airbridge.

4. Baggage loading/unloading

Baggage loading and unloading is one of the most time taking processes during the turnaround. In order to unload and load baggage, baggage handlers who work for a ground handling agent process these operations. First of all conveyor belt is positioned to the baggage compartment and then one or more baggage handlers go inside and unload baggage and put on the conveyor. When the baggage arrives at the end of the belt, it is loaded to the baggage tug and taken into baggage area in the terminal. The loading process starts after the check-in finishes or if there are enough number of baggage to load. The loading process is the opposite of unloading.

5. Catering

Catering is handled by catering companies which the airline is working with. Most of the full service carriers request catering in the turnaround process since they serve food to everyone in every flight. The catering is handled via high-lift catering trucks which are positioned to the left forward and rear doors of the aircraft where the galleys are. If the aircraft is wide body, there may be more than two doors and the catering will be handled from each door. During loading process of the full trolleys, the empty ones are unloaded. However, if it is a low-cost carrier’s aircraft (which are mainly narrow body aircrafts), then catering does not necessarily have to be done in every flight since not many passengers buy food during the flight. That’s why caterers load trolleys according to the estimated amount which will be enough for 2 or more flight legs.

6. Cleaning/Tidy-Up

Cleaning process starts after passengers are disembarked and continues until boarding. Many full service airlines take cleaning between each flight leg. However, low-cost carriers do not take cleaning unless it is really necessary since there is not much food consumption during the flight. Instead of taking cleaning, cabin attendants “tidy-up” the rubbish and take out when the aircraft arrives. This gives them the opportunity to reduce turnaround time and reduce cleaning cost of paying for cleaning agents.

7. Lavatory Service and Portable Water Service

Lavatory service deals with the drainage of the used water especially from toilets while portable water service reloads clean water to the aircraft. A lavatory drainage truck and portable water truck is positioned on both back sides of the aircraft. These operations do not have to be done between every flight for low-cost airlines. There is a consumption limit of clean water where the purser checks and asks for water supply if it is under the limit. It is also the same for lavatory service. If the fullness of used water exceeds the predetermined level, then the lavatory service is requested.

8. Routine Maintenance Check (Pre-flight Inspections)

Maintenance of the aircraft should always be done in before each flight to check everything is working well which can be referred as pre-flight checks. The aircraft technician goes around the aircraft and checks some parts of the aircraft and also adds engine oil and filter if it is needed. This is a routine operation which is a must to do.

9. Fuelling

Fuelling is performed by a fuel company either via fuel tank which contains fuel inside of the tank or via hydrant dispenser vehicle which is connected to the floor to dispense the fuel and transfers it to the aircraft. During the fuelling process, because of the safety, there should not be any passengers inside the aircraft. That’s why fuelling starts after disembarking of passengers and finishes before boarding of passenger. However, if the flight is a transfer flight where the passengers need to wait inside the aircraft, the fuelling can be supplied only with the guidance of fire brigade.

10. De-icing

De-icing is the process of removing ice from the aircraft using buoyant glycol mix. This operation is not in the routine however it may be needed in the winter if the weather is cold.

The general process of turnaround operations handled by most of the airlines is presented in Figure1.1. This flow shows the precedence relationship of operations and sequences. For instance, passengers cannot board until fuelling finishes.

Figure1.1: Flow of Turnaround Operations (Kolukısa, 2011)

In the above figure, all turnaround operations' flow is showed. Flow start with positioning wheel chocks and then either passenger steps or airbridge. Then operations are divided into three flows which are passenger flow and the two others are cargo and baggage flows. At the same time other operations which can be done independently from the flow during the turnaround process are showed on the top of the figure such as exterior cleaning, sanitary services etc. These operations are optional and is requested if there is a need for them.

In this study, Boeing 737-800 aircraft types were taken into consideration since most low-cost airlines have these. The schedule of turnaround operations for this aircraft type is presented in Figure 1.2 which is the aircraft manual of Boeing 737-800.

This item has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

Figure 1.2: Turnaround schedule of Boeing 737-800 aircraft (Boeing, 2013)

This figure on the above presents the basic schedule of the turnaround process which is recommended by the aircraft producers (Boeing). It shows the operations on the left side and then the durations of each operation on the 3rd column and finally Gantt chart representation of the turnaround operations. On the bottom of the figure, time scale is presented with the time intervals of 5 minutes.

The final important information is the places of vehicles where the operations are handled around the aircraft. In order to visually indicate the areas of performed operations, the layout from Aircraft manual of Boeing was showed in Figure 1.3.

This item has been removed due to third party copyright. The unabridged version of the thesis can be viewed at the Lanchester Library, Coventry University.

Figure 1.3: Layout of the turnaround process (Boeing, 2013)

The above figure shows the places where operations are handled and where the equipment and vehicles operates in order to understand the operations clearly. However, here, wheelchair high-lift truck was not mentioned. If there is a need for wheelchair truck, it operates at the same place as Galley Truck (First position). The other operations can be handled at the same time if there is no precedence relationship.

1.3. Problem Definition

This study is based on a real case of one of the Turkish low-cost airline companies. Because of the confidential issues, the company in this study is referred as XYZ Airlines for anonymity. Since it is a real case, the problem which has been discussed and solved in this thesis is based on a real problem as well.

As it was discussed on the background information, optimally planning of turnaround operations for low-cost airlines is very important since every second of the aircraft staying on the ground make company loose profit. In that sense, the airline company was having problems of not completing turnaround processes on time hence causes delays. That's why, the company wanted to reschedule their turnaround operations optimally using up to date data collected from the hub airport of the company. Moreover, the schedule that the company using was not scheduled with an optimisation tool. That's why the reliability of this schedule was not high enough.

Based on these concerns and problems that the company is facing, they have requested to schedule their turnaround operations for 4 different flight types which are for the aircrafts arrived from a domestic destination to the hub airport and departs to a domestic destination, arrived from a domestic port and depart to an international port, arrive from an international port and depart to a domestic port, finally arrive from an international port and depart to an international port. The main reason of considering flight types is because operations or the duration of the operations can differ from one flight type to another. Moreover a decision was needed to be taken for the airlines about which deboarding/boarding style should the company use in order to achieve minimum turnaround time. There are 4 different types of boarding/deboarding strategy in the turnaround process. First of all deboarding and boarding passengers via pax stairs. Secondly, deboarding and boarding passengers via airbridge. Third option is deboarding passengers from airbridge and boarding from pax stairs. Final one is deboarding passengers from pax stairs and boarding them via airbridge. They expect to have 16 different schedules for 4 different flight types and 4 different deboarding/boarding styles.

1.4. Aim and Objectives

The aim of this study is to generate an optimised schedules profile of the turnaround operations of a low-cost airline while achieving the minimum completion time by using mathematical modelling.

There are several objectives of this study where each of them is expected to be achieved at the end of the study. These objectives are listed below:

1. To review state of art practices in the area of turnaround operations in different types of airlines and application of mathematical modelling in this area.
2. To address the logic of the operations that current low cost airlines are applying for their turnaround processes.
3. To collect data of the turnaround operations from the hub airport of the company.
4. To develop a mathematical model of different flight types including boarding/deboarding style options of turnaround operations for XYZ Airlines.
5. To identify the critical path for each schedule in order to highlight critical operations
6. To compare turnaround times of schedules and decide on the best schedule with minimum time.

1.5. Methodologies

Research methodologies used in this thesis shows the methods which are applied to achieve each objective. These methodologies are listed below in an order to correspond to each objective above.

1. Literature Review of previous studies to have a basic idea which tools and techniques have been used in this area (to satisfy objective 1).

2. Observation, flow chart and process mapping (IDEF0) techniques to present and understand logic of the current situation of the ground operations (to satisfy objectives 2 and 3).
3. Stop watch, on-site visits and other structured interview techniques (to satisfy objective 3).
4. Mathematical Modelling approach (Linear Programming) to represent and solve the problem (to satisfy objective 4).
5. Critical Path method to find the critical operations in each schedule (to satisfy objective 5).
6. Experimental design and analysis in order to state scenarios for different turnaround schedules and improvements (to satisfy objective 6).

1.6. Deliverables

Deliverables expected from this research are the outcomes of the objectives. These deliverables are listed below for each of the above objectives.

1. A comprehensive literature review on "the importance and practices of turnaround processes" and "the application of mathematical modelling in ground operations of these airlines".
2. Process Map and Flow Chart diagrams of the current turnaround operations of XYZ Airlines.
3. Gathered and listed data from the relevant data collection process.
4. A mathematical model to imitate the current problem.
5. Gantt Charts of different scenarios to propose as a new schedule for the company and to identify critical path.
6. Best schedule based on minimum turnaround time among proposed different scenarios.

1.7. Research Scope

Purposes of this research are first to discuss the turnaround operations in low-cost airlines and review previous studies in the area of scheduling of turnaround operations. Other purpose is to develop a linear programming model using mathematical modelling technique which minimises the turnaround time. However up to this stage, mathematical model considers resources (staff) who are involved to these operations. Because of the time limitations, with some assumptions, the revised model is proposed without the consideration of resources.

As a final purpose, the case study has been discussed and revised model has been adapted for a low-cost Turkish airline company. From the outcome of the model, schedules for different flight types are proposed and critical path are identified. The best schedule is chosen based on the minimum turnaround time and compared with the turnaround time of the existing schedule. Further studies are proposed and how project conducted was explained using project management tools and techniques.

This thesis does not involve heuristic algorithm to solve the mathematical modelling because of the time limitation and does not include detailed schedule of turnaround operations of the company due to confidentiality limitation.

1.8. Thesis Structure

Thesis structure has been composed in order to give a brief idea about how this dissertation was held regarding to the discussions in each chapter. It guides to find the chapter of expected information. According to the chapter content, the structure is presented below as a diagram in Figure 1.4.

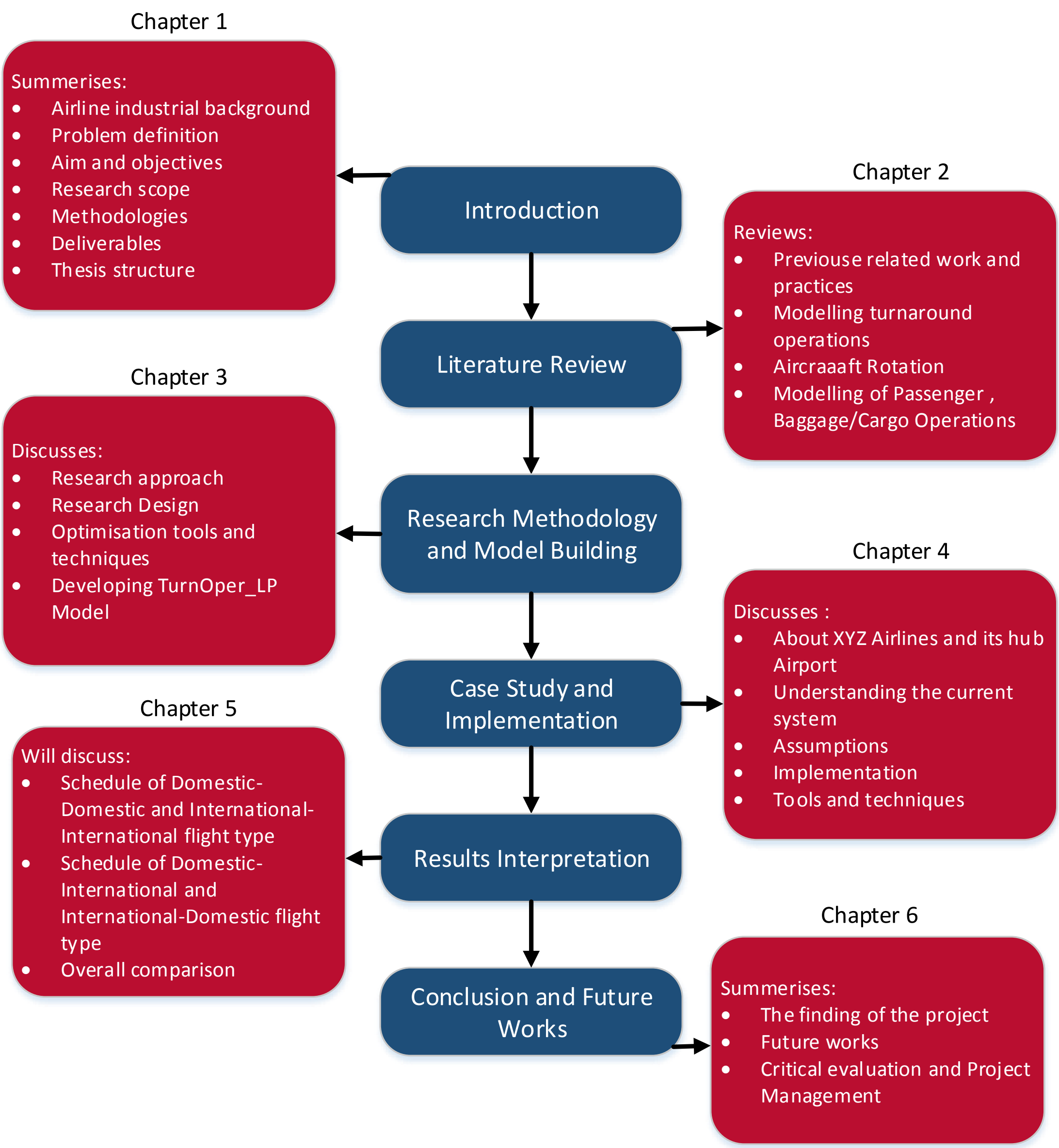


Figure 1.4: Thesis structure

Above figure provides a schematic explanation of content of each chapter and guides to find corresponding subjects easily.

The detailed explanation of each chapter is listed below:

Chapter 1 is the introduction chapter where a brief introduction is explained. Background of the airline industry especially how they process their turnaround operations are presented. Problem that has been discussed through the dissertation are identified. Lastly, project aim and objective are defined and addressed.

Chapter 2 is the literature review chapter in which all the literature about modelling turnarounds and turnaround improvements, aircraft rotation and delay impacts and passenger/baggage/cargo flow are reviewed and explained. Gap in knowledge in these areas are identified.

Chapter 3 explains the research methodology including the research approach, design, strategy, data collection, sampling and research instrument. Moreover model development and formulation of the mathematical model is presented in this chapter.

Chapter 4 outlines the case study which has been conducted in a low-cost airline company. Information about the company and airport are delivered. The real case problem is introduced by explaining the current system of turnaround operations in the company using flow chart and process map. Assumptions and the revised mathematical model based on the assumptions are presented. Finally implementation of the model is showed and tools and techniques used in the development of the model are addressed.

Chapter 5 is the result analysis chapter where the comparison of turnaround operations based on flight types and deboarding/boarding styles are presented and discussed. The schedule with the minimum turnaround time is revealed. Finally, overall comparison of schedules and turnaround times are showed.

Chapter 6 focuses on the conclusion of the dissertation and possible future works. Critical evaluation of the dissertation and lessons learnt is presented. Finally, some of the project management components such as risk management and time management are explained.

CHAPTER 2 – LITERATURE REVIEW

2.1. Introduction

There have been many studies regarding airline turnaround operations in the past and mainly most of them are done to achieve the most efficient turnaround processes by aiming different objectives. In this chapter these objectives, methodologies, tools and techniques that are explored to find solutions are identified and critically analysed to base this study on approved studies and theories.

The related reviews are categorised considering their aspects. These categories are as follows: Problems impact on turnaround times such as modelling turnarounds and turnaround improvements, aircraft rotation and delay impacts and passenger/baggage/cargo flow.

2.2. Previous Related Work and Practices

2.2.1. Modelling Turnaround Operations

Review of modelling aircraft turnaround operations is one of the most important areas for this thesis and for the Low cost Airline Companies since the low cost airlines are trying to find an efficient plan which minimises the turnaround time (the time that aircraft spend on the ground between two flights). Hence on time departure performance will increase without occurring extra cost after a good modelling of turnaround operations. The turnaround operations can also be referred as ground operations or pit-stop operations especially by low cost airlines.

Aircraft turnaround modelling has been studied many times in previous literature by utilising different methodologies; mainly simulation, dynamic programming, heuristics, petri-nets and fuzzy models. All related articles about the turnaround modelling have been discussed below.

Sanz de Vicente (2010) had used a CAST simulation model to analyse the different scenarios in ground handling. The first approach to the problem was by using Microsoft excel, to create Gantt Charts for four different scenarios. Those scenarios cover the ground operations of low-cost and conventional carrier according to their parking positions (apron or terminal). The second approach is simulation with CAST GH (Comprehensive Airport Simulation Tool Ground Handling), which is a simulation tool developed by Airport Research Centre. It is used to analyse the turnaround time and critical path, as well as schedule aircraft and ground handling equipment. The purpose of the CAST simulation model is to show the turnaround processes like in the airport environment and find the critical path. Most important objective is to allocate the related resources to each operation which is not possible to do in excel. HAW Hamburg was the airport that the study has conducted as a case study. The data for turnaround operations were collected in there from the video records. Collected data (duration of each operation) was statistically examined in Matlab program to use it as an input for the simulation. Most of the values were distributed as non-linear and normal. After running all the scenarios, it was found that the critical path is disembarking/embarking passenger process and loading /offloading baggage process. The cost of each operation was also added to the simulation model. Hence, the decision of choosing the model with the least cost and least turn-time became easier. In order to reduce the turn-time and costs, some improvement configurations had been suggested such as foldable passenger seats, sliding carpet, reduction of the height of cargo decks and had been suggested to be used in the ALOHA project which is aiming to find new configurations for low cost aircrafts achieving less turnaround time and cost. This study is a good start in terms of scheduling the turnaround operations and finding a critical path. However CAST simulation model which is used to find an efficient ground handling has already been developed. That's why it would have been better to introduce a new simulation model which is scheduling the turnaround operations, finding the bottleneck operations by considering resource limitations.

Norin et al. (2012) have developed a simulation model for the logistical turnaround operations. In addition to this, an optimization de-icing vehicle scheduling model was proposed. The main objective of both models is to examine the possibility to come up with an improved airport logistics in terms of overall performance by optimizing the de-icing operation belonging to the turnaround. ARENA Simulation was used as a tool and the optimization algorithm has been embedded to the simulation. The study was conducted in Stockholma Arlanda Airport as a case study and the data was supplied from there. According to the conceptual model of turnaround operations; turnaround begins with the on-block and continues with unload baggage, fuelling, load baggage meanwhile de-boarding, cleaning and catering, boarding and at the same time water and sanitation. After all these operations are finished, the de-icing starts and then the turnaround end with the off-block. This is the flow of the turnaround operations used in this simulation model. After optimizing the de-icing process and integrating the model to the simulation and solving them, the efficiency has been compared between 4 different scenarios. Scenario 1 was run without de-icing operation. The 2nd scenario considered the de-icing but just the existence of the operation. In the 3rd and 4th scenario, the 2 different greedy solutions from optimized de-icing were used. The results indicated that scenario 4 which is optimized for overall airport performance gave a better outcome than scenario 3 which is the optimized schedule only for de-icing company; and scenario 2. It is also concluded that by scheduling every operations in the turnaround, a better performance and efficiency could be achieved at the airport. This study proposed a different way of approach to the increase on the performance of overall aircraft turnaround activities by suggesting to schedule each operation in itself and finally to combine them in one simulation model to see the efficiency. The missing part in this study is not taking the other scenarios such as passenger embarking/disembarking from 1-2 doors or parking position of the aircraft into consideration.

Another problem in the turnaround modelling area has been studied by Kunze, Oreschko and Fricke (2012). A Monte Carlo Simulation model has been developed to model the turnaround operations. In this model, the stochasticity of turnaround operations were calculated and used for each fight considering the operational and strategic information. Moreover, a delay model was developed in order to make the model more realistic. Cost and resources were not considered in this paper. Most importantly the study was adapted to a highly automated operation environment. The turnaround operations begin with in-bock time and finish with the off-block. Basic operations were taken into consideration in this paper such as deboarding, catering, cleaning, loading, unloading and boarding. Buffer times were also considered and added to the model. The main objective of this model is to achieve a highly automated level in order to react to the delays. By introducing the sensor technology (RFID) or checkpoints (such as in cleaning), achieving this automation level has been aimed. Frankfurt Airport was mentioned to show a delay pattern as an example. As a result of this study, it is concluded that according to the created models, it is possible to achieve a better turnaround within highly automated environment. This study shows the importance of the information flow in the turnaround time. However, the missing point in this study was the ground handling resources such as personnel. It would have been a more accurate model if the resource constraints were added to the model.

Mao, Roos and Salden (2009) developed a stochastic programming model to schedule aircraft ground operations. The mathematical model has been written as a multi-agent project scheduling problem within uncertainty. Multi-agent scheduling tries to consider two agents which are aircraft and turnaround operation holders. That’s why both agents will effort to accomplish their own objectives. The objective for the resource agents is to minimize the resource usage variations and the cost occurred with this variation. On the other hand, for the aircraft agent, the objective is trying to minimise the trade-off between the minimum allocations or usage cost of the resources and makespan of the turnaround process. In the solution part, priority based centralised heuristics were used to solve the MPSP (Multi-project scheduling programming) while genetic algorithm was used to find the distribution of the near optimal slack time. For the MPSP model, the different sequences of turnaround operations were considered with different aircraft types and simulated in an airport environment. Results showed that, centralised scheduling heuristic is one of the best model in terms of performance when compared to other in the cooperative online scheduling scheme. The scenarios which are conducted in a real environment showed that the uncertainties of the turnaround activities are being taken into consideration by the model and converge to a steady state. This paper shows a detailed project scheduling model considering resources and heterogeneous agents. The mathematical model was developed from a job shop scheduling perspective. Hence the solution time of the problem is very large and reaching the optimal solution is not possible. Integrating the agents' decision to the problem is a very good approach to the turnaround scheduling problem.

Van Leeuwen (2007) has developed an extreme decoupling model as an airport planning methodology. The problem consists of 2 phases. In the first phase, a strategic plan was developed which shows the plan of the turnaround operations up to 2 month prior to the actual handling date. The other phase was to develop the turnaround operations again just 2 hours before the actual time which is the tactical decision. The main concern of these model are to first plan a stand allocation plan by considering the actors in each processes and then to make small changes in the actual strategic plan according to the situation occurring at that time. The purpose of the first model was to minimize the coordination between actors in the planning phase. On the other hand to find the best stand allocation plan according to the small changes made by local planners with respect to the specific airport constraints. In these models the used turnaround operations are mainly baggage and cargo handling, de-boarding and boarding of the passengers, cleaning, catering, fuelling (which was recognized to be handled between de-boarding and off-blocks) and finally maintenance. Sub-tasks such as pre-boarding, cabin crew boarding, cabin check and positioning and removal of the blocks cones were not considered in order to keep the domain simple. The technique that was used in this paper was the temporal and decoupling and also Simple Temporal Network representation. After models are solved step by step using Simple Temporal Network, the solutions have been presented. This paper again is a different approach to the problem by using decoupling methodology. The usage of Simple Temporal Network is a good tool to represent the times and make it to understand easily. However, this paper did not consider some of the sub-processes of turnaround operations such as cabin-crew boarding and positioning of the vehicles. Moreover, different scenarios of parking position or flight type differenced have not been considered.

Another approach is made by Han, Chung and Liang (2006) to the planning of the turnaround problem. The fuzzy critical path method has been developed in airport cargo ground operations. In this model, all the activities were calculated as fuzzy times and precedence relations were taken into consideration as constraints. The problem has been developed as a case study in Chiang Kai-Shek (CKS) airport with 8 month collected data. The ground operations involved to this problem was cargo operations which makes this paper different from other papers within this title. The objective of this study was to find a critical path using fuzzy operations and times. The solutions created the networks and corresponding critical path. The decision makers have also been considered in this model and the output can be altered according to those decisions. The fuzzy critical path method is a different perspective to model the ground operations and it was well represented. However, the ground operations were only for the cargo not for passenger and baggage handling operations. It would probably be more complex if the passenger and baggage operations were considered and the domain of the problem would increase.

Fitouri Trabelsi et al. (2013) had developed an online decentralised management structure using fuzzy formalism. The model concentrated on ground handling management problem at airports. In the second part of the problem a heuristic approach were suggested to solve the multi fleet allocation problem. The objective of the decentralised multi-fleet management problem is to minimize the ground handling variable costs and minimize the travel distance between airport fleet that are in charge of ground handling. The purpose of on-line ground handling multi-fleet fuzzy heuristic is to reduce the delay to the minimum while assigning each ground handling vehicles to the aircrafts. The heuristic start with ordering the flights according to their expected arrival times to the airport. Fuzzy times have also been considered while developing the heuristic. A case study was conducted in the Palma de Mallorca Airport (PDM), hence all data belongs to the operations in that airport. Different scenarios were considered since there are different types of fleet in the airport at the same time. It was concluded that the cooperation between variety of tactical decision makers had able to deliver an efficient ground handling multi-fleet management structure. The model was more focused on the airport side rather than the airline. The perspective was not on the airline's side where it is differ from this thesis.

Vidosavljević and Tošić (2010) had developed an aircraft turnaround model using petri nets (PN). The model includes the turnaround operations such as air-bridge positioning/removal, passengers disembarking/barding, portable water, catering, lavatory service, baggage loading/unloading and fuelling. In the development phase of the model, the airport was the consideration of the problem; hence the allocation of resources (ground handling equipment, personnel, aircraft stands) was one of the purposes of this mode. The other objective was to maintain the efficiency of the turnaround operations. The critical path method has also used in this problem to detect the operations which are in the critical path. There were different tools used in the modelling of the turnaround which are Petri Net types: Coloured Petri Nets (CPN), Timed Petri Nets (TPN), Stochastic Petri Nets (SPN) and Hierarchical Petri Nets (HPN). According to the two different experiments on the modelling of turnaround, experiment 1 which is the automatic assignment strategy had given a better result in terms of minimum departure delays when it is compared to the experiment 2 (strict gate assignment strategy). This study showed that the developed model is applicable to any airport operations and can be used at almost all the phases from strategic to operational. Study shows the importance of using the petri-nets in the area of turnaround modelling. However, this paper differs from this thesis in the point of the area of focus which is the airport perspective.

The final approach to the turnaround modelling is Gomez and Scholz's (2009) paper which is about the improvement of turnaround operations for a low cost airline. The Direct Operating Cost Method has been used to analyse the improvements. With this method it is aimed to achieve the least costly improvement among the turnaround operations. One of the improvements that were suggested was to use a more autonomous aircraft in which Automatic Push-back System is used. The other improvement was to use air stairs which is the type of stairs integrated inside of the aircraft. Using the third door during the disembarking and boarding is another alternative. After analysing the Direct Operating Cost of each scenario, it was concluded that for an A320 aircraft, the cost of integration of two air stairs, a sliding carpet and an automatic push-back system is 3.45% lower than the regular A320. This study showed the importance of turnaround operations and its effect on the direct operating costs. However, it would be better to show these effects of improvement in terms of turnaround time and costs by developing a mathematical or a simulation model.

2.2.2. Aircraft Rotation

Another problem type which aircraft turnaround time was discussed is Aircraft Rotation Problems. Aircraft rotation also known as aircraft routing, tail assignment or aircraft assignment is the allocation of each aircraft to flight legs in order to reduce the operating costs or to increase the revenue. Many rotation problems has covered the turnaround processes since each leg of an aircraft requires the turnaround processes hence has an effect on the rotation.

Most of the studies that are conducted in the area of aircraft routing used mathematical modelling and simulation as a methodology which includes the duration of the turnaround. That's why before modelling the turnaround, it is important to know how the turnaround time has an effect on aircraft rotation problems.

Wu and Caves (2002) developed an aircraft rotation model in a multiple airport environment using simulation. In the development process, two sub models are considered. One of them is aircraft turnaround model and the other one is enroute model. The aircraft turnaround model which is the focus of this study emphasises the turnaround operations in the airport. On the other hand, in the enroute model, the flight time of the aircraft in the airspace was considered. The aim of this study is to develop a model where the schedule punctuality was improved since it has a significant effect for the airline company in terms of cost and revenue. The data was used from a Turkish schedule airline as a case study and the aircraft rotation model's performance was validated. The result of the simulation model showed that the performance of departure and arrival punctuality, delay and expected delays in the rotation schedule measurement turned out to be good. After the implementation of the model into the case study, it was found that the operational efficiency of aircraft turnarounds and the aircraft rotation schedule design affects the promptness of aircraft rotation. This study is important in terms of understanding the importance of turnaround time in the aircraft rotation and the relation with rotation schedule. The turnaround model has only considered the passenger and cargo flow. Fuelling, clean water supply and lavatory drainage services could also be considered. Instead of finding an optimal schedule of turnaround operations, the uncertainties and delays were considered.

The second study in this area was also written by Wu and Caves (2004). This time, a Markov simulation model has been developed to see the operational uncertainties occurring from aircraft turnaround operations. In addition to Markovian simulation model, Monte Carlo simulation has been used to get the uncertainty of operations and flight punctuality. As they have considered the departure and arrival punctuality in their previous paper, they have used a different approach to the problem using Monte Carlo and Markovian simulation approach. The turnaround operations that they have considered in this paper is almost the same however in addition to the passenger and baggage flow, they considered the cabin cleaning. With these simulation models they have aimed to have a new approach to the performance aircraft turnaround operations at an airport by investigating how aircraft turnaround efficiency is related with the schedule punctuality. The case study was handled in a Turkish Airline company and; the results and comparisons are based on the data which was collected from that airline. The simulation results and analysis showed that, there is a relation between the departure punctuality of a turnaround aircraft and the scheduled buffer time. As a result, the mode is applicable to any airline to use in ground operations in order to increase their operational efficiency of aircraft turnaround. In general the purpose of this study is not the same as optimally scheduling the turnaround operations. Only basic ground operations were considered and the options such as parking positions of the aircraft or examining the operations in terms of domestic and international were not pointed out.

In the other study by Wu and Caves (2004) , a stochastic mathematical model has been used for the optimization of aircraft turnaround time at an airport. The analytical model simulates the efficiency of aircraft turnaround efficiency considering the operational costs. The objective of this study is to reduce the expense of productivity and to minimize the system costs. Operational uncertainties and buffer times are considered in this model. This paper is very similar to the Wu and Caves (2004) in terms of purpose of the study however the methodology in the previous one was simulation while this study is concentrated on stochastic modelling. In the methodology of the problem, the cost functions including system cost and delay cost functions were presented and a mathematical modeming with stochastic times was constructed. As a result of this study, by minimising system costs, the punctuality of turnaround performance was achieved by using schedule buffer times. It was also found that the arrival punctuality has a great effect on the departure punctuality of the aircraft. Moreover, related to turnaround operations, the turnaround time distribution of an aircraft is being effected by the scheduling of buffer times. This paper proves the relation of buffer time scheduling, turnaround time, turnaround efficiency and arrival/departure punctuality considering operational costs. However the detailed schedule of operations which can be used in general, not in an operational way was not explained.

According to Wu (2005), inherent delays occurs because not scheduling enough buffer times and stochastic obstacles in airline operations. In order to find a reliable airline schedule a Markov Chain algorithm and a discrete event simulation has been used. As the modelling of turnaround is the main concern of this thesis, it is important to describe the objective of turnaround model and the techniques used to develop this model. The main purpose of this study in general, is to evaluate the flight operations of airline schedules while examining the impact of delay propagation to achieve schedule reliability. The turnaround model was developed in two methods. First of all in Markov Chain algorithm has been created and then implemented by Monte Carlo simulation. Discrete-event simulation was used to model the other aircraft services such as maintenance checks and fuelling. Because of the uncertainty of these operations, Discrete-event simulation was used to support the Markov Chain. All data was gathered from a Turkish carrier and the result of these data which were run in simulation models showed that the stochasticity of flight operations in an airline needs to be considered in order to schedule the operations reliably and to avoid delays. Moreover, buffer times are needed to be used to create a proper schedule with minimum delays propagation. In this study, the turnaround times were calculated by considering the punctuality and delays. Finding the optimal schedule was not valid for this problem since the simulation model was used and the detailed operations were not considered in the simulation modelling of turnaround operations and duration of each operation.

Adeleye and Chung (2006) developed a combined network and simulation model to find a contingency sequence of turnaround operations which are maintenance and logistical operations. The develop model helps to analyse the effect of delays as well as to see the effect of different logistical and maintenance turnaround operations. Therefore, the purpose of this study is to find a more affective contingency plans where these delays were reduced to some point. A flow chart of turnaround operations were presented including the operations: passenger deplane, baggage offload, catering, fuelling, cleaning, maintenance, passenger enplane and baggage upload. Moreover, Arena simulation model has been used to simulate the turnaround operations using relevant distribution operation times. Finally, at the experimental design part, the model was presented as a network diagram to see the activities which are in critical path and which has slacks. According to the analysis, the activities which are in the critical path are baggage offload and upload. The research results showed that without any delay in the turnaround operations, the schedule will remain the same however if any of the activities delayed more than their slack time or if the operations on the critical path are delayed, then the defined buffer times will be taken into consideration by the airline company hence help to plan the turnaround. The study shows the significant of scheduling the turnaround operations. Using a network model to identify the critical path is significant for the experimental design and to see the slack values.

The last model where the simulation was used is from Fricke and Schultz (2009). A Monte Carlo simulation model has been developed for each delay category to see the delay impacts onto turnaround performance. The objective of the developed model is to dynamically schedule buffer times in order to avoid delays occurred during the turnaround operations. The sequence of turnaround operations used in the model was identified from the Aircraft Operation Manuel for aircraft type A380. According to the data collection the critical path was identified as de-boarding, cleaning, catering, fuelling and boarding. Delays for each operation were also recorded and inputted to the model. According to the analysis of the MC simulation model's results, it was achieved to decrease in en-route delay around $\mu = 4.5$ minute. Furthermore, the stochastic model has proved that the arrival delay can be reduced to 33%. This study is very useful in terms of minimizing delay propagation and optimal time buffering. However the scheduling of turnaround operations were not considered in detailed and the aircraft model is different from the one used in this thesis.

Sherali, Blish and Zhu (2006) have discussed the various mixed integer programming models for the fleet assignment problem. The main models which are related with the turnaround are the mathematical model of Abara (1989): Basic fleet assignment model using a connection network structure and the model of Hane et al. (1995): Basic fleet assignment model using a time-spaced structure. The turnaround concept in this model (using connection network structure) occurs to make the flight connections arrival and departure of a flight feasible by taking consideration the minimum turnaround time between them. On the other hand, in the second model where the time-spaced structure has been used to define what type of representation is needed to be constructed and how long turn-time need to be added to the arrival time of the aircraft. Other integrated fleet assignment models has also been considered. However, the main part that is being focused in this thesis is the fleet assignment model using a connection network structure and a time-spaced structure since it is related with the turnaround times. For the FAM using a connection network, the objective is to maximise the expected revenue and reduce the operating cost. The objective of the one with time-spaced structure is to maximize revenue or to minimise the assignment cost. From the authors' perspective, the turnaround importance in this field was emphasised. This review showed the other areas and models where the turnaround time is being taken into consideration has been presented and discussed.

Lan, Carke and Barnhart (2006) have proposed a different approach by developing a mixed-integer modelling with stochastically generated inputs. There are two approaches to the problem which are routing aircraft and retiming departure times of flights. The main focus for the thesis is the first part of the problem where the turnaround time was taken into consideration. After the development of the mixed-integer programming model, an algorithmic approach has been used to solve the problem. A slack variable was defined as the difference between planned turnaround time and minimum turnaround time. The objective of the model is to formulate the robust aircraft maintenance routing model. The historical data of a major U.S. carrier from 2000 has been used to fed the model and analyse the results. The solution approach used in this problem was "Branch-and-price which is the linear programming relaxation of branch-and-bound solved using column generation at each node of the branch-and-bound tree." The algorithm was solved using C++ and CPLEX 6.5. As a result of this study, the on-time performance was improved while the number of passenger disrupted had decreased. By adding the turnaround time, this study showed that the delay propagation can be reduced significantly. Therefore, the need for to schedule the turnaround in an optimal way is important.

According to the paper of Jiang and Barnhart (2013), in order to enable application of dynamic scheduling in hub-and-spoke operations, they have developed robust schedule design models and algorithms. The model mainly considers flight re-fleeting and re-timing. As the focus is the turnaround (ground) operations, the minimum time needed to turn a one type of aircraft in a leg can be observed in the model as a parameter. The flow also consists of ground arcs which show the stay of the aircraft on the ground at the same place. The purpose of this model is to maximise the number of route connections with respect to their revenue. There are two models formulated and for the solution technique, column generation and a decomposition-based approach have been used. The results were examined according to the data which is collected from a US carrier as a case study. The model was implemented in C using ILOG CPLEX 9.0. The results proved that the profitability of the robust schedule design approach increases as the demand variability rises. This paper showed another approach to the aircraft rotation problem using a dynamic schedule model. As a further improvement, the author can consider first optimally schedule the turnaround operations and finding the turnaround time and use this time in their model which may result in more realistic result.

Haouari, Aissaoui and Mansour (2009) have developed network flow-based heuristic models for the aircraft fleeting and routing problem (AFRP). First of all a 0-1 programming formulation is used as a heuristic and the lower bound computation has been discussed. The second heuristic method is two-phase network flow-based heuristic. This model has been explained with two phases inside. Phase 1 to solve successive linear assignment problems in order to use them to build an initial solution. In Phase 2, the minimum cost flow problem has been solved to build an improved solution. The objective of all of these models is to develop such algorithms that can be solved fast and be optimisation-based. The focus part again is based on the turnaround time and how they have used it in their model. As an input, they have had the activity constraints which are turnaround time restrictions used in the AFRP model. The problem has been conducted with the real-data given by Tunis Air and according to results occurred from the model using these data, it was shown that the proposed algorithm can consistently generated near-optimal solutions which are less than 1% and achieved very short CPU at the same time. This paper is a good example of how the turnaround time has an effect on the aircraft fleeting problem. The turnaround time is affected by many factors and those factors affects the turnaround time. However in this paper these affects and how the turnaround time is identified haven’t been discussed.

Weide, Ryan and Ehrgott (2010), has developed heuristic models for aircraft routing and crew scheduling. Previous studies have worked to solve both models (crew pairing and aircraft routing) by optimizing them independently. In this paper, it was aimed to solve two models with an iterative approach to increase the robustness and decrease the cost. Domestic airlines schedules’ data was used and the results were analysed. According to these results, it was achieved to increase the robustness with less cost when it is compared with the other studies. In addition, the turn-time involved in this model explained as the time between arrival and departure of the aircraft and a relation is built with sit-time (the time that crew spent on the ground between arrival and departure of the aircraft). The relation is explained as follows: minimal turn-time is always less than or equal to the minimal sit-time. It is also mentioned that defining the turnaround duration is very important and there is a trade-off between delay cost and the opportunity cost occurring because of aircraft being on the ground instead of the additional buffer time for turnaround. That explains the importance of defining the turnaround time in detailed by considering all the detailed operations. That could have been another discussion in this paper.

Dunbar, Froyland and Wu (2012) have developed two mathematical models for crew pairing and aircraft routing problems. Then propagated delay has been estimated including the delays occur from turnaround operations such as ground handling and passenger connection delay. Turnaround time is used in the sense that calculating the propagated delay. After the explanation of the delay propagation, pricing problem has been explained and then both crew pairing-aircraft routing and pricing problems were introduced some algorithms. The objective of the integrated aircraft routing and crew problem is to achieve the minimum propagated delay cost. Several tools and techniques have been used to solve these problems. One of the techniques is using algorithms namely: Propagated delay evaluation, Label setting algorithm for crew and AC routing problems. The models have been solved using a real airline network's schedule data. According to the results, integrated routing and crewing with propagated delay approach was improved by 7.2% when it the same problem solved with sequentially. On the other hand, the same problem has been compared with two sequential approaches and the results showed that propagated delay approach improves over simple delay approach. The final comparison was between sequential simple delay and integrated propagated delay. As a result of this, it was found that integrated propagated delay has a higher improvement percentage of 10.5. Results proved that solving both problems together and integrating them gave a better improvement in aircraft scheduling. The turnaround scheduling hasn't been discussed much in this paper. Since integration of sub-problems is important to find a better aircraft schedule, turnaround scheduling could have been discussed and integrated to this paper as well.

The aircraft routing problems had been discussed and concluded that turnaround time takes an important place in these models as it can be seen from the papers. The method approaches has been covered to these problems and the results were given. Better understanding of the relationship of turnaround operations with aircraft routing and scheduling were indicated.

2.2.3. Modelling of Passenger, Baggage and Cargo Operations

Airports are complex places in terms of passenger, baggage and cargo handling. A passenger goes through series of operations in order to board the plane. Meanwhile the baggage of that passenger follows a different path and operations and loaded to the same plane that the passenger was boarded. Since there are many operations and processes for passengers and baggage/cargo, it is important to see the flow of these operations. That's why, these flows have been mainly modelled in simulation and the bottleneck processes were identified. The following literature review provides a brief understanding how these flows are modelled, where the bottlenecks mainly are and the effect of the flow into the turnaround processes.

The first paper about the passenger flow in an airport was modelled by Gaatersleben and Weij (1999). A Simulation model has been developed to model the passenger handing in an airport. The objective of this simulation mode is to study the passenger flow and congestions in the airport building. Some of the area in the airport building that was taken into consideration is check-in counters, baggage reclaim, and immigration desks. Most importantly, the bottlenecks in this flow were identified and the reason for considering the congestions and waiting time in a 5 year scope is to make the model suitable for any airport. To understand the flow and to gather data, airport organisation experts have been consultant. Data collection involves process times, waiting time pf passengers, queue lengths and the number of passengers in the waiting areas. There have been future scenarios developed to considering minimum, expected and maximum times of passenger flow. The results showed many outputs and resource utilisations, each path that passengers used, waiting times and the other performance measures. After defining the bottlenecks, improvements on those areas had been done. This paper is useful in a way to scheduling of ground operations. It shows that simulation is a suitable method to use in planning the turnaround operations. However this study does not consider the whole passenger flow. It only shows the flow until boarding and the operations such as boarding or disembarking of passengers has not been considered.

Guizzi, Murino and Romano (2009) had developed a discrete event simulation to model passenger flow in an airport terminal. The model mainly focused on the optimization of all check-in desks and security check points in Naples Airport. The purpose of the developed model is first create a simulation model and then to find the optimal solution among the simulation output which minimises the closing operating cost of security check and check-in desks. There are several tools and techniques used in this paper. One of them is the main tool to build the simulation model which is Rockwell Arena Software and the other one is OptQuest which is an optimization tool in Arena. The developed model has tested and justified in the Naples International Airport in South Italy since it was easily adaptable and having a suitable architect and interface. The result of this solution proved that for that airport the optimal solution is to open 6 check-in desks and 6 security control checkpoints with around €214,000. To make a brief comment how this work can be related to the turnaround operations goes through the observation and modelling the check-in desk operations in an airport. It has a significant effect in turnaround operations. When a passenger arrives to an airport, the first thing they need to do is to go through the check-in procedure. The closing time of a check-in desk or how many check-in desks are needed to be used affects the turnaround time. Hence, finding the optimal time to close a check-in desk or the right number of check-in desks which is studied in this paper is very important in this context. The rest of the terminal operations have an effect on turnaround time as well. Security check and walking distance to the gate are some of the operations that are needed to be considered. There should be an enough amount of time between the check-in desk and the gate in order to let the passenger arrive to the boarding pass check at the gate quickly.

Another work in the area of passenger flow modelling was developed by Fotiadis (2010). A simulation model has been developed to see the potential benefits of simulation on passenger flows in an international airport. The simulation model concept is called Business Process Re-Engineering which is used when to improve the already running operations. The first objective was to model the operation areas in the airport and then to improve the existing or forthcoming bottlenecks. Different from the previous problem, in addition to check-in and security controlling operations, boarding has been considered. As a tool, another simulation software was used which was called Simul8. Macedonia International Airport of Thessaloniki was used as a case study and the model has been adapted to this airport. Data is collected from this airport including waiting time of passengers, service time of operations, queue lengths for check-in, security control. The results showed that optimization of existing operations in terminal have been achieved successfully. Passenger flow in the peak times has also been achieved to be validated. It was found that by using the maximum number of grouped check-in counters, 87% utilization has been accomplished in the peak time. According to Van Landegham and Beuselinck's paper, it was found that the maximum delays had occurred in the boarding process from the study of reduction of aircraft turnaround times. From this perspective, since Fotiadis' paper discussed and took the boarding process into consideration, this article is useful in terms of relating the last step of the passenger flow with the turnaround operations.

Schultz and Fricke (2011) have focused on managing passenger handling at airport terminals. 2 different types of model were introduced in this paper. One of them is a stochastic mathematical mode which is developed to see the passenger movement including their decisions, route choices and the action on handling processes. The other one is the simulation model in which the whole processes are modelled. The objectives of developed models are to create such a model that runs according to the passenger's perspective and analyse the efficiency of the system according to experimental design. During the modelling process, the turnaround and boarding has been discussed and considered. The different scenarios were considered such as boarding or de-boarding passengers from one door, two doors, randomly, block sequence. Moreover, regarding the turnaround sequential constraints, two decisions has been discussed: fast turnaround and regular turnaround where the difference is; in the fast turnaround the catering and cleaning are handled at the same time on the other hand in the regular turnaround, catering cannot start unless cleaning finished. For the fast turnaround, the expected boarding time is approximately 30min and standard deviation is 9min. As a result of the boarding simulation, average of 26.8min and of 0.6min boarding time has been achieved with 0.6min standard deviation. In this paper, it can be observed that the turnaround has been considered during the model development and the importance of turnaround can be seen from the results. Instead of using simulation, an optimization model could have been used to model the turnaround.

After reviewing all the papers about passenger flow in an airport and after the research of some airlines' strategies in turnaround operations, it can be concluded that some of the turnaround activities especially boarding has been added to the studies since it is one of the most important turnaround operation and the influence of other operations into the turnaround operations cannot be negligible as well. From the papers, it was seen that the amount of reduction in the terminal operations could have a significant decrease on the turnaround time in general.

Literature Review Matrix has been prepared to identify where the gap in knowledge is and how this study is filling this gap showed in Table 2.1 below. Literature review matrix is composed of rows and columns where columns represent the programme technique used to develop the model and rows are showing the subject studied in articles. Inside the literature review table, article names are presented in the places in which articles belong to a subject and applied programming technique

2.3. Literature Review Matrix and Gap in Knowledge

Table 2.1: Literature Review Matrix

	Simulation	IP	SP	DP	Heuristic Methods	Fuzzy	Petri Net
Aircraft Rotation and Delay Impacts	(Wu and Caves, 2002), (Wu and Caves, 2004), (Wu, 2005), (Adeleye and Chung, 2006), (Fricke and Schultz, 2009)	(Sherali, Bish, and Zhu, 2006), (Lan, Clarke and Barnhart, 2006)	(Wu and Caves, 2004)	(Jiang and Barnhart, 2013)	(Haouari, Aissaoui and Mansour, 2009), (Weide, Ryan and Ehrgott, 2010), (Dunbar, Froyland and Wu, 2012)		
Modelling of Passenger/ Baggage / Cargo Operation	(Gatersleben and van der Weij, 1999), (Guizzi, Murino and Romano, 2009), (Fotiadis, 2010), (Schultz and Fricke, 2011)		(Schultz and Fricke, 2011)				
Modelling Turnaround and Improvements	(Sanz de Vicente ,2010), (Norin, et al., 2012), (Gomez, Scholz, 2009)		(Mao, Roos and Salden, 2009), (Kunze, Oreschko and Fricke, 2012)	(Kunze, Oreschko and Fricke, 2012)	(van Leeuwen, 2007)	(Han, Chung and Liang, 2006), (Fitouri Trabelsi et al., 2013)	(Vidosavljević and Tošić, 2010)

Literature matrix was which is presented in this way in Table 2.1, in order to identify gap in knowledge. The empty boxes in the matrix shows that there are no studies done in the area of any subjects presented in the first column using any of these programming technique presented in the first row. The works have been done so far are in the area of "Aircraft Rotation and Delay Impacts" are studied mainly using simulation, heuristics, integer programming, stochastic programming and dynamic programming. Modelling of Passenger, Baggage and Cargo Operations are predominantly using simulation modelling and one article on stochastic programming. Finally, Modelling Turnaround and Improvements are studied using different programming techniques which are simulation, stochastic programming, dynamic programming, heuristic methods, fuzzy critical path technique and finally petri-nets.

In this study the gap is aimed to be filled in the area of Modelling Turnaround and Improvements using integer linear programming technique. There have been 24 articles reviewed in this thesis and most of them did not focused on linear programming because of the complexity. Instead of using linear programming techniques, most of them had chosen to use simulation or heuristic methods. The nearest papers to this study are the articles in the area of Modelling Turnaround and Improvements. The closest paper from this area is the work of Sanz de Vicente (2010) since the turnaround are scheduled and presented as Gantt charts and the aim of the project is very similar.

2.4. Chapter Summary

All the aforementioned papers show the importance of modelling the turnaround operations, the different modelling approaches to the problems and most importantly, how they are different from the turnaround model that is being suggested in this thesis in terms of turnaround operations, turnaround times, operations precedence relationships and resource constraints.

The gap in knowledge has been identified using literature review matrix (Table 2.1) and the most used techniques have been discussed in the three areas. The nearest area was found as Modelling of Turnaround and the technique as integer linear programming.

CHAPTER 3 – RESEARCH METHODOLOGY AND MATHEMATICAL MODELING

This chapter focuses on the methodology used in this study explaining the research approach, research design including research strategy, sampling and data collection, research instrument development and analysis of data.

In the second part of this chapter, as a method of study, the mathematical modelling has been presented including objective function, constraints as well as sets, indices, parameters and variables.

3.1. Research Approach

Before getting into the research methodology in detail, the method of research and the approach needs to be clarified. There are two different approaches which are quantitative and qualitative.

According to Creswell (1998) qualitative approach is the way of understanding a human or social phenomenon, based on methodological research conditions. Qualitative approach is mainly related with non-numerical approach and explained within a natural context. This approach can be used if the knowledge which is being applied to the phenomenon is new, not researched deeply and if theory building and testing is used. The most common data collection techniques for this approach are group discussions, archival analysis and semi-structured interviews.

On the other hand, quantitative approach is described as explaining a phenomenon by collecting numerical (quantitative) data that are mathematically analysed by Aliaga and Gunderson (2002). This approach is related to numerically examining the data however the collected data does not have to be in numerical format. After the data collection, if the data collected can be interchanged to a numerical representation, then the quantitative approach should be used. Most common data collection techniques are questionnaires, surveys and experiment.

According to this study, the quantitative approach has been chosen since the collected data and analysis represents numerical and statistical analysis. Mathematical modelling in its nature is a numerical technique. Hence the approach to the research becomes quantitative.

3.2. Research Design

Research design is an important component of research methodology since the rest of the study is depended on the design of the research. That's why it is significant to present a well-developed research design. According to the design of this research as it is discussed in the research approach, the quantitative approach has been used. After that as a first step the strategy of the research has been discussed. Then how the data is collected, what sampling approach has been used and what kind of research instrument has been developed is discussed as part of the research design. At the end the data analysis approach has been mentioned and clarified.

3.2.1. Research Strategy

The research strategy is important in defining the research questions and meeting the objective of the study. That's why it is crucial to correctly decide on the strategy at the beginning of the study. Some of the research strategies explained by Saunders, Lewis and Thornhill (2007) are experiment, survey, case study, action research, grounded theory, ethnography and archival research.

Experiment research strategy is mainly used in social science and psychology. That strategy concerns the effect in one variable caused by changing the other variable, the relations of these variables. Survey research strategy is one of the most popular strategies in business and management studies. It has mainly; a deductive approach where who, where, what, how many and how much questions are asked. The main tool of this methodology is questionnaires and helps to collect quantitative data. Another strategy is Case Study which is focusing on defining relationships that exist in reality and mostly in one organisation using more than one source of evidence. The questions which are being expected to be answered are 'why?' and 'what?'

questions. There can be different kind of data collection techniques such as observation, interviews and documentary analysis. Action research strategy is the 4th strategy which focuses on research in action, not research about action. The process mainly flows like this: Diagnosis, Planning, Taking Action and Evaluating. Its main concern is taking actions within an organisation in case of an issue and resolution these issues. The question asked for the Action Strategy is mainly 'how to?'. Another strategy is Ground theory which is concentrating on explaining individual's behaviours. The purpose of this strategy is to build a new theory rather than testing the existing one. Most used data collection method is doing observations one after another. Ethnography as another strategy type generally focuses on the explanation and description of the social world. This strategy had evolved from the area of anthropology. The data collection technique is the extended participation observation since the research takes a lot of time. The final strategy is archival research mainly differs from the others because of the data source that is used. In this research, main data source is historical documents and records.

After having a brief idea about each research strategy, for this study, it has been concluded that combination of action research and case study research is the best and most suitable strategy when all approaches and data collection techniques have been considered.

The case study research has been found suitable since it involves the researcher's observations, it seeks to answer "how?" and "why?" questions and it is being conducted in a field where not many studies have been undertaken. The triangulation of data collection which means collecting data using more than one technique was another reason of choosing Case Study strategy. The techniques used in data collection are observations and documentary data. However instead of multiple case studies, single case study approach has been chosen since it is being conducted for one specific company which makes the case unique.

On the other hand the reason for choosing action research strategy is that the action research concern about the resolution of an organisation's problem which is in the case of this study. First of all the problem is being diagnosed, then it is being planned and there comes a stage where the action is taken and finally evaluation takes place. Asking “how to?” question is another strategy used within the action research.

3.2.2. Sampling and Data Collection

Deciding on the sample and which data needs to be collected from which sample was important before beginning the data collection. The reason for sampling simply occurred since it is impossible to collect the data of an entire flight’s turnaround times and most importantly the time constraint.

There are several sampling techniques mentioned by Saunders, Lewis and Thornhill (2007). These techniques first divided into two which are probability sampling and non-probability sampling and then within each type they are further classified. First of all since the statistical inferences must be made from these samples, the technique belongs to the probability sampling. In order to further describe the classification of sampling, the question of if the sampling requires a sampling frame having relevant clusters or not was asked. Since there are 4 different flight types, 5 samples were collected for each flight type: domestic-domestic, domestic-international, international-domestic, and international-international. These flight types can be defined as cluster groups. Hence the sampling technique was noted to be Cluster Sampling. Within each cluster, the samples were chosen according to simple random sampling which allows choosing the samples randomly. It can be concluded that, first attempt on defining the sampling method was identified as Cluster Sampling and after that within each cluster group, the sampling approach has been defined as Random Sampling.

In the data collection phase, the Non-participant Observation has been chosen to collect data. According to non-participant observation type of data collection, the observer does not intervene with the participants. The data is mainly collected by the observation of the system from a distance and taking notes about the situation and numerical data if it exists. In the case of this study, the observation was handled with 3-day site visit to the hub airport of the company. In the airport, from a distance point, how turnaround operations are handled, the sequence of the operations, number of resources used and the starting and finishing time of each process have been observed and recorded on the research instrument paper which was prepared prior to the observation.

5 aircrafts were observed for four different types of flights. In total 20 observations were recorded. Before the on-site visit, another data collection type which is collecting the existing data from the company related to turnaround operations, their sequence and number of resources used in each process has been asked and received. This type of data collection can be referred to Primary Data Collection, since the data was received from the first hand (from the company). This data helped to prepare the research instrument and understand how different is the operations shown in the manual from the reality (observed data).

3.2.3. Developing the Research Instrument

After defining the research approaches and design, the next step was to prepare a research instrument in order to collect data. Since the data collection relies on the structured observation for this study, preparing an instrument is crucial.

Structured documents which have been prepared for 4 different flight types are shown in Appendix B. This document shows the turnaround operations broken down into sub-processes as well as alternative operations. Each operation is given a number and with the data document collected from the company prior to the observation, the processes has been defined and the precedence relationships have been stated which made it easy to follow the operations in the correct order during the observation process. Then, the number of staff column has been added to the table. Finally start time and end time columns added in order to get the duration of each process.

The advantages of creating the own research instrument is to be able to follow all the processes in an order and easily note the starting and finish times of each process.

3.2.4. Analysing the Data

The collected data has been inputted to excel after all the data collection (observation) finished. Then the difference between the finish time and start time of each process has been calculated. In order to use them in the mathematical model as an input and to have a general idea of duration of each process, the average duration of each operation has been calculated. Since there are 4 different flight types having 5 samples, average duration of the different operations for each flight type have been calculated within itself.

Finally, each flight type's operations has been assigned an average duration from the collected data. This is how the observed and collected data was analysed. To know how to analyse data at the beginning of the methodology was very important since the collected data may be useless it is well planned before.

3.3. Optimisation Tool and Techniques

Optimisation is a scientific approach and a branch of Operations Research. It uses mathematical techniques to make decisions. The main concern of optimisation is to maximise or minimise the objective considering the constraints (limitations) and decision variables. The aim of optimisation is to find the best feasible solution among other solutions which is referred to "Optimal Solution".

There are several optimisations techniques that are used to solve real life problems. Some of these techniques are Linear Programming (LP), Nonlinear Programming (NLP), Integer Programming (IP), Dynamic Programming (DP) and Stochastic Programming (SP). Since the linear programming technique has been covered in this study, it is mentioned more detailed in the following section.

Some of the tools which are used in optimisation to solve problems are excel, Gams, Lindo, Tora and ILOG CPLEX.

3.3.1. Linear Programming

Linear Programming (LP) is one of the most common programming techniques which uses a mathematical model to define the problem. The word "programming" in the title does not mean computer programming; rather it refers to "planning".

The main property of this programming form is the objective function and constraints composed of linear functions. There are different types of linear programming which are Transshipment Problem, Multidivisional Problems, Decomposition Principle for Multidivisional Problems, Multitime Period Problems, Multidivisional Multitime Period Problems, Stochastic Programming and Chance-Constrained Programming.

3.3.1.1. Origin

Linear Programming was first formulated by Fourier; a French mathematician in 1800s.The aim of this formulation was to improve economic planning. During the World War 2, the need for allocation of resources efficiently was required for military planning. In 1947, George Dantzig developed the simplex method for US Ari Force which was the first application of LP in the real-world problem. That's why, Dantzig is found as an important scientist in the history of linear programming (Hillier and Lieberman, 2000).

3.3.1.2. Types of Linear Programming Models

Linear Programming has a very broad problem types and these problem types can be very specific. These special types of linear programming problems are Transshipment Problem, Multidivisional Problems, Decomposition Principle for Multidivisional Problems, Multitime Period Problems, Multidivisional Multitime Period Problems, Stochastic Programming and Chance-Constrained Programming.

Transshipment problem is the extension of the transportation problem and can be simply solved as a transportation problem using transportation simplex which is a linear programming solution procedure. Multidivisional problem is the other class of linear programming which deals with coordinating the decisions of the separate divisions of a large organisation. This problem type can be solved by decomposition principle; otherwise it may not be solved since the problem consists of many constraints and variables. Decomposition principle for multidivisional problems is a very similar type of linear programming with multidivisional problems. In this problem, a decomposition approach is used to solve the problem. First problem is reformulated to reduce the number of functional constraints and then the revised simplex method is applied.

The other type is the multitime period linear programming which is used to plan several time periods into the future. As in the multidivisional problems, this problem type can also be almost decomposable into subproblems. Multidivisional multitime period problems are composed of many subproblems and each of them concern to optimise the operation of one division during on one of each time periods. This ptoblem type again considered as a type of linear programming and solved using decomposition principle for multidivisional problems however this is the more extended version of it.

The last type of linear programming is called as *linear programming under uncertainty*. The main speciality of this programming model is that parameters consist of random variables. Stochastic programming and chanced constrained is one of the most common problems in the practical application of linear programming which belongs to that problem type. Stochastic programming requires all constraints to be probabilistic on the other hand chance constrained programming allows a small probability of violating any functional constraint. In order to solve both problems by simplex method, they need to be reformulated as new equivalent linear programming models where the assumption of uncertainty is satisfied.

3.3.1.3. Fields of Applications

There is a very broad field of application of linear programming. The most common area is the problem of allocation of limited resources to activities. The other general application areas are production, finance, marketing and distribution problems (Hillier and Lieberman, 2000).

One of the examples regarding to its application is the petroleum refineries problem. The objective of this problem is to find the best location for pipelines and find best routes and schedules for tankers. Other common application objectives are to minimise production cost, maximise optimal production profit and minimise cost or distance in transportation.

Problems in Aviation where LP was used are crew scheduling, flight scheduling, aircraft routing, fleet assignment, manpower planning, gate assignment, revenue management and fuel management problems (Bazargan, 2010).

3.3.1.4. Mathematical Modelling Structure

Mathematical model is composed of an objective function and number of constraints (limitations) which are equations or inequalities. In order to make decisions, there are decision variables which can be denoted as $x_1, x_2, x_3, \ldots, x_n$. As an input to the model, some constants are defined such as c_j, b_i and a_{ij}. The following symbol descriptions and model is the classic LP model for a resource allocation problem (Luenberger and Ye, 2008).

Z = value of overall measure of performance.
x_j = level of activity j (for $j = 1, 2, \ldots, n$).
c_j = increase in Z that would result from each unit increase in level of activity j.
b_i = amount of resource i that is available for allocation to activities (for $i = 1, 2, \ldots, m$).
a_{ij} = amount of resource i consumed by each unit of activity j.

$$\text{Maximize} \quad Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n, \quad \rightarrow \text{Objective function}$$

subject to the restrictions

$$\left.\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &\le b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &\le b_2 \\ &\vdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &\le b_m, \end{aligned}\right\} \text{Functional constraints}$$

and

$$\left. x_1 \ge 0, \quad x_2 \ge 0, \quad \ldots, \quad x_n \ge 0. \right\} \text{Nonnegativity constraints}$$

This model maximises Z which is the overall performance measure. Functional constraints are ensuring that resource usage per unit activity does not exceed the available amount of resource. Nonnegativity constraints are ensuring that decision variables do not get negative values.

This model assigns such values to decision variables that the objective function gets the maximum value.

3.3.1.5. Sensitivity Analysis

Sensitivity analysis takes a very important part in mathematical modelling especially if some improvements are being considered to be made about a problem. The main purpose of sensitivity analysis is to see the effects in objective function if some values of sensitive parameters are changed (Hillier and Lieberman, 2000). Sensitive parameters are the parameters who can affect the objective function if they are increased or decreased. This is the best technique to analyse “what if…” scenarios and compare with each other and see the importance of parameters in the problem

3.3.2. Developing “TurnOper_LP” Mathematical Model

Finding the best schedule of turnaround operations are important in order to turn the aircraft on time and to standardize the process. In order to achieve this objective a MIP model has been developed.

First of all the TurnOper_LP model was considered as a Project Scheduling Problem with Workforce Constraints. The Project Scheduling Problem in general minimises either makespan (completion time of the last job) or total tardiness. There are other objectives used in project scheduling however these are the most common ones. For this problem, the objective is to minimize the Makespan which means that the operations will be scheduled in such a way that the completion time of the last job will be the minimum among all other schedule alternatives. After defining the objective of the model, some constraints were introduced. The main restrictions of the turnaround process are the precedence relationships of the operations. As it was mentioned in chapter one, operations are given in an order and some of them cannot be performed at the same time because of the safety and security reasons or because of the nature of the operations. For example, some airlines do not let fuelling to start before pax disembarking finishes and boarding starts. The reason of this is because of the safety reasons. There shouldn't be any passenger inside the airplane during the fuelling just in case a fire. Another example in which the nature of the process restricts the model is; baggage cannot be offloaded if the conveyor is not positioned. It is impossible to offload the baggage without positioning the conveyor.

The other constraint is the space constraint. Some operations need to use the same space or door during the turnaround and there should be a restriction not to process them simultaneously.

The final constraint which is considered is the workforce constraint. Turnaround operations are performed by the staff working for different ground handling companies. Cleaning, Fuelling and Baggage Handling are some of them which are performed by different company's staff. Moreover, for each operation, there are number of staff doing these operations. However, even though the number of staff needed for the turnaround of the aircraft for an operation doesn't mean that this operation has to be handled by exactly that many staff. That operation can only require half of the available staff. In that case, a resource constraint is needed to distinguish the operations which need the same type of staff. For example, according to the precedence constraint, some operations can be handled at the same time, which means there are no restrictions by the precedence constraint. However if these two operations need the same staff from the same workforce pool (number of staff who are responsible with these operations), and if the total number of required staff from both operations exceeds the available number of staff in that pool, then those operations cannot be done at the same time. One of them should start after the other.

After considering all these constraints, the TurnOper_LP Model has been developed based on the Project Schedule with Workforce Constraint model of Pinedo's (Pinedo, 2005). According to Pinedo's model the precedence and workforce are also valid for the developed model. Then in addition to these constraints, space constraint has been added to the model and a new model has been developed. The non-linear formulation of the mathematical model is presented below.

$$\text{Minimize} \sum_{t=1}^{M} t.F_{n+1,t} \qquad (1)$$

subject to

$$\sum_{t=1}^{M} t.F_{jt} + p_k - \sum_{t=1}^{M} t.F_{kt} \leq 0 \qquad \forall_{j\to k} \in A \qquad (2)$$

$$\sum_{j=1}^{n} \left(W_{ij} \sum_{l=t}^{t+p_j-1} F_{jl} \right) \leq W_i \qquad \forall_i \in I \text{ , } \forall_t \in T \qquad (3)$$

$$\sum_{t=1}^{M} F_{jt} = 1 \qquad \forall_j \in J \qquad (4)$$

$$p_k + \sum_{t=1}^{M} F_{jt} \leq \sum_{t=1}^{M} F_{kt} \quad \veebar \quad p_j + \sum_{t=1}^{M} F_{kt} \leq \sum_{t=1}^{M} F_{jt} \qquad \forall_{j,k} \in B \mid j \neq k \qquad (5)(6)$$

$$F_{jt}, y_{jk} = \{0,1\} \qquad \forall_{j,k} \in J, \forall_t \in T \qquad (7)$$

According the model, the objective function minimises the makespan. Objective function $\sum_{t=1}^{M} t.F_{n+1,t}$ minimises the finish time of the last job which is a dummy node showed as n+1. Job n+1 is the successor of all other operations. From time t=1 to sum of duration of all jobs (big M), find the time t in which the job n+1 is completed.

Constraint (2) $\sum_{t=1}^{M} t.F_{jt} + p_k - \sum_{t=1}^{M} t.F_{kt} \leq 0$, $\forall_{j \to k} \in A$ is the *Precedence Constraint* ensures that the precedence relationships of operations are satisfied. It defines the finish time of operations (jobs) considering the precedence relationships where job j is the immediate predecessor of job k. Considering only the precedence set A, in time t, job k can be completed after job j if and only if the time that job j is competed plus processing time of job j does not exceed the completion time of job j.

Constraint (3) $\sum_{j=1}^{n} \left(W_{ij} \sum_{l=t}^{t+p_j-1} F_{jl} \right) \leq W_i$, $\forall_i \in I$, $\forall_t \in T$ is the *Workforce Constraint* which implies that total demand for pool i at time t does not exceed the availability of pool i. For all pool i and time t, sum up all number of staff needed from pool i for each job being processed on the same time interval. Here, *pool* represents the different group of staff based on their skills. So if there i=2, that means the staff who belongs to pool 2 according to their skillsets. This sum of staff used from pool i in that time interval should not exceed the existing amount of staff in that pool. If two operations are coinciding each other (being processed at the same time interval), and if both of them uses the workforce from the same pool, then this constraint acts and tries to define if the total of used resources by both operations in the coincided time exceeds the total number of staff in that workforce pool, then the constraint will not let both operations process at the same time interval.

Constraint (4) $\sum_{t=1}^{M} F_{jt} = 1$, $\forall_j \in J$ ensures that each operation is performed. Each job within the time interval from 1 to M, which is an upper bound calculated as sum of all the operation durations to achieve a big enough time bound, should be completed for all job j.

Constraint (5) and (6) are the *Disjunctive Constraints* which are first written in the nonlinear format. The non-linear format of the constraint was as follows:

$p_k + \sum_{t=1}^{M} F_{jt} \le \sum_{t=1}^{M} F_{kt} \quad \bar{\vee} \quad p_j + \sum_{t=1}^{M} F_{kt} \le \sum_{t=1}^{M} F_{jt} \;, \forall_{j,k} \in B \,|\, j \neq k$. These constraints ensure that two operations using the same space (area) cannot be processed at the same time. That means only one of them could be active. Either job j will precede job k or job k will precede job j for only a set of specific operations which uses the same area in the ramp. Here, B is the set of jobs using the same space and the constraint is being created for only the jobs which are in set B and for different jobs from each other.

In order to linearize these two equations, a new binary decision variable has been introduced. The new variable y_{jk} gets the value of 1 if the first equation is satisfied. Otherwise it will get 0. There is a need for linearization of this constraint since in this study a linear programming model is being worked hence the model should satisfy that each constraint is linear. The linearization process is explained briefly below;

Linearization:

Step1: Representation of both equations with binary variables

$$y_{jk} = \begin{cases} 1, \text{ if } \; p_k + \sum_{t=1}^{M} F_{jt} \le \sum_{t=1}^{M} F_{kt} \\ 0, \text{ otherwise} \end{cases} \qquad y_{kj} = \begin{cases} 1, \text{ if } \; p_j + \sum_{t=1}^{M} F_{kt} \le \sum_{t=1}^{M} F_{jt} \\ 0, \text{ otherwise} \end{cases}$$

Step 2: Logical representations by variables

$$y_{jk} \,\bar{\vee}\, y_{kj}$$

Step 3: Mathematical representation

$$y_{jk} + y_{kj} = 1 \quad = \quad y_{kj} = 1 - y_{jk}$$

$$p_k + \sum_{t=1}^{M} F_{jt} \le \sum_{t=1}^{M} F_{kt} + M\left(1 - y_{jk}\right) \qquad p_j + \sum_{t=1}^{M} F_{kt} \le \sum_{t=1}^{M} F_{jt} + M.y_{jk}$$

The above two linearized constraints have been achieved within these 4 steps and used in the mathematical model.

Lastly, constraint (7) $F_{jt}, y_{jk} = \{0,1\}$ is the binary constraint which ensures that the variables can only take the values 0 or 1.

The **final form of the mathematical mode**l after the linearization process is shown below:

$$\text{Minimize } \sum_{t=1}^{M} t.F_{n+1,t} \qquad (1)$$

subject to

$$\sum_{t=1}^{M} t.F_{jt} + p_k - \sum_{t=1}^{M} t.F_{kt} \le 0 \qquad \forall_{j \to k} \in A \qquad (2)$$

$$\sum_{j=1}^{n} \left(W_{ij} \sum_{l=t}^{t+p_j-1} F_{jl} \right) \le W_i \qquad \forall_i \in I \ , \forall_t \in T \qquad (3)$$

$$\sum_{t=1}^{M} F_{jt} = 1 \qquad \forall_{\mathrm{j}} \in J \qquad (4)$$

$$p_k + \sum_{t=1}^{M} F_{jt} \le \sum_{t=1}^{M} F_{kt} + M\left(1 - y_{jk}\right) \qquad \forall_{\mathrm{j,k}} \in B \mid j \ne k \qquad (5)$$

$$p_j + \sum_{t=1}^{M} F_{kt} \le \sum_{t=1}^{M} F_{jt} + M.y_{jk} \qquad \forall_{\mathrm{j,k}} \in B \mid j \ne k \qquad (6)$$

$$F_{jt}, y_{jk} \in \{0,1\} \qquad \forall_{\mathrm{j,k}} \in J, \forall_t \in T \qquad (7)$$

Notation of the mathematical model is shown below including sets and indices, parameters and decision variables.

Mathematical Model Notations

Decision variables are one of the main components of the mathematical model. These variables presented below will decide on the objective function of the model. Both of them are binary variables which mean they can only get the values 1 or 0.

The first decision variable is $F_{jt} = \begin{cases} 1, \text{ if job j is completed on time t} \\ 0, \text{ otherwise} \end{cases}$. F_{jt} gets the value of 1, if job j is completed on time t. Otherwise it will get the value of 0. Here, the index j represents the turnaround jobs or operations. It can be presented as $\text{j} = \{1,..,|J|\}$ which shows that j belongs to set J which starts from 1 until total number of operations in the system. Other index is t which is the time index. The set which t belongs to T can be presented like this $t = \{1,..,|T|\}$. Here, t starts with minute 1 and gets all the values until T which is the total number of minutes in the process. To sum up, there are J*T number of variables as F_{jt} and each of them either gets either 0 or 1.

The other decision variable is $y_{jk} = \begin{cases} 1, \text{ if job j is proccessed before job k} \\ 0, \text{ otherwise} \end{cases}$ which decides which job will be processed first. Index j represents the jobs as it was discussed in the previously and here k also represents jobs and belongs to the same set as j. That means y_{jk} is 2 dimensional variables which create JxJ number of variables. If job j is processed before job k, then y_{jk} will get the value of 1. However if job k is processed before job j, then it will get the value of 0.

Parameters used in this model are the constants of this mathematical model. They are known facts which are the input for the model.

The first parameter is N which is $N = \text{number of different pools in the workforce}$

$\text{W}_i = \text{total number of staff in pool i}$, where i is the pool index which is explained as: there are some staff which have the same skillset and can do certain kind of operations. In order to distinguish them and assign them correctly to the operations, staff are assigned to pools based on the ability of doing same kind of jobs.

Another parameter is $W_{i,j}$ which is the number of staff job j needs from pool i.

p_j is basically the processing time of job j. It shows the duration of each operation.

Finally Big M is formulated as $M=\sum_{j=1}^{n} p_j$ which is the total duration of operations in the system. It is the extreme case of turnaround time if all jobs are processed as a series. Since it is impossible, M is the upper bound of the model and big enough number to include every operation.

Model inputs and outputs are shown in Figure 3.1.

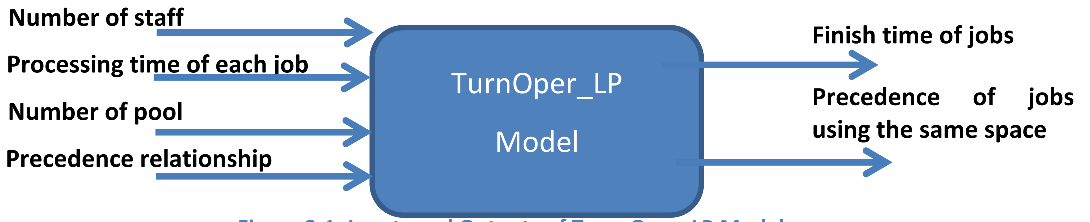


Figure 3.1: Inputs and Outputs of Turn_Oper_LP Model

Above figure explains what are used as an input to the mathematical model and what is being expected to get as an output.

3.4. Chapter Summary

This chapter concludes the research methods and development of the mathematical model. Research approach, design and data collection were mentioned within the research methodology and as a method, developed mathematical model has been introduced with detailed definition of objective and constraints.

CHAPTER 4 – CASE STUDY AND IMPLEMENTATION

This chapter explains the case study of a low-cost airline company. The real case problem is explained by mentioning the current state of the turnaround operations used by the company. The revised mathematical model has been introduced and implementation of the model is showed. Tools and techniques used in the development of the model were presented.

4.1. About the "XYZ" Airline and its Hub Airport

This study was conducted on a low-cost airline company based in Turkey as a case study. The company is the most rapidly growing airline in Europe having 44 Boeing 737-800 airplanes, in total 47. The company started its schedule flights in 2005. Fight network of the company has reached to 76 locations since then (45 international and 31 domestic flights) in 30 countries according to 2013 results. Their strength in the industry is achieving a high percentage of average departure rate calculated as approximately 90% for 2013. With using this strength, they are aiming to attract more customers.

As every low cost carrier, one of their missions is to make everybody fly achieving a low cost price policy. In order to provide the low cost prices, they are using some strategies. One of these strategies is reducing the seat pitch to a minimum so that the capacity of the aircraft could increase. The other strategy is to fly to the airports where the airport fees are less when compared to others in the same city. Moreover, by limiting the available baggage weight to a minimum and limiting the number of cargo baggage and hand baggage for each passenger can take, they reduce the weight of the aircraft as it consumes more fuel. Other than these strategies, there are some others which are still being considered to reduce these costs.

The company's hub airport is 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 aircrafts/year while the other airport has 350,400 aircrafts/year capacities which is the hub airport for the flag carrier of the country. The hub airport for the low cost carrier has only 1 runway and the carrier uses 70% capacity of the airport. Some pictures of the airport taken during the data collection period are showed in the below figures (Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4)

Figure 4.1: Tow-car Connection

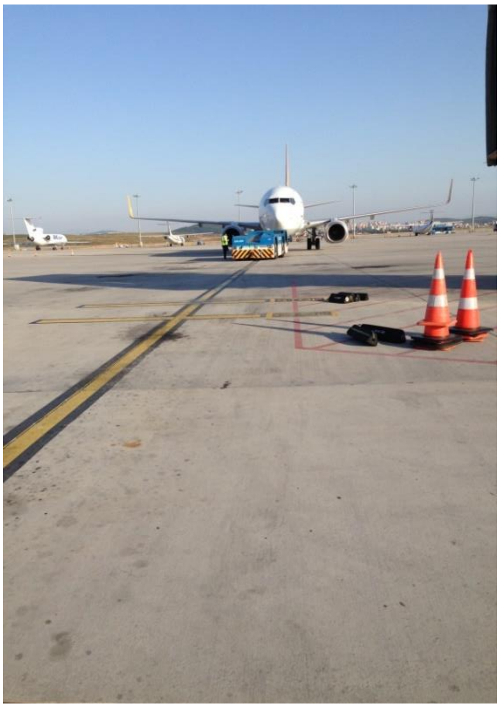


Figure 4.2: Push-back Process

Figure 4.3: End of Push-back Process

Figure 4.4: Airbridge connection

4.2. Understanding the Current System

The company aims at achieving even lower cost prices to attract more customers and in order to achieve some of the strategies that were mentioned above. Their main concern is to keep the level of departure rate stable or even increase the percentage. This can help them to increase customer satisfaction. However, this is not an easy job. The problem that is faced at this point is the aircraft rotation and turnaround modelling which is mentioned in the literature review in detailed. The on time departure rate can only be achieved if the turnaround is planned well and the rotation is considered. In this case, the company has stated that their on-time performance is being affected with the turnaround times. In order to find a solution to the decreased on-time departure percentages, they needed a new schedule of operations to achieve the minimum turnaround time.

At the beginning, the existing turnaround schedule has been collected as a data prior to the observation in order to understand the system. According to this data, there were 4 different scheduled turnaround times, one of them for the flights arriving from a domestic port and departure from the hub to a domestic port (domestic-domestic) which is scheduled between 30 minutes. Flights which arrive from an international port to the hub and depart to a domestic port (international-domestic); or arrive from a domestic port and depart to an international port (domestic-international) were given a 40 minute scheduled turnaround time. Finally the turnaround time of flights arrive from an international port and depart again to an international port (international-international) was scheduled as 35 minutes. According to provided document, the operations which make the differences between turnaround times for these 4 different flights were analysed. Some other questions were asked as well in order to fully understand the turnaround process, all the operations, the precedence of operations and resources used in each process.

According to this analysis, the flow of the operations was presented as a flow chart (Figure 4.5 and Figure 4.6). This chart basically shows the precedence relationships of the operations starts from the chock-on process until chock-off. However, the scheduled and actual departure and arrival times are calculated from opening the passenger doors until closing them. As it was mentioned in the introduction chapter, most of the airlines takes the chock-on and chock-off times as a start and finish activity of a turnaround. That's why, different from the existing schedule, the turnaround process was examined from the chock-on until the chock-off time.

In this flow chart, only operations start and finish times are presented. Delays haven't been stated in the flow chart since in the modelling process delays were not taken into consideration. In order to show operations which can be done simultaneously, parallel sign = is used in the flows.

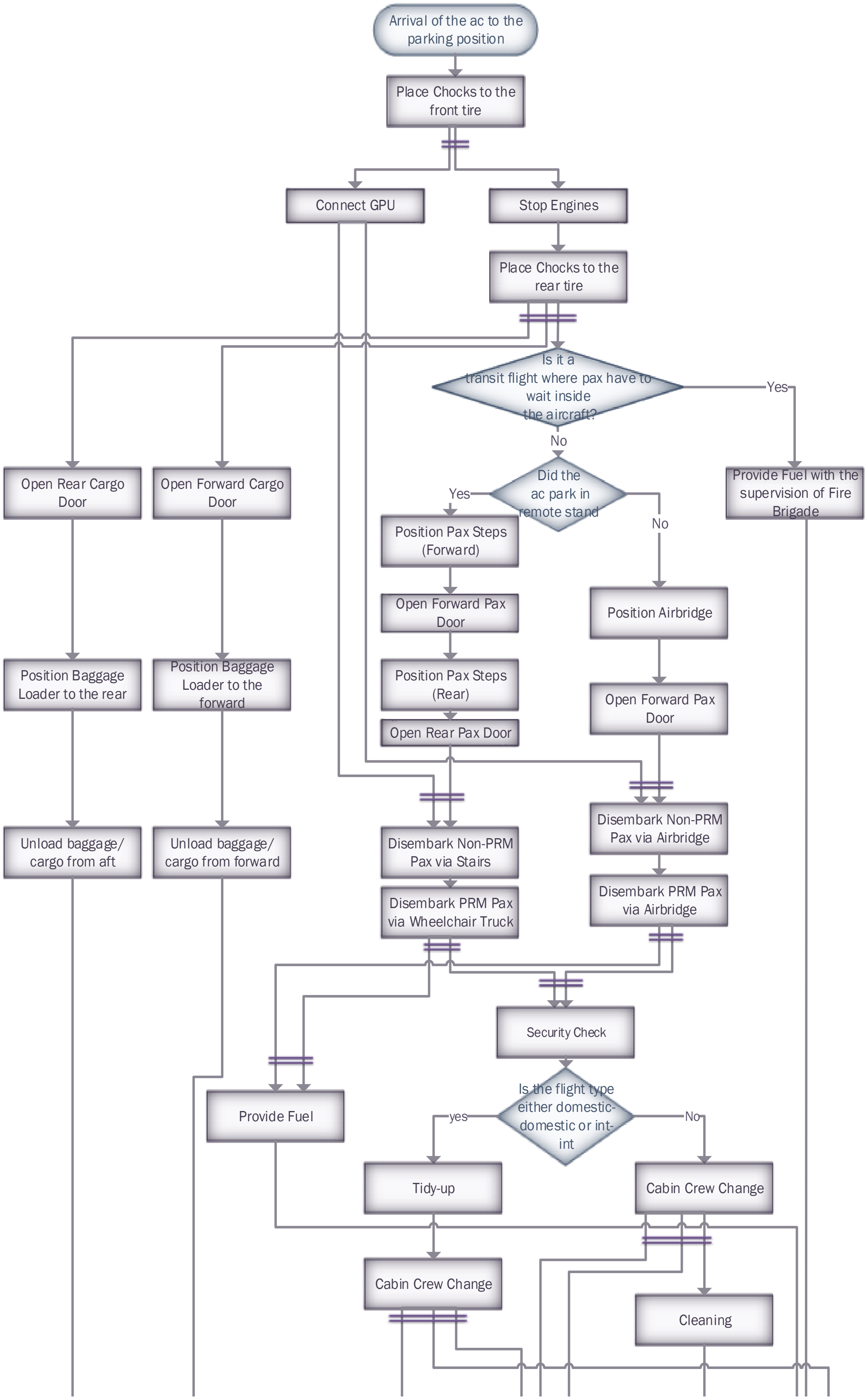


Figure 4.5: Flow Chart of the current system at the Hub Airport

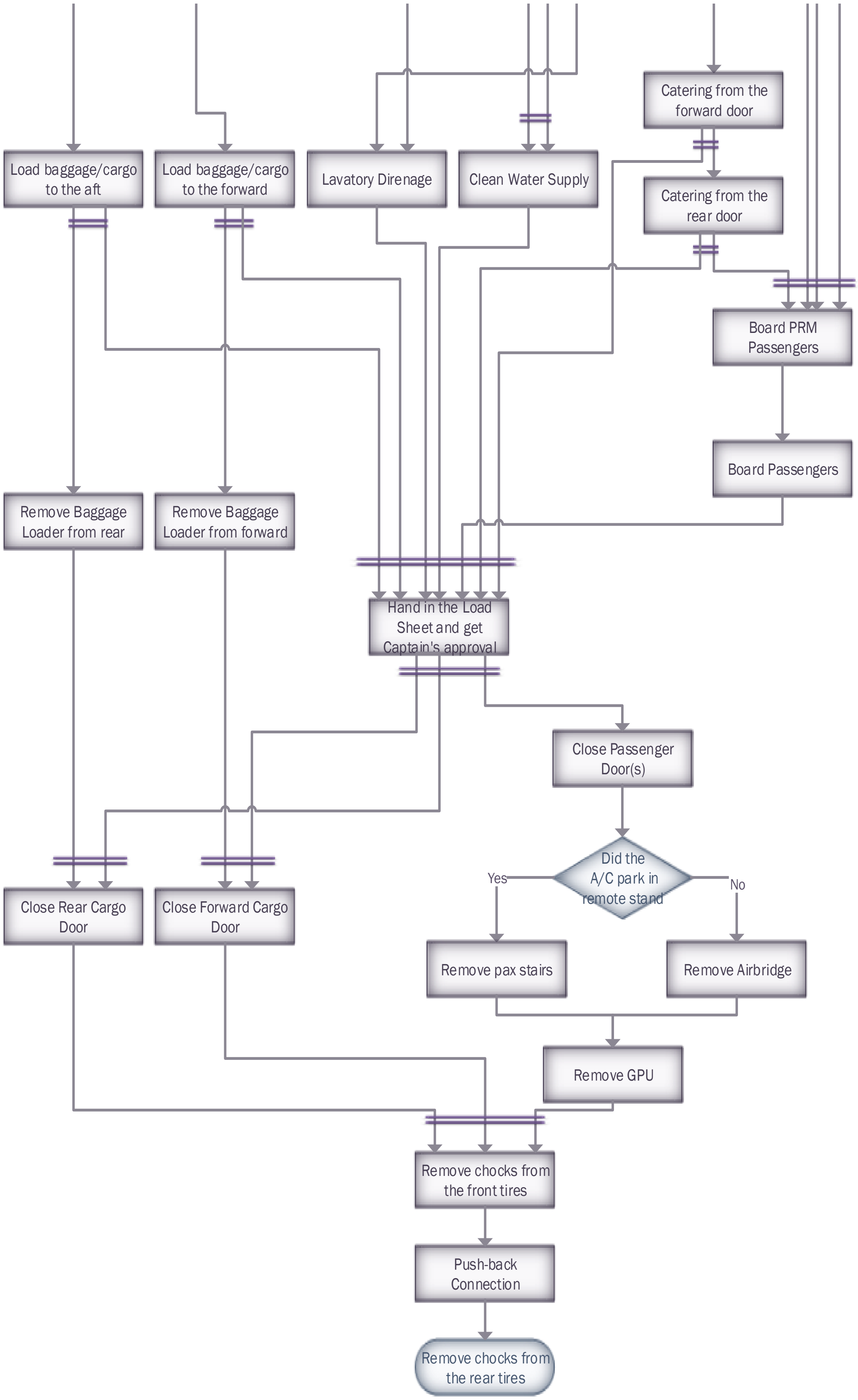


Figure 4.6: Flow Chart of the current system at the Hub Airport (Cont.)

According to the above flowchart, turnaround process starts with the arrival of the aircraft to the parking stand and placing chocks to the front tire. After that, GPU is being connected and engines are stopped. After engines are stopped, chocks are put front and back of the rear tires. Then, forward and aft cargo doors are opened. Meanwhile according to the flight type, if it is a transit flight, then fuel can be started if there is fire brigade supervising in front of the plane. Otherwise, if it is not a transit flight, then fuel can start after all the passengers leave the aircraft. According to the parking position, if the aircraft is parked in a remote stand, first of all passenger stairs (steps) are positioned to the forward door and forward passenger door is opened. Then stairs are positioned to the rear door and rear door is opened. Finally non-PRM passengers are disembarked first and a hi-lift truck disembarks the PRM passengers (wheelchair passengers). However, if aircraft doesn't park at the remote stand which means it is parked in front of the terminal, the airbridge is positioned and forward pax door is opened. First, non-PRM passengers are disembarked and then PRM passengers are disembarked via airbridge.

Security check starts when there are no other passengers left in the airplane and at the same time fuelling starts. After security check, depending on the flight type, either tidy-up or cleaning are performed. If the flight type is domestic-domestic or international-international, then tidy-up is preceded. If the flight type is domestic-international or international-domestic, then first cabin crew is changed and then cleaning is processed. After tidy-up, cabin crew is changed then, PRM passengers start boarding and finally non-PRM passengers are boarded. However, after cleaning process, before passengers start boarding, first catering is performed from forward and rear door. Then PRM passengers are allowed to the plane first and non-PRM passengers are boarded after them. Meanwhile, after cabin crew change, lavatory and clean water service is processed if needed.

At the beginning, after opening rear and forward cargo doors, baggage loaders (conveyors) are positioned to the baggage doors and baggage are unloaded from both doors. After baggage unloading is finished, with the arrival of the new baggage, baggage loading starts to the forward and aft. Finally baggage loaders are removed from forward and rear.

There is a load sheet which shows how much baggage is loaded to where or how much fuel was taken. This load sheet is handed in to captain after baggage are loaded, lavatory and clean water service is done, catering is finished and passengers are boarded. After getting the approval for the load-sheet, cargo doors and passenger are closed. If the aircraft (A/C) was parked in remote stand, passenger stairs are removed. Otherwise, airbridge is removed. Finally, forward chocks are removed, tow-car is connected for the push-back and chocks are removed from the rear tires. This is the end of the turnaround flow of XYZ Airlines.

In order to implementation of the case study into the mathematical model, process mapping tool has been used. The process mapping shows all the operations handled in the hub airport during the turnaround process for 4 different flight types. For each operation, inputs, outputs, constraints and resources have been shown. This tool was very useful in order to define the constraints in the work flow. Process Map which was prepared for the domestic-domestic flight type is presented below. It starts with the parent diagram and then some operations are decomposed into the child diagrams and sub-processes have been showed within these diagrams. Parent Diagram is showed in Figure 4.7 and 1st level child diagrams are presented for DomDom/IntInt and DomInt/IntDom flight types in figures respectively.

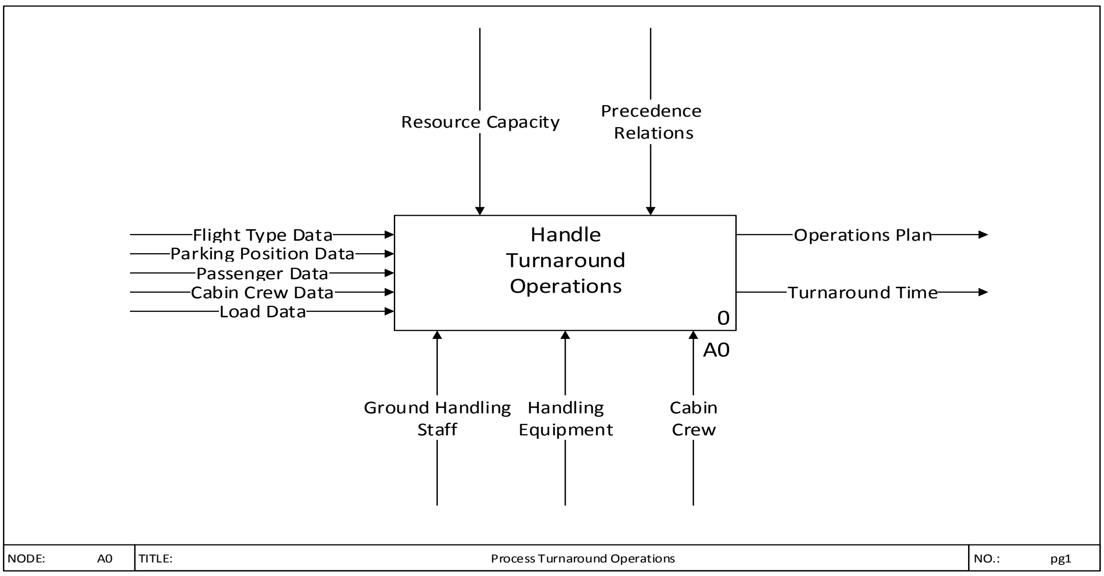


Figure 4.7: Process Map Level 1 (Parent Diagram)

In the process map, the rectangle shaped boxes represent processes. Arrows coming from the left to the process box shows the inputs for the process and outgoing arcs on the right shows the output of the process. Incoming arcs on the top indicates the constraints and limitations of the process and finally incoming arc from down shows the resources used in the process such as equipment and workers.

In Figure 4.8 and Figure 4.9, the most general form of the turnaround process is represented. This process map is called Parent Box and has an ID as 0 and sub-diagram of this map are A0s. In this diagram, inputs to the handling of turnaround operations activity are flight type data, parking position information, passenger data, cabin crew data which is to know if cabin crew will change or not and finally load data which is the information about the amount of fuel, clean water and baggage is needed for the flight. Outputs of this process are turnaround plan (schedule) and turnaround time. There are some constraints of this process which are precedence relationship of operations and resource capacities. Some operations should wait others to be processed that shows the precedence relationship and some operations requires the same resource that shows the resource capacity constraint. Resources which are used during this process are ground handling staff, handling equipment and cabin crew.

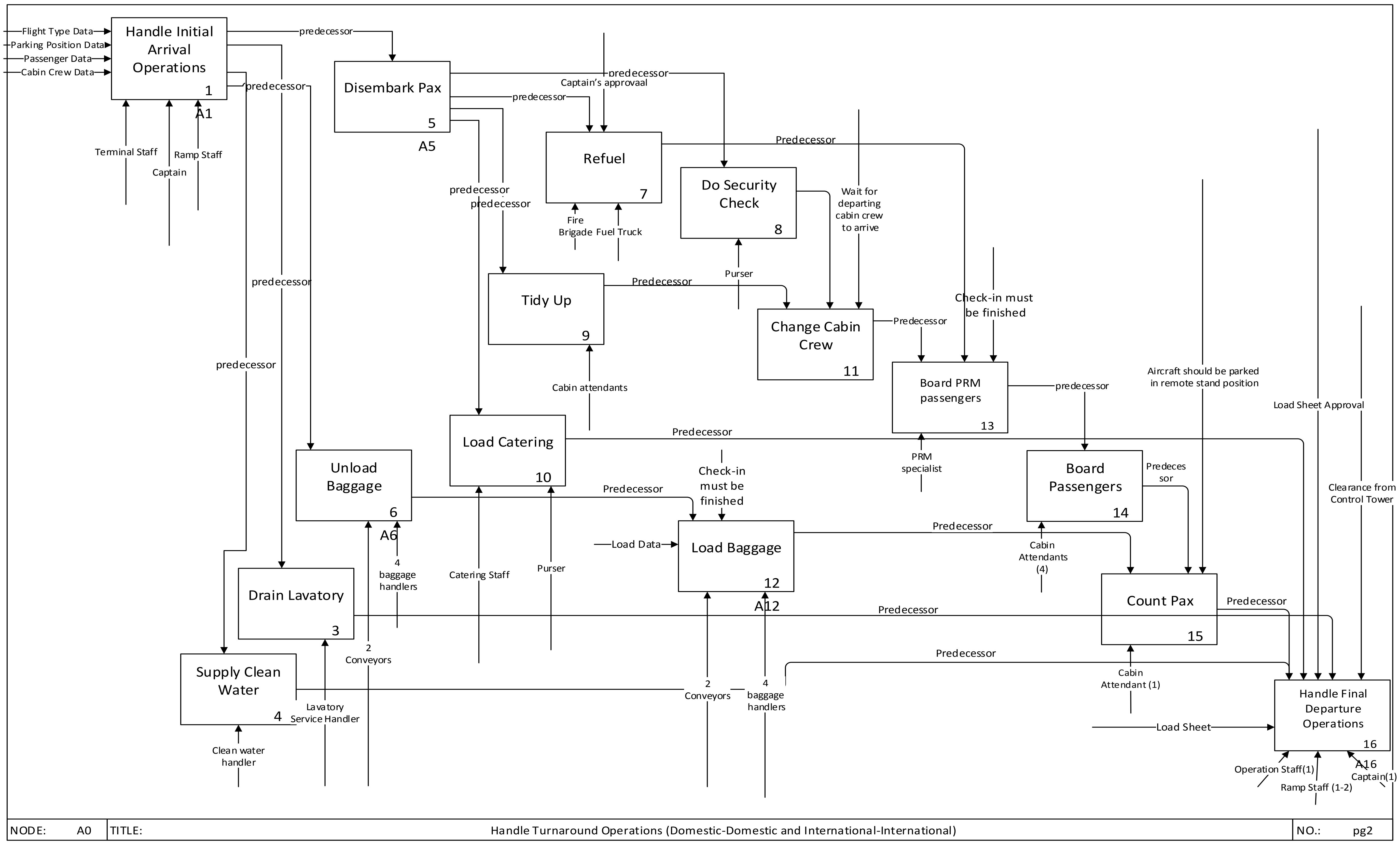


Figure 4.8: Turnaround Process for DomDom and IntInt flight type

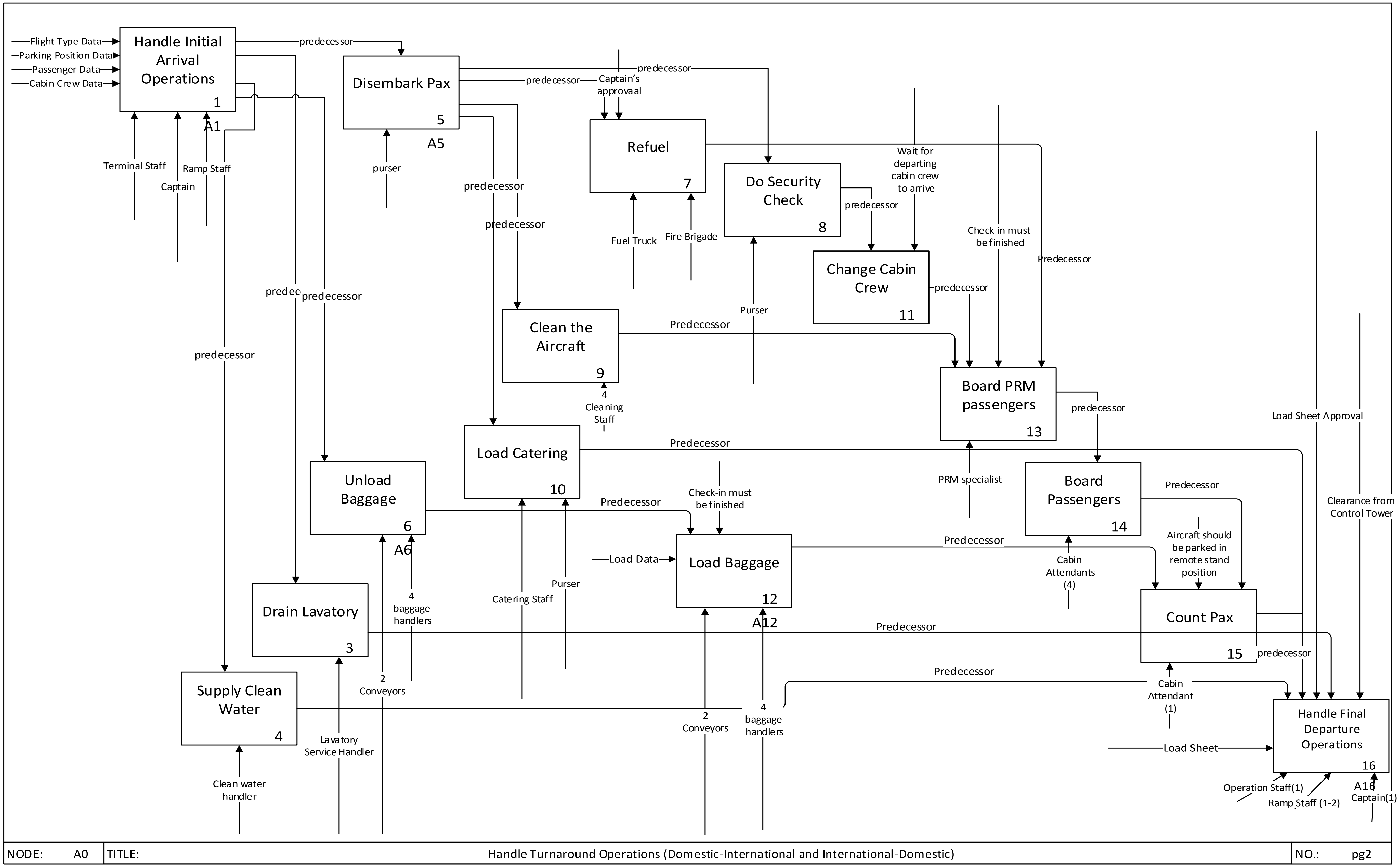


Figure 4.9: Turnaround Process for DomInt and IntDom flight type

After decomposing the process number 0, two other diagrams are presented which are based on the flight types. Figure 4.8 is the diagram with DomDom/IntInt flight type and Figure 4.9 is with DomInt and IntDom flight type. Operations in both figures are very similar. Process begins with the initial arrival operations with flight type data, parking position, passenger and cabin crew information as an input. Terminal staff, captain and ramp staff are involved in this process. This process is also broken down into more detail processes which are shown in Appendix C. After that, as being a constraint for disembark passengers process, unload baggage process, drain lavatory process and supply clean water process, these operations begins to be proceed. For supply clean water process the staff that is responsible with this activity is the resource of the process. The same is valid for lavatory service where the staff who is responsible with that job is the resource. Unloading baggage is handled by baggage handlers and conveyors (baggage loaders) are used in this process. Process of disembark passengers is predecessor of many other operations such as refuel, tidy up (for DomDom and IntInt), aircraft cleaning (for DomInt and IntDom) and catering. In order to begin refuelling there is another constraint, captain's approval on the amount of fuel. This process is done by a fuel truck and a fire brigade if necessary. Tidy-up process is handled by cabin crew only in DomDom and IntInt flight types. Cleaning on the other hand handled by cleaning agents and processed only in DomInt and IntDom flights. Loading catering is handled by catering staff and purser. However it is not always necessary that a purser is needed. Another output of passenger disembarking is the constraint of security check where the cabin crew checks inside the aircraft in case someone left their stuff.

Output of the tidy up process is the predecessor of cabin crew change. On the other hand, output of cleaning is the predecessor of boarding of PRM passengers. Cabin crew change's other constraint is waiting for the other cabin crew to arrive. The output of this process is the constraint of board PRM passengers which means, PRM passengers cannot be boarded unless cabin crew is changed. However for passenger boarding other important constraints are that refuelling should be finished and check-in must be finished.

Baggage unloading process is the constraint for baggage loading process. Another constraint for baggage loading is that check-in must be finished. This process is also handled by the same staff and equipment: conveyors and baggage handlers. 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 .Other constraints of this process is baggage loading and aircraft should be parked in remote stand position. As a final step, final departure operations are handled by operations staff, ramp staff and captain. Input of this process is the load sheet approval. The constraints of this process are predecessors: drain lavatory, supply clean water, count passengers, load sheet approval, load catering and clearance from the control tower.

4.3. Modelling Assumptions

Turnaround operation is not an easy process. It is a complex process where there are many variables. That's why in order to model it mathematically, the complexity becomes a problem. So, some assumptions have been made in order to make the problem solvable in a polynomial time.

Assumptions which are made for the mathematical model are;

- Some operations are considered to be done in every flight:
    - Cabin Crew change
    - Fuelling
    - Lavatory Service
    - Water Service
    - Boarding and Disembarking PRM passengers
- All the equipment and vehicles are ready in the parking area before the aircraft arrives
- There is infinite number of resources for each operation.

4.4. Implementation

In the implementation phase of the study, the mathematical model had to be adapted to the case study. However when the computational complexity of the problem has been considered, the RCPSP (resource-constrained project scheduling problem) is a combinatorial optimisation problem which is almost impossible to trace. According to (Blazewicz et al. 1983), minimising the makespan of a RCPSP is computationally NP-hard.

Being NP hard and belonging to combinatorial optimisation, makes the problem "hard" to solve because of the time limitation. The problem is not possibly solved in polynomial time (Brucker and Knust, 2012). Therefore, the mathematical model has been revised without considering workforce constraints and time index which creates the complexity. With the workforce constraints, the generated number of F_{jt} variables equals to the number of operations multiplied by time interval. In this case the number of operations is minimum 41 and the time interval is in minutes from 0 to at least 3600. Thus, the multiplication of these creates 147,600 variables. The problem not only has the extensive number of variables but also the number of constraints. Thus, the problem becomes even more difficult to be solved.

The revised/ reduced mathematical model based on the assumptions above is as below:

$$\text{Minimize } C_{\max} \qquad (1)$$

subject to

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

$$C_{\max} \geq S_j + p_j \qquad \forall_j \in J \qquad (3)$$

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

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

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

According to the revised model, the objective function minimises the makespan which is the completion time of the final operation. Constraint (2) $S_k \geq S_j + p_j \ , \forall_{j \to k} \in A$ is almost the same as the previous model's constraint. However instead of using finish time, start time of operations S_j are considered. This constraint ensures that from the precedence set, if operation j is the precedence of operation k, the start time of operation k should be greater than or equal to the start time of the previous operation j plus its duration. Constraint (3) $C_{\max} \geq S_j + p_j, \forall_j \in J$ defines $C_{\max}$. For each operation j, $C_{\max}$ should be greater than or equal to the start time plus processing time of job j. Constraints (4) and (5) $S_k \geq S_j + p_j - M\left(1 - y_{jk}\right) , \forall_{\text{j,k}} \in B \mid j \neq k$, $S_j \geq S_k + p_k - M \ y_{jk}, \forall_{\text{j,k}} \in B \mid j \neq k$ are the space constraints which is similar to the ones in the first model. These disjunctive constraints are linearized the same way showed in the model which is in chapter 3. They ensure that for operations belongs to set B and operations where j and k are not the same, either job j is processed before job k or job k is processed before job j. Job j precedes job k if y_{jk} gets the value of 1 and job k precedes job j if y_{jk} gets the value of 0. The final constraint (6) $S_j, C_{\max} \geq 0$, $y_{jk} \in \{0,1\} , \forall_{\text{j,k}} \in J$ ensures that Nonnegativity is achieved and y_{jk} is binary.

Decision Variables used in the mathematical model are as follows:

$$C_{\max} = \text{Completion time of the last job}$$

$$S_j = \text{Start time of job j}$$

$$y_{jk} = \begin{cases} \text{1, if job j is proccessed before job k} \\ \text{0, otherwise} \end{cases}$$

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

Sets which are used in this model are A and B. A indicates the set of immediate pairs and B is the set of jobs using the same space. In the real case model, A is presented in Appendix D as a matrix where j is the predecessor of k if the value is 1. For all flight types, the model where only pax stairs are used has a B set including (i,k)→(28,25), (25,26). B set for model where airbridge used only is (i,k) →(25,26). For the model with pax stairs for disembarking and airbridge for boarding, B set composed of (i,k)→(28,25), (25,26). Finally for the model where pax are disembarked via airbridge and boarded via stairs has the B set as (i,k) → (29,25), (25,26). Operation names which correspond to the operation number are shown in Appendix E.

Finally, parameters used in this model are p_j which is the processing time of job j and $M=\sum_{j=1}^{n} p_j$ which gives the upper bound as total duration of operations.
Below are the inputs and outputs of the revised TurnOper_LP model. (Figure 4.10)

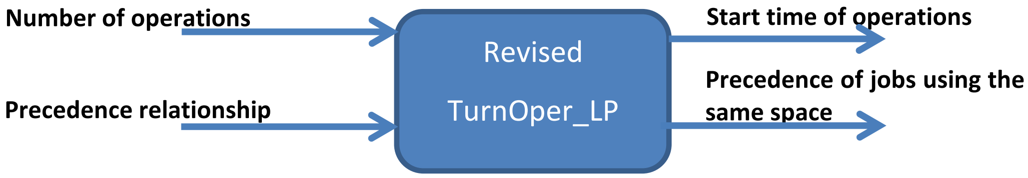


Figure 4.10: Revised TurnOper_LP Model Inputs and Outputs

According to the company request, there are four models created for different flight types which are domestic-domestic, domestic-international, international-domestic and international-international mentioned in the understanding the current system part in detailed. Apart from the type of flights, the way of boarding and disembarking of passengers (using pax stairs in both disembarking and boarding, airbridge in both disembarking and boarding, disembarking from pax stairs and boarding from airbridge; and finally disembarking from airbridge and boarding from pax stairs were compared with each other for each flight type. Hence, each model has run for 4 different usages of boarding/disembarking vehicles. At the end, there have been achieved 4 different scenarios for 4 different flight types.

Open form of the revised TurnOper_LP Model with the data collected from the company is presented below for operations i=1 and j=2:

$$\text{Minimize } C_{\max} \quad (1)$$

subject to

$$S_2 \geq S_1 + 11 \quad (2)$$

$$C_{\max} \geq S_1 + 11 \quad (3)$$

$$S_{1,}, S_2, C_{\max} \geq 0 \quad , \quad y_{12} \in \{0,1\} \quad (6)$$

In this model, since operation 1 and 2 do not belong to the B set, constraints 4 and 5 are not valid.

When operations i=25 and j=26 are considered for the model where airbridge is used only, the model's open form is as follows:

$$\text{Minimize } C_{\max} \quad (1)$$

subject to

$$C_{\max} \geq S_{25} + 109 \quad (3)$$

$$S_{26} \geq S_{25} + 109 - M(1-1) \quad (4)$$

$$S_{25} \geq S_{26} + 89 - M.1 \quad (5)$$

$$S_{25}, S_{26}, C_{\max} \geq 0 \quad , \quad y_{25,26} \in \{0,1\} \quad (6)$$

In this model, constraint 2 is not working since there is no precedence relationship between operations 25 and 26.

4.5. Used Tools and Techniques

In the implementation of the case, first of all, the problem was formulated as a mathematical model and then written using Optimisation Programming Language (OPL) in IBM ILOG CPLEX software. The software is capable of solving mathematical programming optimally including Linear Programming (LP), Mixed Integer Programming (MIP), Quadratic Programming and Mixed Integer Quadratic Programming models. Furthermore, it is capable of solving combinatorial problems with constraint programming.

The TurnOper_LP model was solved in IBM ILOG OPL Studio Version 6.3 (Appendix F). Four different models have been created and each model ran for 4 different inputs regarding the aircraft parking position which generates the “what if” scenarios.

Other tools used in the development of mathematical model and understanding the system are flow chart and process map which are showed in chapter 4.2. Flow chart is a very helpful tool to understand how the processes flow and which process follows which one. Similarly, Process Map shows all the processes, relationship of processes, inputs, outputs, resources and constraints of each process.

CHAPTER 5 – RESULTS INTERPRETATION

This chapter presents the results of each scenario showing the optimal schedule of turnaround operations for each flight type and comparison of the scenarios related to the way of disembarking and boarding of passengers from/to the aircraft. Results of the turnaround time of scenarios have been compared with each other within each flight type. Furthermore, an overall comparison has been revealed to indicate the differences.

In the Gantt charts presented rest of the sections, red painted blocks shows the critical operations. That means, these operations cannot be delayed, otherwise finish time of the turnaround would be delayed.

5.1. Schedule of Domestic-Domestic and International-International

In this section, Gantt Charts of different scenarios; boarding/disembarking styles are given. According to the optimal results, the turnaround time of each scenario has been compared. The operations of Domestic-Domestic and International-International are very similar. Hence, the results of these turnaround operations are also similar. The only difference is the duration of operations.

Figure 5.1 shows the turnaround time for both DomDom and IntInt flight types comparing different disembarking/boarding styles.

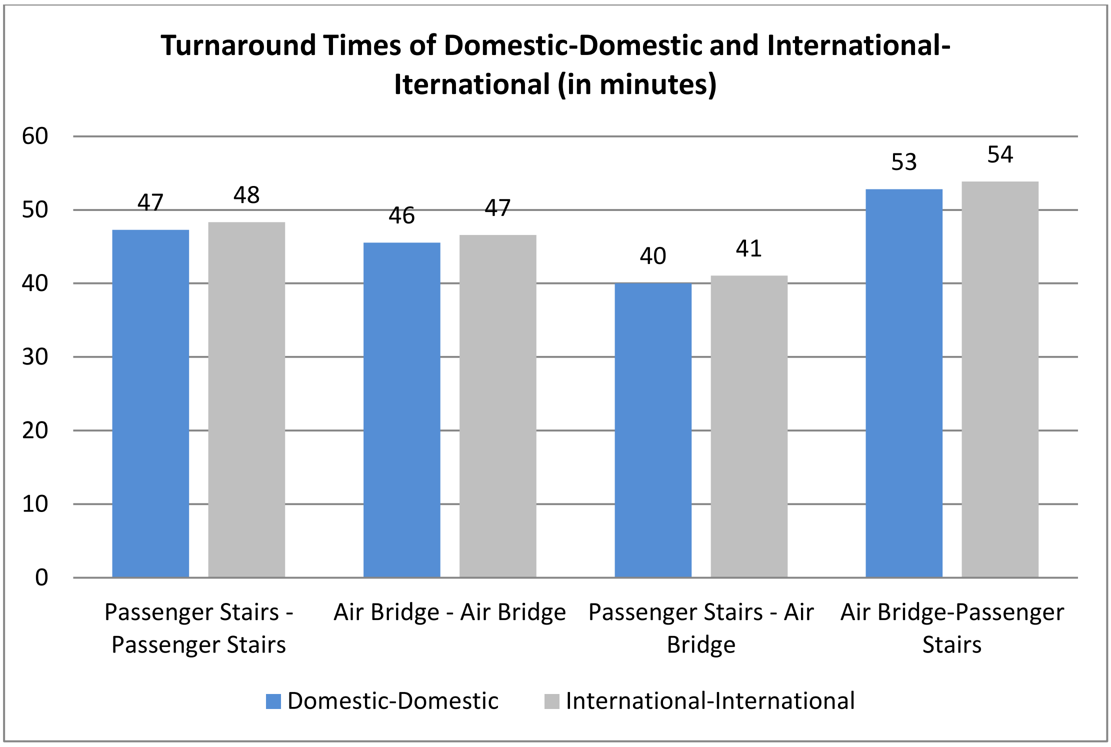


Figure 5.1: Turnaround time (in seconds) comparison for domestic-domestic and International-International flight types

According to this figure, the best schedule with least turnaround time for domestic-domestic flight type is to disembarking passengers via passenger stairs and boarding passengers using airbridge which gives 2,402 seconds or (approx. 40 minutes) of turnaround time. The second best option is to use airbridge for both disembarking and boarding. That gave 2,733 seconds which is approximately 46 minutes of turnaround time. The least efficient option is to use airbridge for disembarking and use pax stairs for boarding of passengers which results in 3,169 seconds (approx. 53 minutes) of turnaround time.

Since the turnaround times of both DomDom and IntInt are so close and the difference is the same between the time of disembarking/boarding style (i.e. Pax Stairs-Pax Stairs) for DomDom and IntInt, the best result is to use pax stairs for disembarking and airbridge for boarding with the result of 2,463 seconds (approx. 41 minutes). The second best is again using airbridge only, with 2,794 sec. which is approximately 47 min.

In the following sections, the schedule of each scenario is further presented in detailed showing the duration and starting time of each operation.

5.1.1. Scenario 1 - Using Pax Stairs Only

Schedule of DomDom and IntInt using passenger stairs only, is almost the same except few differences in some operations. The operations and their sequence are totally the same however the duration of some of the operations are different from each other such as fuelling and baggage loading/unloading. For example, in DomDom, fuelling duration is less than the one in IntInt because of the flight distance to the destination. Duration of baggage loading/unloading is also less for DomDom since the amount of baggage that passengers take to a domestic destination is less than the ones in IntInt.

Both models were run according to their precedence relationships and durations. Hence, the schedule which is showed in Figure 5.2 for DomDom and Figure 5.3 for IntInt was achieved.

Schedules are presented as Gantt Charts to see the operation sequence and durations more clearly. From the chart which was showed in Figure 5.1, the turnaround time of DomDom schedule is 2,838 seconds (approx. 47 min.) while IntInt is 2,899 sec. (approx. 48 min.).

In order to see the critical activities which affects the turnaround time if the durations are changed, are painted as red. That path in Figure 5.2 and Figure 5.3 with red operations shows the critical path of the turnaround schedule. For both schedules, the critical path is the same. The only difference is the duration of fuelling which is a critical activity. That's why; the duration of turnaround time is different for DomDom and IntInt. According to this path, the critical operations for both DomDom and IntInt are as follows (Table 5.1):

Table 5.1: Operations which are in the critical path for DomDom and IntInt with Pax Stairs

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
23	Tidy-up
27	Cabin crew change
20	Fuelling without fire brigade
29	Board wheelchair pax via truck
30	Pax boarding
37	Head count
38	Hand in the Load Sheet and get Captain's approval
39	Close pax doors
40	Remove stairs
44	Push-back connection
45	Remove rear chocks

According to above table, critical operations are presented with an order. Critical path start with the arrival operations which are Place front chocks, Stop engines and Place rear chocks. Then, since this model includes passengers disembarking using pax stairs, positioning pax stairs is the 4th operation in the path. Other operations are listed in the table in an order. At the end critical path is completed with removing stairs, push-back connection and removing rear chocks. None of these operations can be delayed because each of them is dependent to each other. For example fuelling cannot start if cabin crew did not change. Hence, delay in cabin crew change will delay the start time of fuelling operation and fuelling operation will delay boarding wheelchair passengers and it will continue like this until the final operation, which means that the turnaround time is delayed.

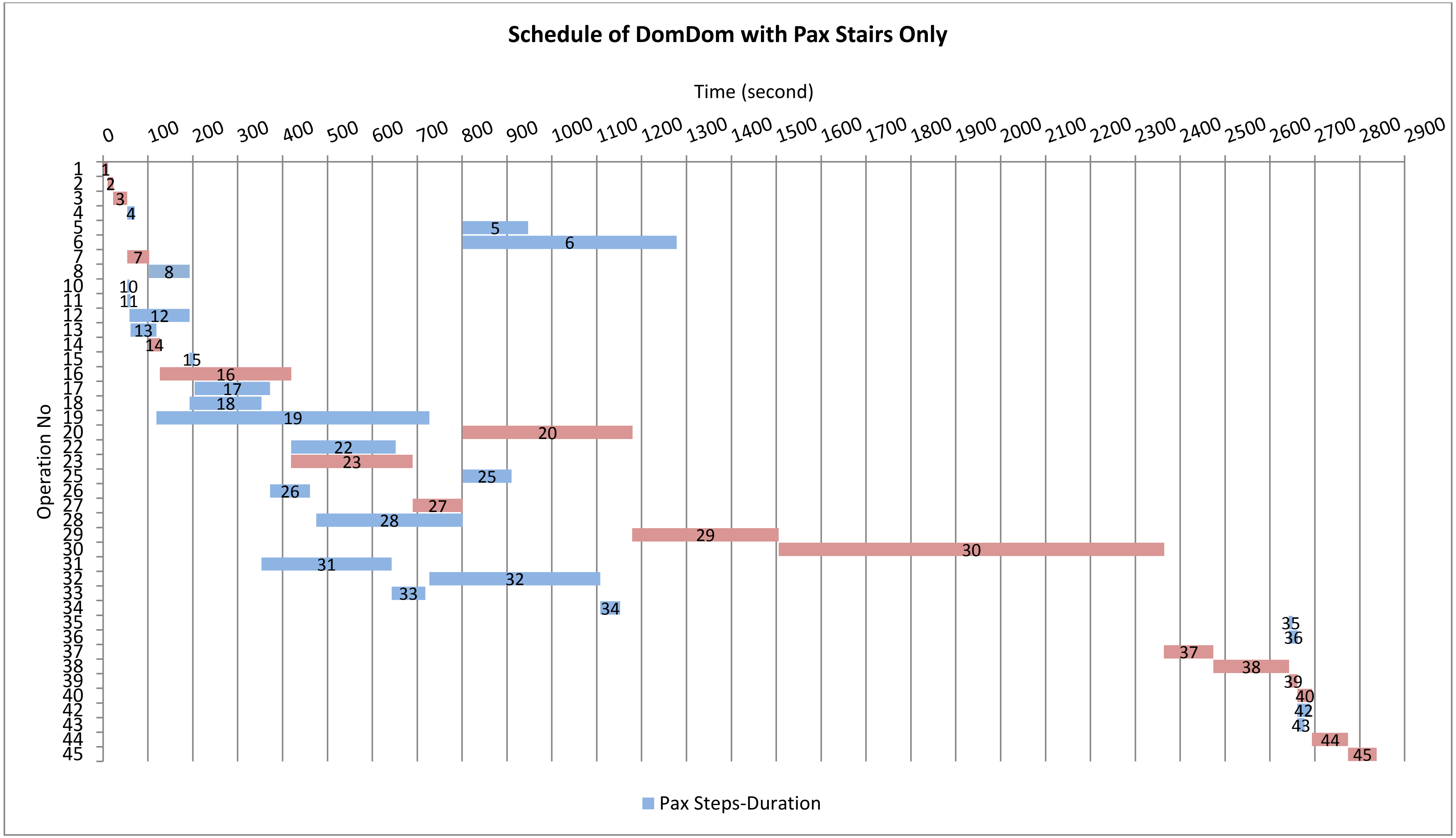


Figure 5.2: Schedule of Domestic to Domestic Turnaround Operations using Pax Stairs during disembarking and boarding of Pax

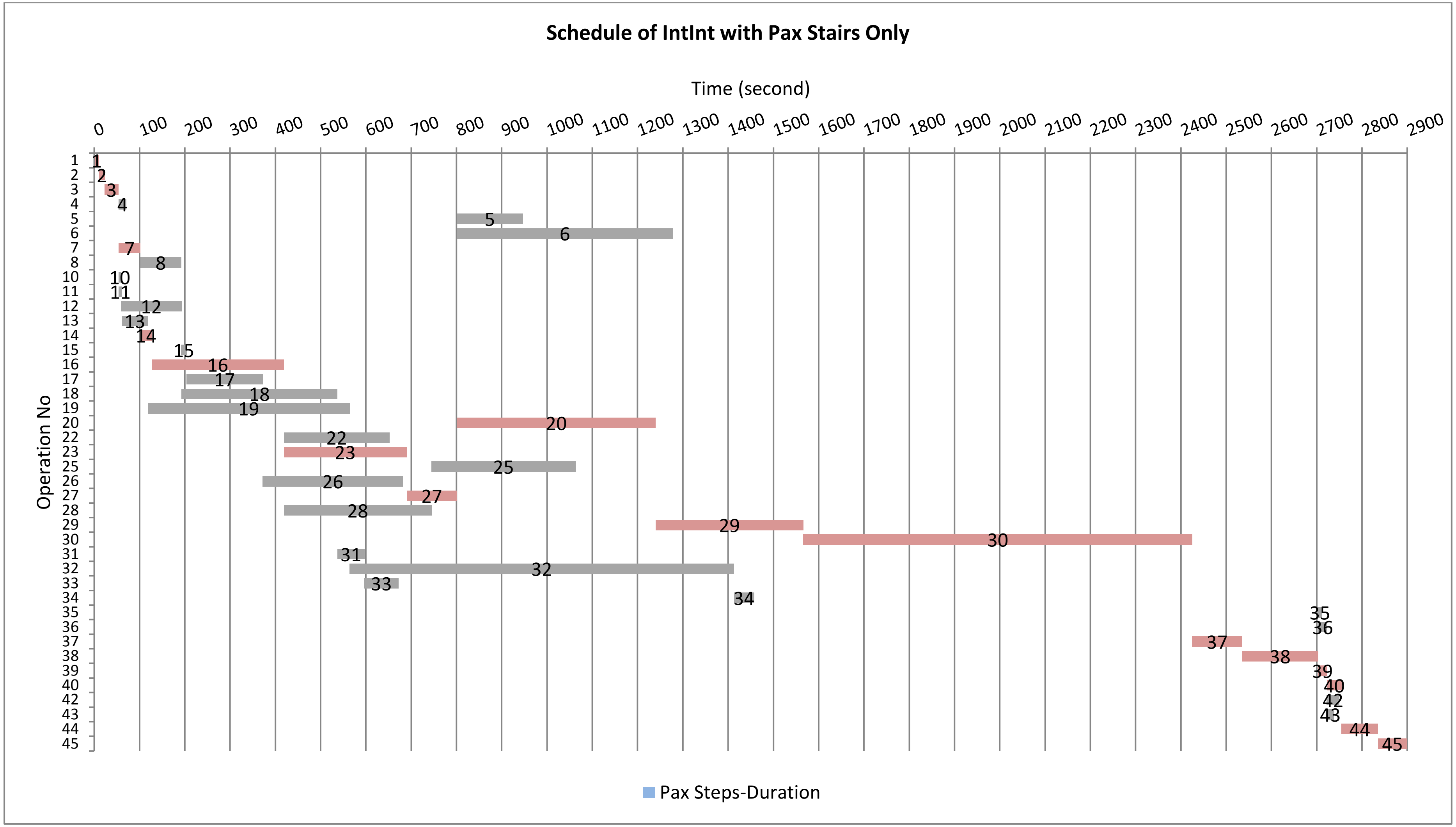


Figure 5.3: Schedule of Domestic to Domestic Turnaround Operations using Pax Stairs during disembarking and boarding of Pax

According to the above Gantt charts, turnaround operations are shown as blocks. Verticle axis and numbers on the blocks represent operations' ID numbers. Names of the corresponded numbers, start time of operations and durations are given in Appendix G for DomDom and IntInt for using airbridge only. Although the critical path is the same for DomDom and IntInt, there are some differences on other operations. For example, baggage unloading from forward (no 18) for IntInt takes more time on the other hand baggage unloading from aft (no 19) for DomDom takes more time. Fuelling which is operation 19 takes more time for IntInt. Besides, duration of catering from the forward and rear door also takes longer time for IntInt. Finally, as baggage unloading, baggage loading also differs between two schedules. The important similarity for both schedules is that both of them process tidy-up operation instead of cleaning.

5.1.2. Scenario 2 - Using Airbridge Only

In this model the schedule of DomDom and IntInt has been presented considering disembarking and boarding via airbridge. Both schedules are again very similar. Schedule for DomDom is showed in Figure 5.4 and IntInt is showed in Figure 5.5. They have been run using their own precedence relationship table, activity and duration list.

The resulted schedule for DomDom is shown in Figure 5.4 and the total turnaround time is 2733 seconds (approx. 45min.). For IntInt, the turnaround time is calculated as 2,794 sec.(approx. 45min) which is only 1 minute more compared to DomDom. Corresponding critical path for both flight types are painted as red in the Gantt chart and listed in Table 5.2. The turnaround time was affected by the duration of fuelling once more.

Table 5.2: Operations which are in critical path for DomDom and IntInt with Airbridge

Operation No	Name of the Operation
1	Place front chocks
2	Stop engines
3	Place rear chocks
9	Position airbridge
14	Open front pax doors and ask purser if there are any PRM pax
16	Disembark pax from the forward door
23	Tidy-up
27	Cabin crew change
20	Fuelling without fire brigade
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

As it can be seen from the above table, critical operations are listed in an order. Different from the previous critical path table, here positioning and removing airbridge were done instead of pax stairs. Duration of some operations are also different from the previous ones such as disembarking and boarding passengers from the forward door takes more time compared to the previous one.

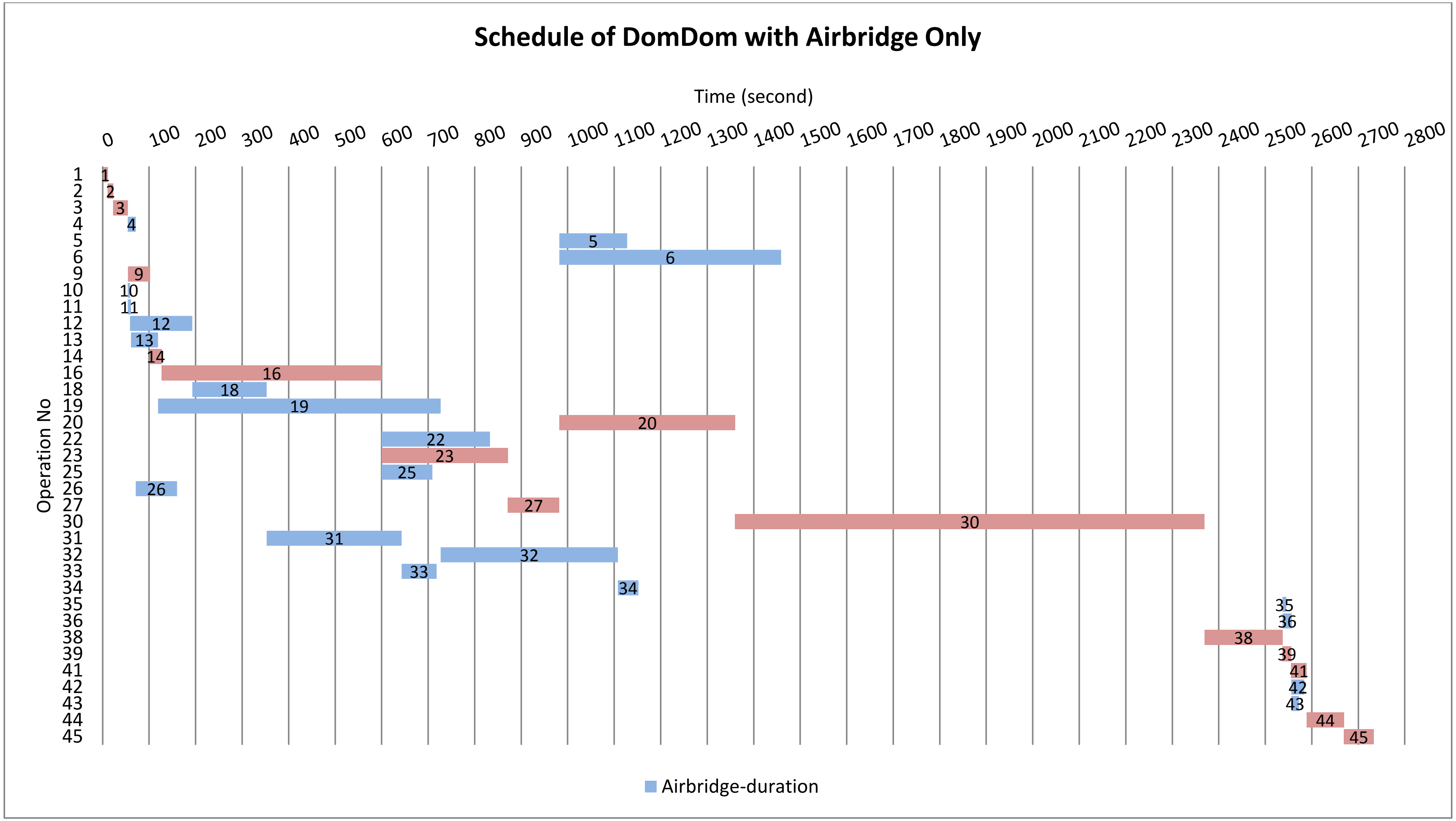


Figure 5.4: Schedule of Domestic to Domestic Turnaround Operations using Airbridge during disembarking and boarding of Pax

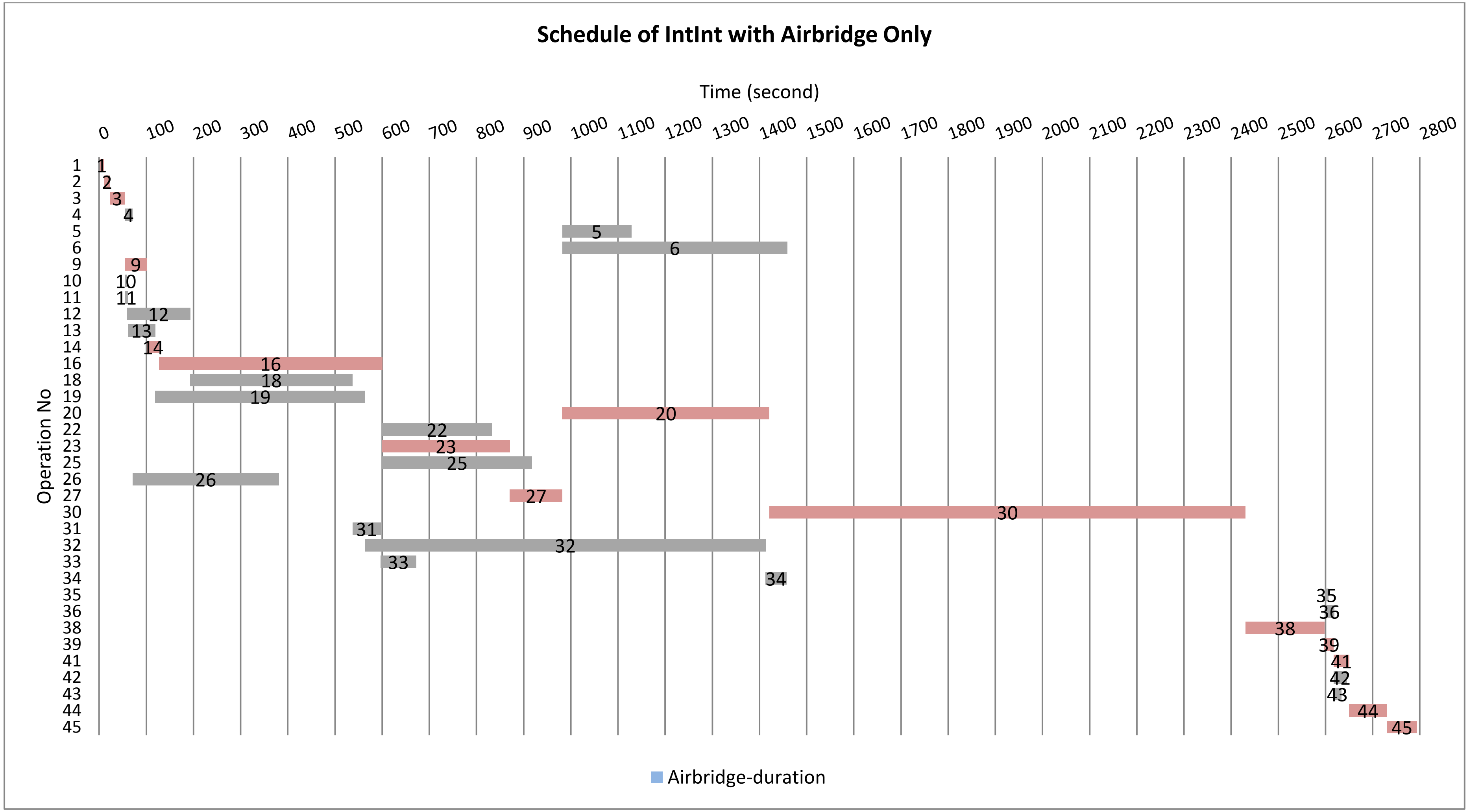


Figure 5.5: Schedule of International to International Turnaround Operations using Airbridge during disembarking and boarding of Pax

Gantt charts which are showed above are composed of operations, start time of the operations and their durations. Both charts are very similar to each other however there are still some differences. As it can be seen from the figures, schedule starts with operation 1, and operation 2 continues it. Each of them has their own starting time and located according to that. These durations and other detail information about operations can be found in Appendix G. As mentioned in the previous Gantt charts, unloading and loading baggage, catering from forward and rear are different in durations. This time, since airbridge is used, the operations related to the usage of airbridge are different. For example operation 9 is used instead of operation 7 and 8 which are about positioning pax stairs and airbridge. These schedules do not include opening rear pax doors since when airbridge is used, only front door is opening. Head count is not shown in these schedules as well because when passengers are boarded to the aircraft from airbridge, there is no need to count passengers inside the aircraft.

5.1.3. Scenario 3 - Using Pax Stairs for Disembarking and Airbridge for Boarding

The results of this model were achieved by running both models using their own data including precedence, activity numbers and durations. Then, according to makespan (completion time of the last job) and start times of the operations which have been found from the execution of models. Results were interpreted as a Gantt charts which can be seen in Figure 5.6 for DomDom and Figure 5.7 for IntInt. Furthermore, the critical path is remarked as red in the chart and listed in the below Table 5.3.

The numerical results of the turnaround time is found as 2,402 seconds (approx. 40 minutes) for DomDom and 2,463 sec. (approx. 41 min.).

Table 5.3: Operations which are in critical path for DomDom and IntInt 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
23	Tidy-up
27	Cabin crew change
20	Fuelling without fire brigade
29	Board wheelchair pax via truck
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

Above table shows the critical operations in DomDom and IntInt using airbridge. First three and last three operations are the same as the previous critical path table. This time, positioning pax stairs (forward) and removing airbridge is on the critical path. Operations are listed in the correct order according to their start and finish times.

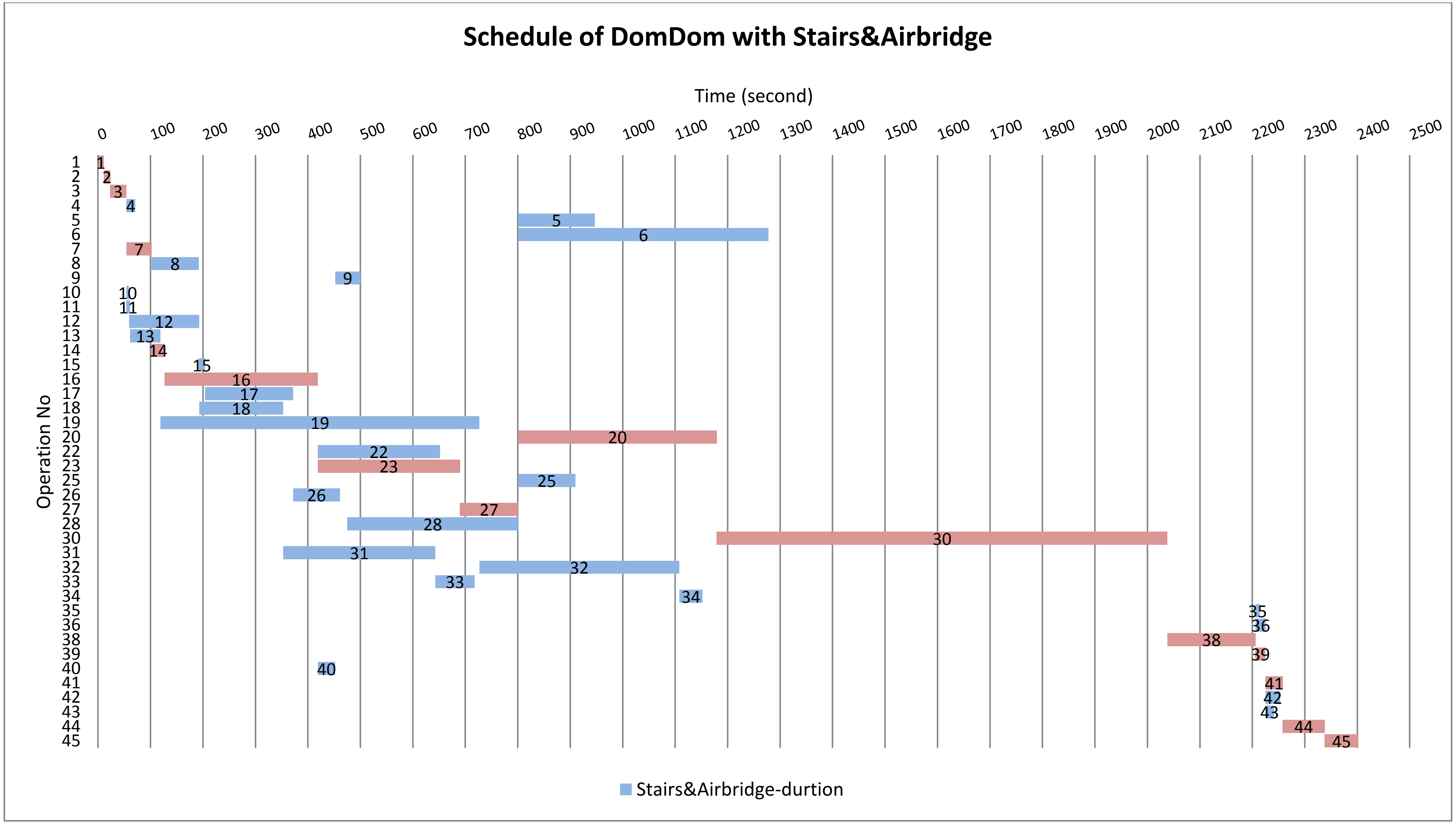


Figure 5.6: Schedule of Domestic to Domestic Turnaround Operations using during Pax Stairs disembarking and Airbridge during boarding of Pax

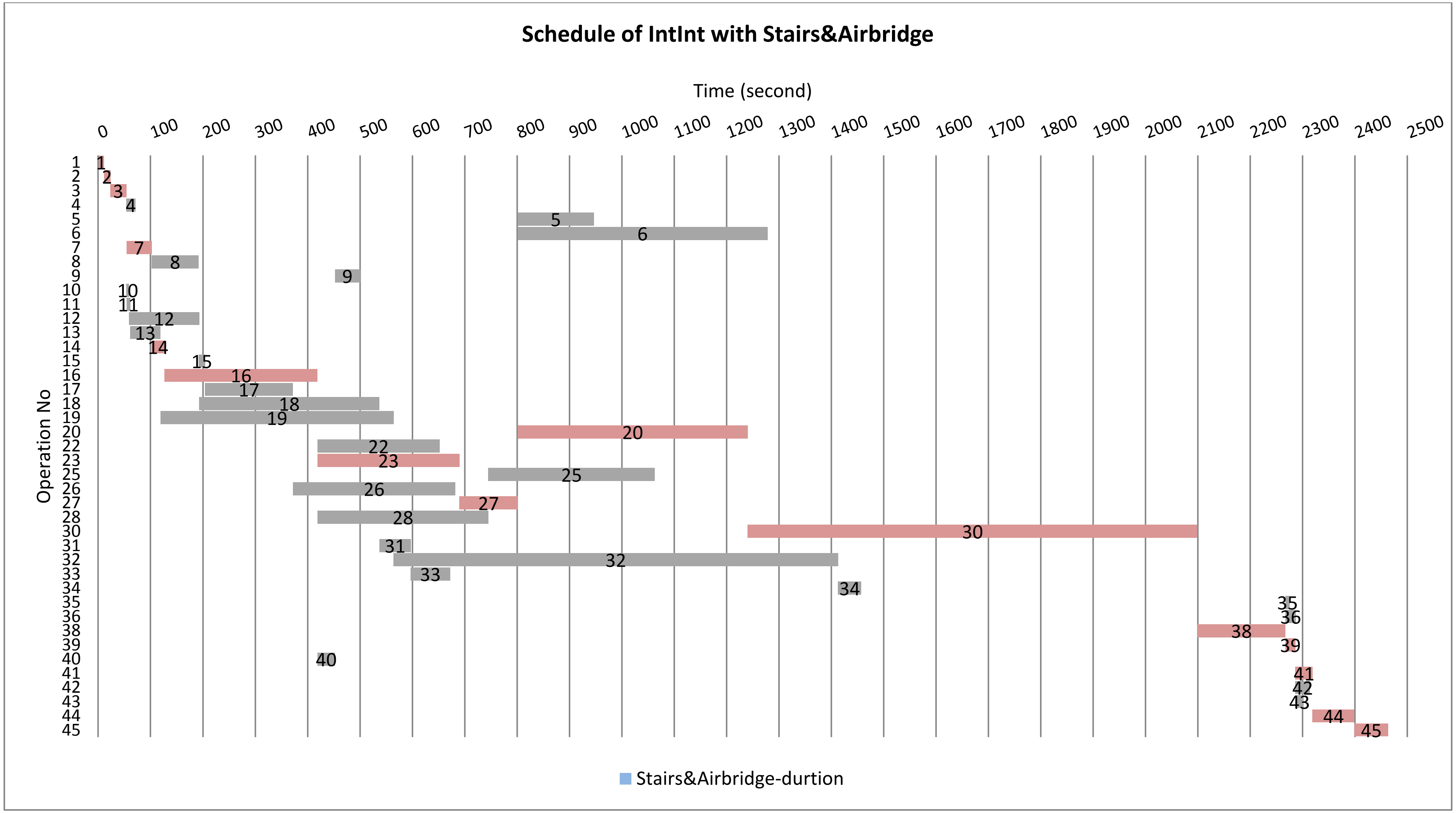


Figure 5.7: Schedule of International to International Turnaround Operations using during Pax Stairs disembarking and Airbridge during boarding of Pax

Above Gantt charts present the duration, sequence, start and finish time of the operations for DomDom and IntInt using pax stairs for disembarking and airbridge for boarding passengers. Detailed information about name, duration, start time and finish time of activities can be seen in Appendix G. Again, the differences of both schedules are the same such as duration of unloading baggage, fuelling, catering and loading baggage. However what makes these schedules different from the others is that passengers are being disembarked from both doors but they are boarded only from the forward door via airbridge. Positioning pax stairs when aircraft arrives to the both doors and removing airbridge before aircraft departs are the other differences special to this scenario.

5.1.4. Scenario 4 - Using Airbridge for Disembarking and Pax Stairs for Boarding

The final scenario for DomDom and IntInt is to examine the turnaround schedule when passengers are disembarked via airbridge and board via stairs. The results of these models were achieved by using specified data for these models. The turnaround schedule of domestic-domestic which was found after running the model can be seen in Figure 5.8 and the result of international-international turnaround schedule is showed in Figure 5.9. The critical path for DomDom and IntInt is also showed in Table 5.4.

Table 5.4: Operations which are in critical path for DomDom and IntInt with Airbridge & Pax Stair

Operation No	Name of the Operation
1	Place front chocks
2	Stop engines
3	Place rear chocks
9	Position airbridge
14	Open front pax doors and ask purser if there are any PRM pax
16	Disembark pax from the forward door
23	Tidy-up
27	Cabin crew change
20	Fuelling without fire brigade
29	Board wheelchair pax via truck
30	Pax boarding
37	Head count
38	Hand in the Load Sheet and get Captain's approval
39	Close pax doors
40	Remove stairs
41	Remove airbridge
44	Push-back connection
45	Remove rear chocks

Above table clearly shows the sequence of critical operations for DomDom and IntInt. Usage of airbridge and pax stairs are creating some differences since the related operations are in the critical path such as positioning airbridge, removing airbridge, pax boarding and disembarking.

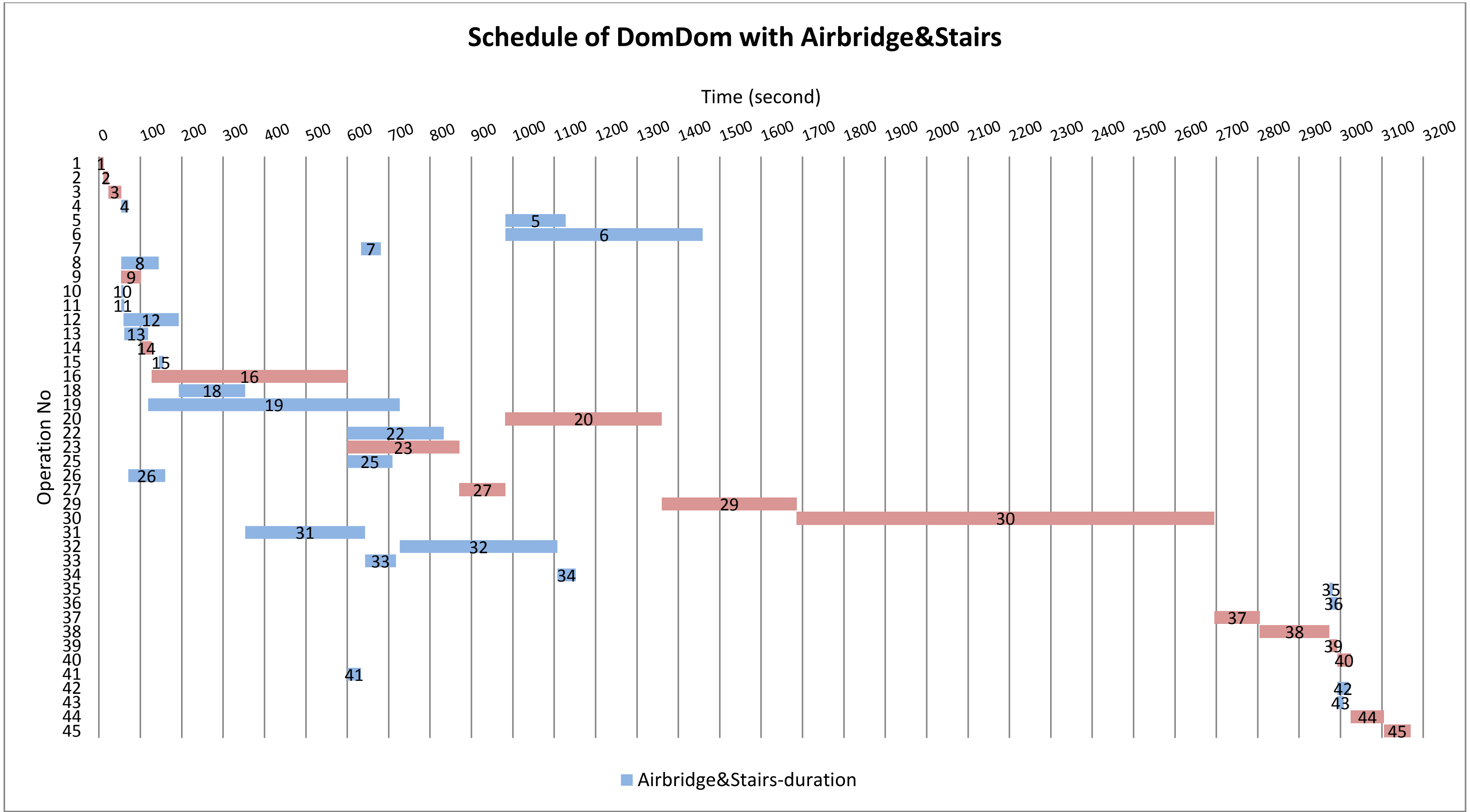


Figure 5.8: Schedule of Domestic to Domestic Turnaround Operations using during Airbridge disembarking and Pax Stairs during boarding of Pax

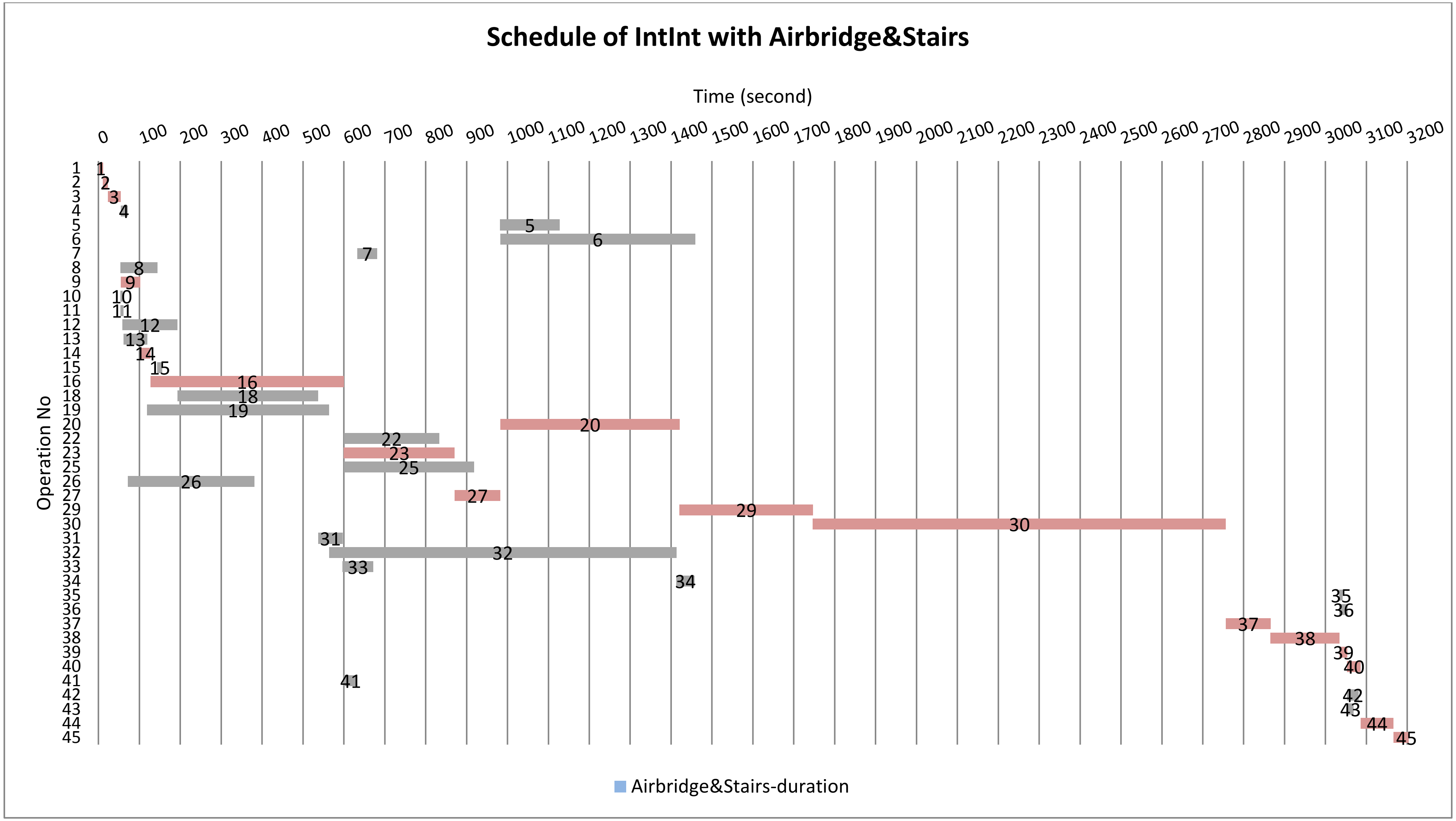


Figure 5.9: Schedule of International to International Turnaround Operations using during Airbridge disembarking and Pax Stairs during boarding of Pax

Final schedules for DomDom and IntInt are showed in above Gantt charts. ID numbers of operations, start times, durations and names of the operations are listed in Appendix G in detailed. Differences of two schedules are actually the same as the others which arise from baggage loading and unloading, fuelling and catering durations. Most important differences in these schedules are positioning airbridge first for disembarking, and then deboarding passengers from the front door via airbridge. Positioning pax stairs to the forward and rear doors and boarding passengers from both doors are the other differences. And finally at the end before push back connection, removing both stairs shows the difference.

5.2. Schedule of Domestic-International and International-Domestic

In this section, turnaround times of aircrafts where aircrafts arrive from a domestic port to the hub and depart to inernational destination, and the oposite which arrive from an inernational port and depart to a domestic destination were introduced. Figure 5.10 shows the turnaround times of both DomInt and IntDom flight types.

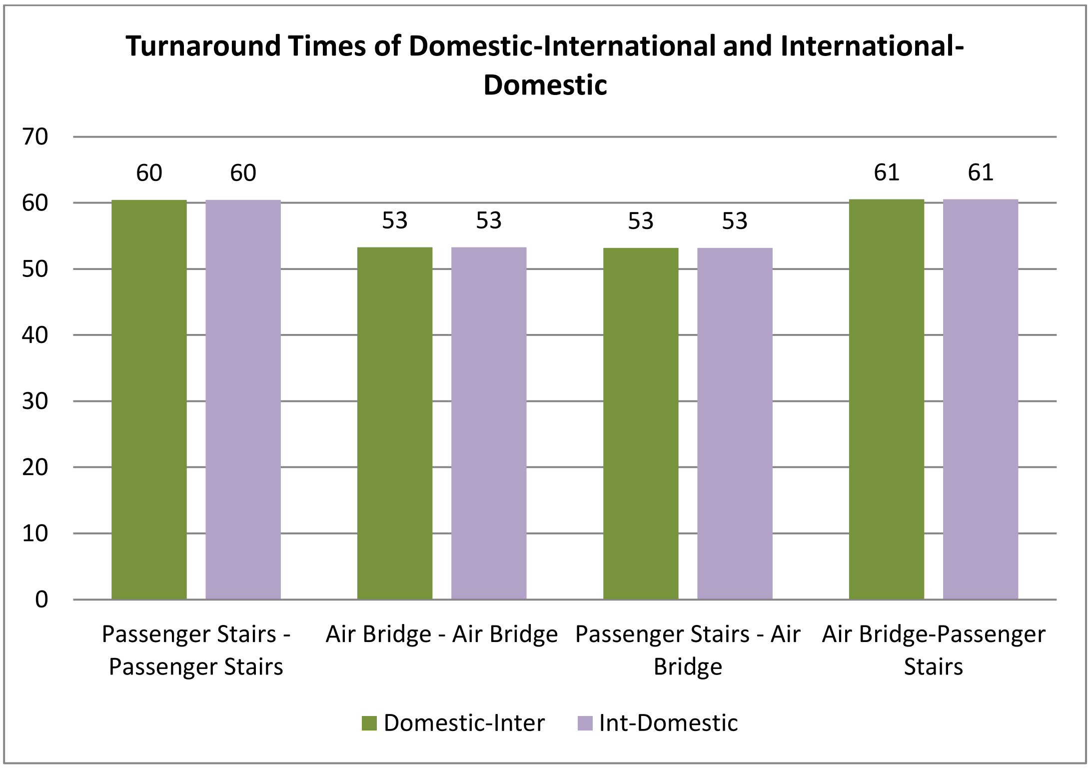


Figure 5.10: DomInt and IntDom Turnaround Time Comparison

As it can be seen from the figure, both flight types got the same tunraround time since the operations and their durations are almost the same. Moreover, it can be concluded that the operations in the critical path are the same for each boarding/disembarking style and the durations of operations in the critical path are clearly the same. The critical paths will be detailed in the next 4 sub-sections.

According to these results, best options to use while planning the turnaround is to assign airbridge for boarding of passengers and to assign either airbridge or passenger steps for disembarking of passengers. Both give approximately 53 minutes of turnaround time in total which are 3,191 and 3,166 seconds. The worst scenario is to board passengers via pax stairs and disembark them via airbridge. That gives the result of approximately 61 minutes (3,632 sec.) where the difference is 8 minutes compared to the first two scenarios.

In the following sections, the schedule of each scenario is further presented in detailed showing the duration and starting time of each operation.

5.2.1. Scenario 1- Using Pax Stairs Only

The schedule for only using passenger stairs was achieved by running the model with the data for DomInt and IntDom. The data of operations is the same. Number of operations and their sequences for both models are the same. Data related to the duration of operations is different such as the duration of baggage loading/unloading.

The resulting turnaround times for both models are 60 minutes (3,627sec.). There is no time difference between turnaround times since the operations and durations which are in the critical path are the same.

Schedule of domestic-international turnaround is showed in Figure 5.11 and international-domestic in Figure 5.12. Operations which are in the critical path is showed in red in the Gantt chart and listed in Table 5.5.

Table 5.5: Operations which are in the critical path for DomInt and IntDom with Pax Stairs

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
29	Disembark wheelchair pax via truck
30	Pax boarding
37	Head count
38	Hand in the Load Sheet and get Captain's approval
39	Close pax doors
40	Remove stairs
44	Push-back connection
45	Remove rear chocks

According to the table above which shows the critical path, different from DomDom and IntInt, "Disembark wheelchair pax using truck" was entered to the path while fuelling leaves. Another different operation is the "cleaning" which replaced "tidy-up" since for DomInt and IntDom there is always cleaning instead of tidy-up. All these operations are listed according to their sequences.

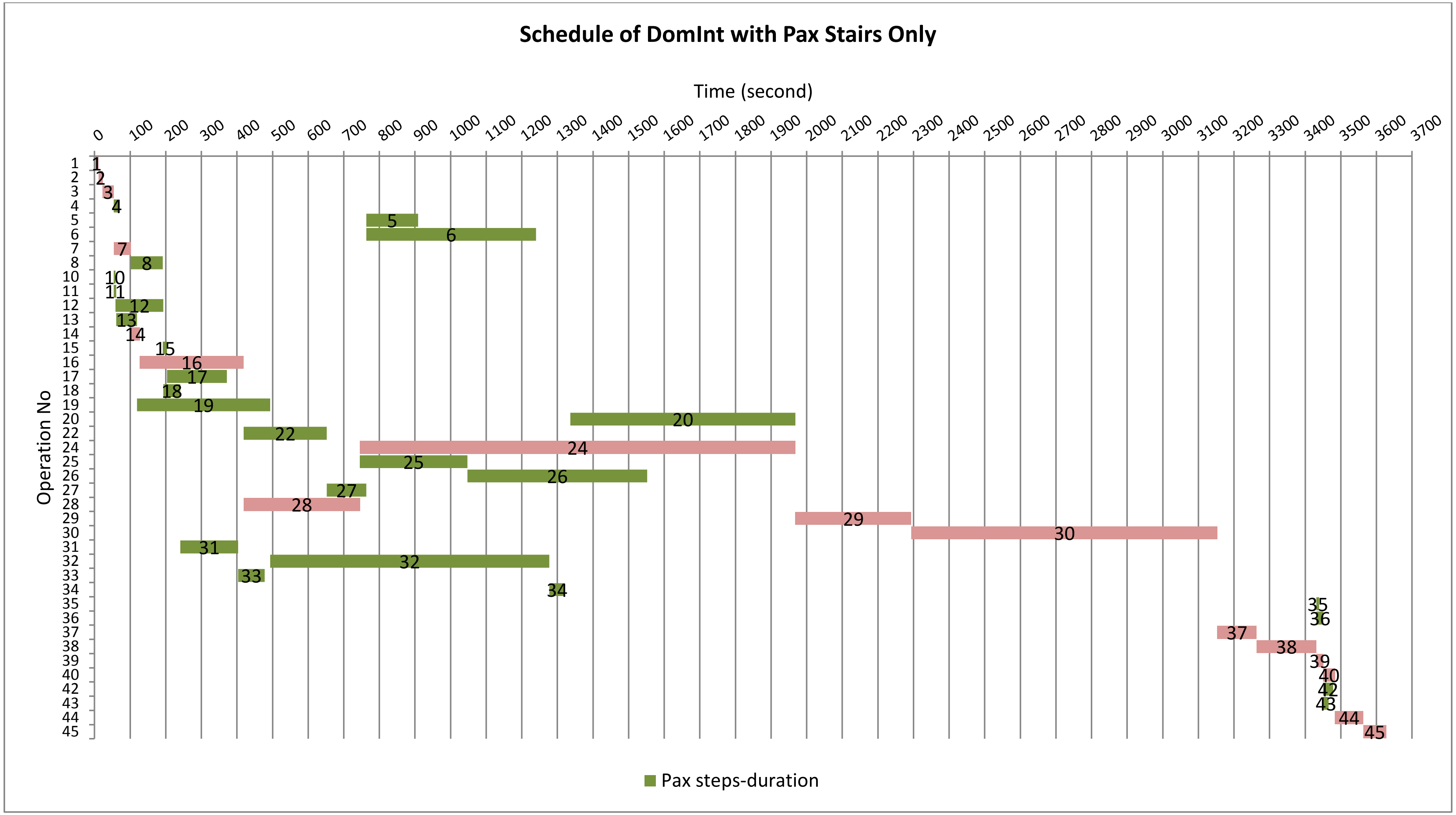


Figure 5.11: Schedule of Domestic to International Turnaround Operations using Pax Stairs during disembarking and boarding of Pax

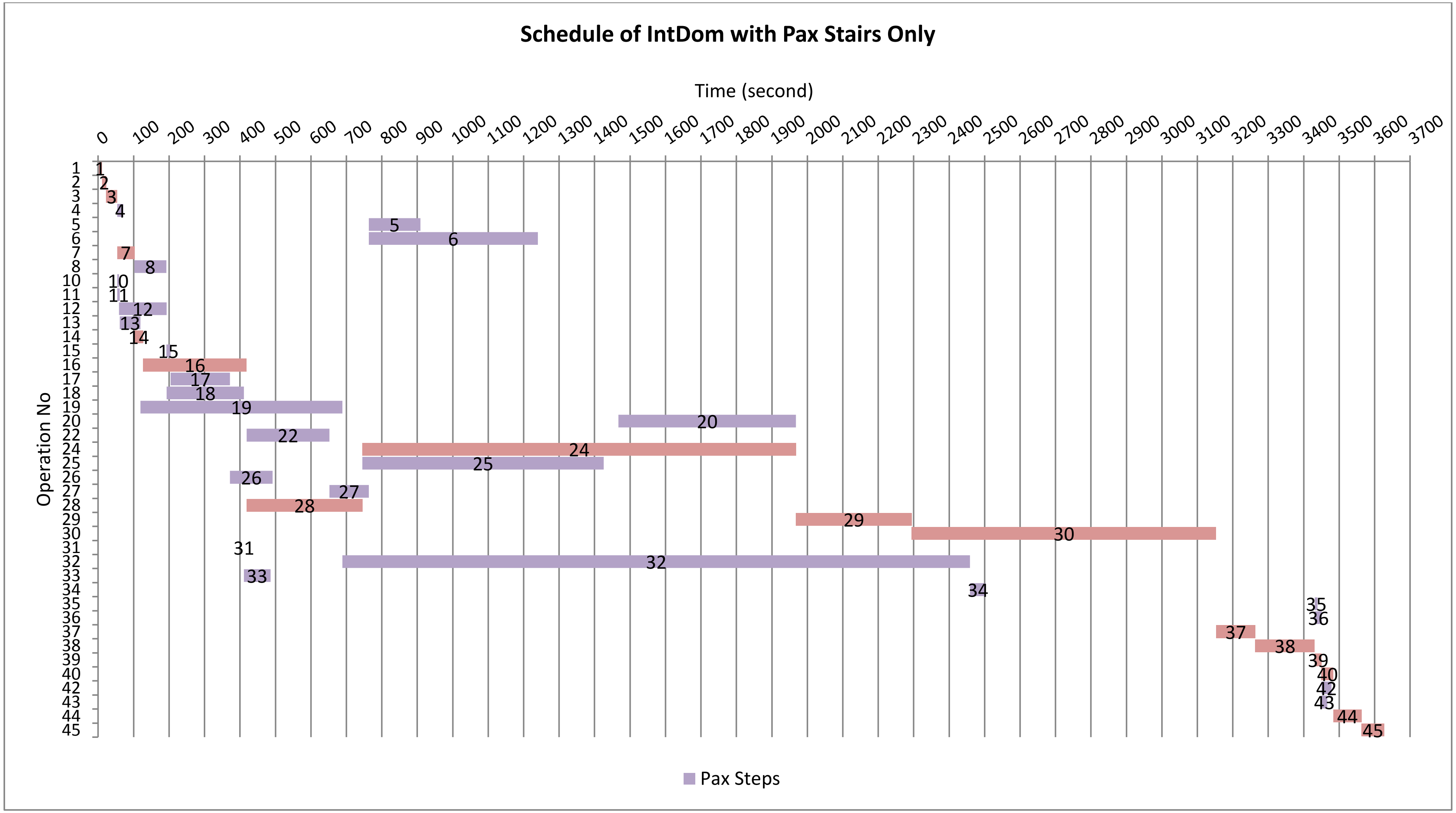


Figure 5.12: Schedule of International to Domestic Turnaround Operations using Pax Stairs during disembarking and boarding of Pax

Schedules on the above clearly state the operations' sequences and when an operation should start and how long it should take. Details of these schedules are showed in Appendix G in terms of start times, durations and names of operations for DomInt and IntDom for using only pax stairs. There are little differences between two schedules. In schedule of DomInt, duration of unloading baggage from both doors is higher than IntDom's. Moreover, duration of catering from the forward door takes more time for DomInt but catering from the rear door takes less. Baggage loading operation is again different in two schedules. In DomInt, total baggage loading to the forward compartment is taking more time; on the other hand for IntDom, baggage loading to the aft compartment takes less time. The most important difference in both operations which distinguishes DomDom and IntInt are that there is the cleaning operation instead of tidy-up.

5.2.2. Scenario 2 - Using Airbridge Only

This time models for DomInt and IntDom were run with their corresponding data set and the result of schedules were showed in Figure5.13 and Figure 5.14.

Turnaround time for both DomInt and IntDom is 53 minutes (3,196 sec.). The critical path for both flight types is also the same which can be seen from Table 5.6. Different from the previous schedule (the one with pax stairs), disembarking and boarding wheelchair pax via truck, and head count is not in the critical path and in the schedule.

Table 5.6: Operations which are in critical path for DomInt and IntDom with Airbridge

Operation No	Name of the Operation
1	Place front chocks
2	Stop engines
3	Place rear chocks
9	Position airbridge
14	Open front pax doors and ask purser if there are any PRM pax
16	Disembark pax from the forward door
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 which is stated above shows the critical operations for IntDom and DomInt when airbridge is used. Operation numbers and name of the operations are given in an order. If any of these operations are delayed, then the whole turnaround time will be delayed. That's why it is really crucial for company to know the critical operations.

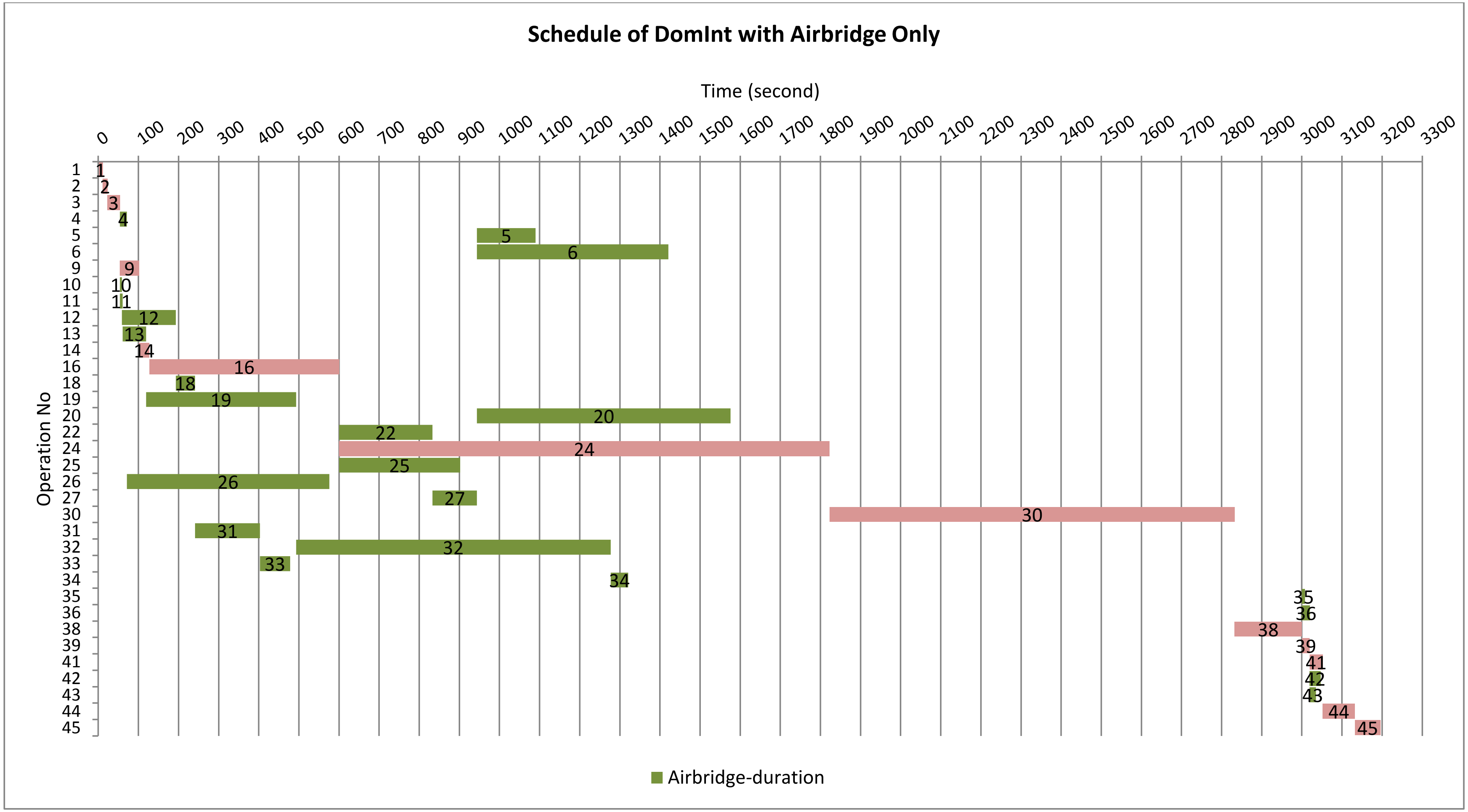


Figure5.13: Schedule of Domestic to International Turnaround Operations using Airbridge during disembarking and boarding of Pax

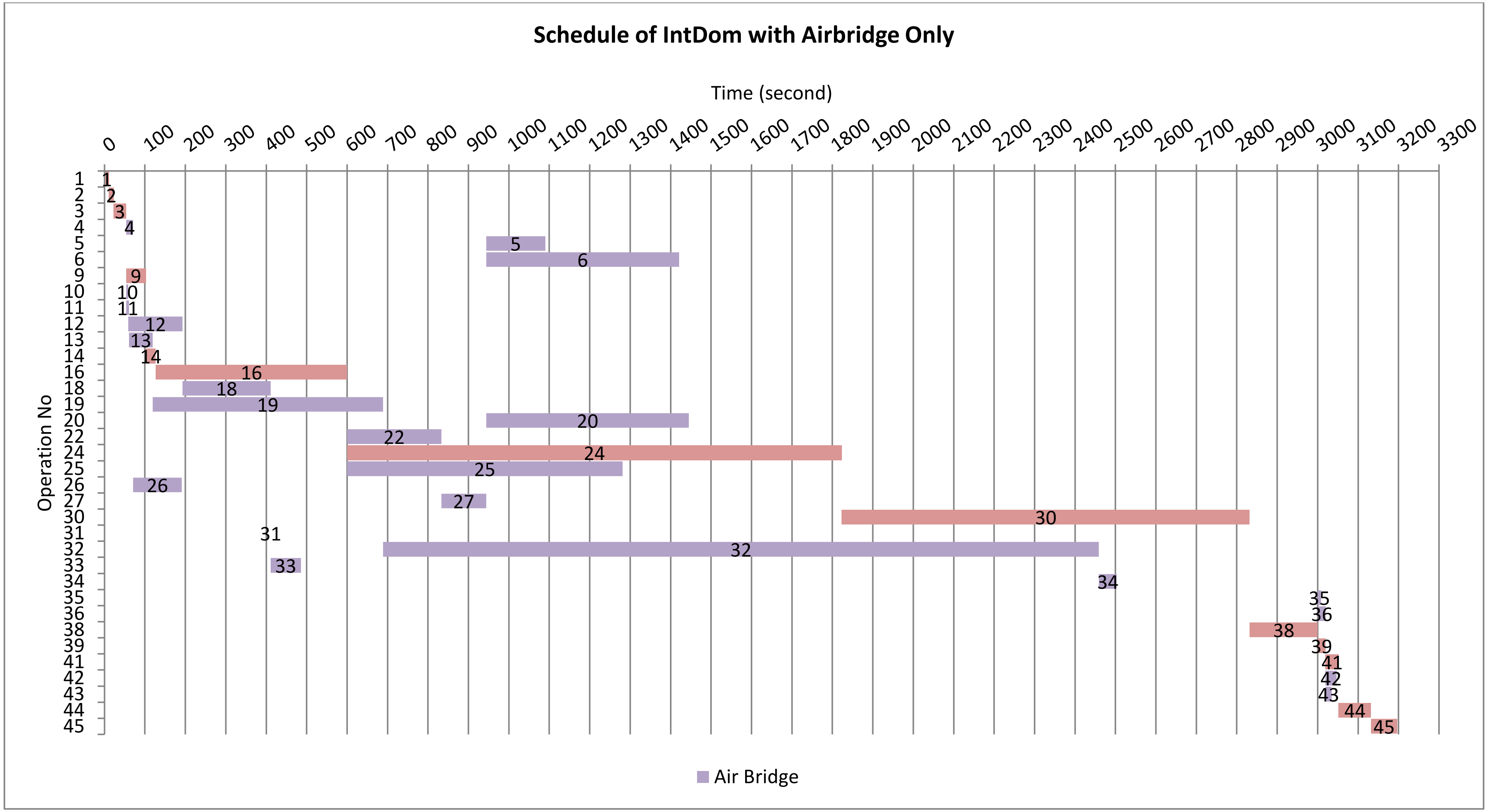


Figure 5.14: Schedule of International to Domestic Turnaround Operations using Airbridge during disembarking and boarding of Pax

Schedules which are stated above show the duration of operations and their sequences briefly. (Detail information is stated in the Appendix G). As previously explained, operations which create the difference are baggage loading, baggage unloading, fuelling and catering. Most important differences in both schedules which distinguish those from others are positioning airbridge and disembarking passengers from the front door, boarding passengers from the forward door and finally removing airbridge. Here it can be seen that catering operation from the rear door starts before catering from the forward door, since passengers are being disembarked at that time from the front. That's why according to the precedence relations, catering from the forward door start after passengers leave the plane (Operations 25 and 16).

5.2.3. Scenario 3 - Using Pax Stairs for Disembarking and Airbridge for Boarding

Disembarking passengers via stairs and boarding via airbridge was run for domestic-international and international-domestic flight types using precedence relationship, operations and operation durations data.

Results are almost the same for turnaround time with the previous boarding/disembarking style (airbridge&stairs) in terms of seconds. It was found that the turnaround time is 3,191 minutes, 5 seconds less than the one used airbridge only.

Schedule of both DomInt and IntDom flight types are presented in Figure 5.15 and Figure 5.16 respectively. Furthermore critical operations are painted as red in the Gantt chart and listed in the Table 5.7. Since the boarding is done via airbridge, the head count is not included in the model that's why it is not in the critical path.

Table 5.7: Operations which are in critical path for DomInt and IntDom 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

This table shows the critical operations in an order for DomInt and IntDom schedules. Like the other critical paths for DomInt and IntDom; cleaning, pax boarding load sheet approval and the others are the same. However operation 7 and 41 is different from the previous ones which are positioning pax stairs and removing airbridge. Disembarking and boarding durations are also different when it is compared with the durations in DomDom and IntInt.

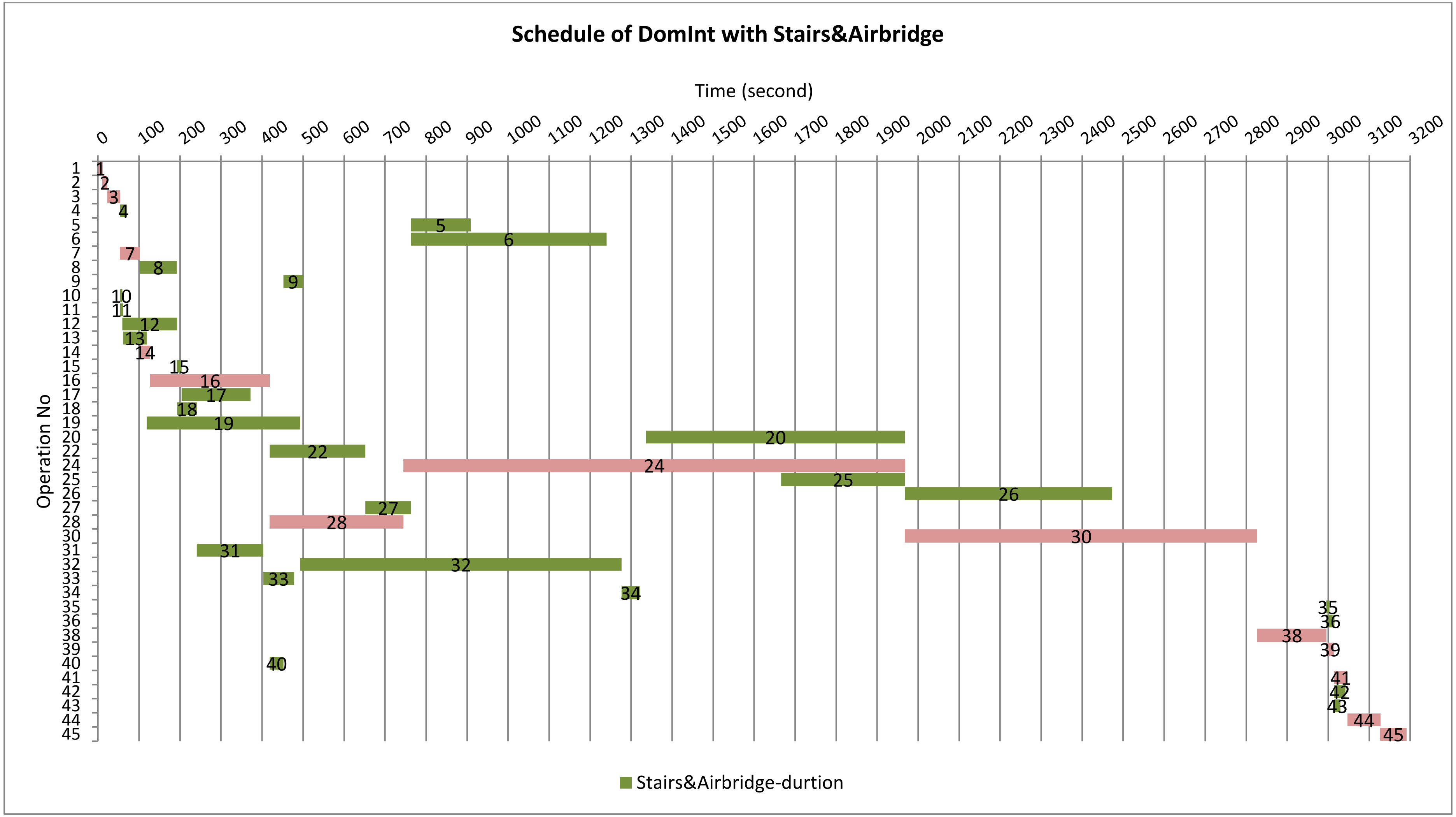


Figure 5.15: Schedule of Domestic to International Turnaround Operations using during Pax Stairs disembarking and Airbridge during boarding of Pax

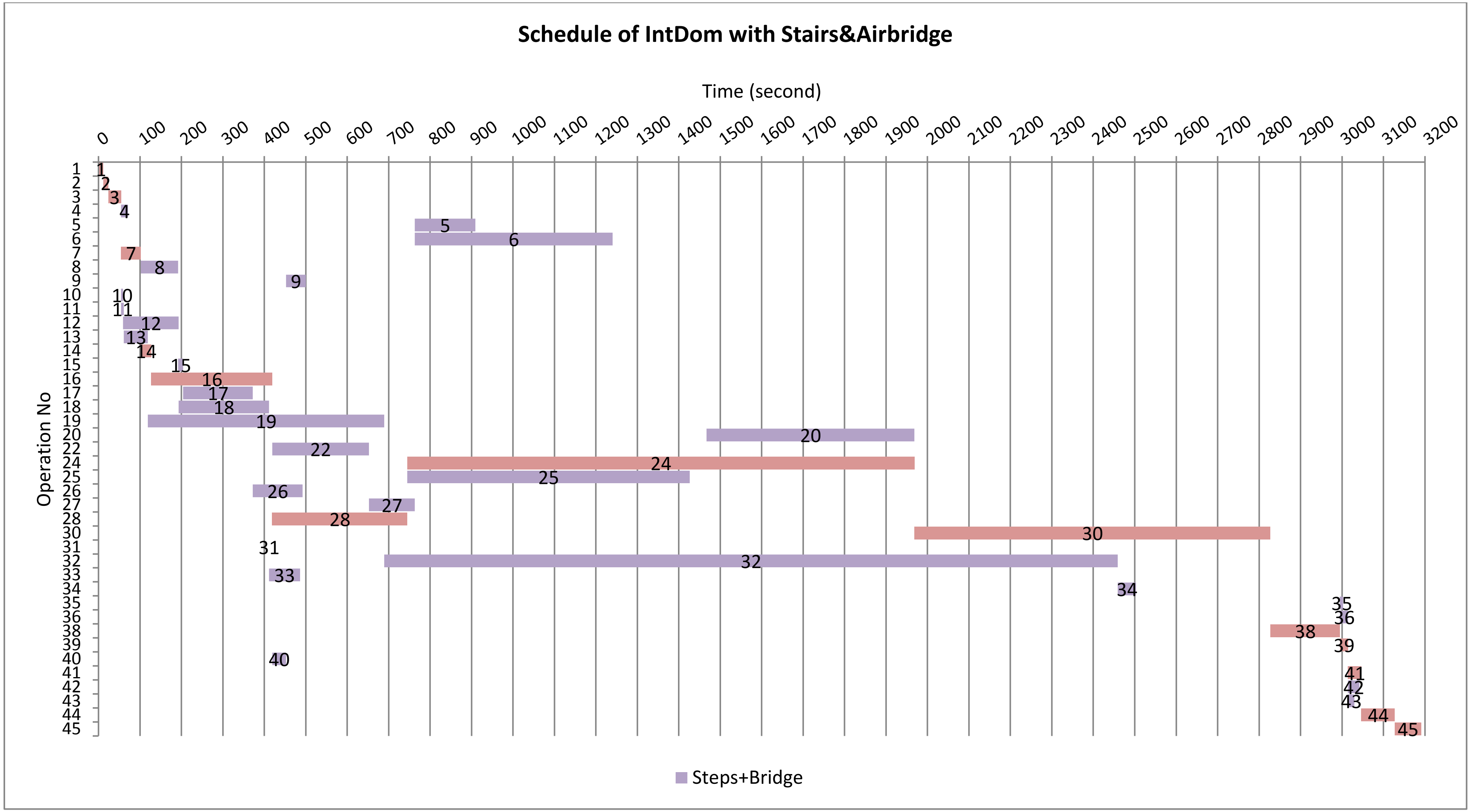


Figure 5.16: Schedule of International to Domestic Turnaround Operations using during Pax Stairs disembarking and Airbridge during boarding of Pax

Gantt charts which are showed above are special for DomInt and IntDom for using pax stairs for boarding and airbridge for disembarking. Positioning pax stairs and removing airbridge, duration of disembarking and boarding of passengers, duration of baggage loading and unloading are different from the other schedules. As it was showed in the mathematical model, space constraint limits operation 25 and 28 not to be handled at the same time. Because catering from the forward door (No 25) and disembarking wheelchair pax via truck (No 28) uses the same area and door. That's why even though passenger disembarking finishes, catering is scheduled after wheelchair pax disembarking. This can verify space constraint in the mathematical model since either of these two operations were supposed not to be processed at the same time. Details of the schedule such as duration of operations, starting times and names can be reached from Appendix G.

5.2.4. Scenario 4 - Using Airbridge for Disembarking and Pax Stairs for Boarding

As the last scenario, DomInt and IntDom flight types are considered with the usage of airbridge in disembarking and pax stairs in boarding.

Turnaround times of both flight types are the same with approximately 61 minutes which is 3,632 seconds. It is the worst scenario for this flight type but the difference is negligible when it is compared with the first scenario's result (using pax stairs) which was found as 60 minutes.

Results of DomInt and IntDom were transferred to the Gantt chart and the schedules have been established for DomInt which is in Figure 5.17 and for IntDom which is in Figure 5.18. Critical path for these schedules is also listed in Table 5.8.

Table 5.8: Operations which are in critical path for DomInt and IntDom with Airbridge & Pax Stair

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

Table in the above shows the critical operations. Different from the previous tables, this time first airbridge is placed for disembarking and finally stairs are placed to board passengers. Since passengers are boarded via stairs, head count is needed and done for this model which is also in the critical path.

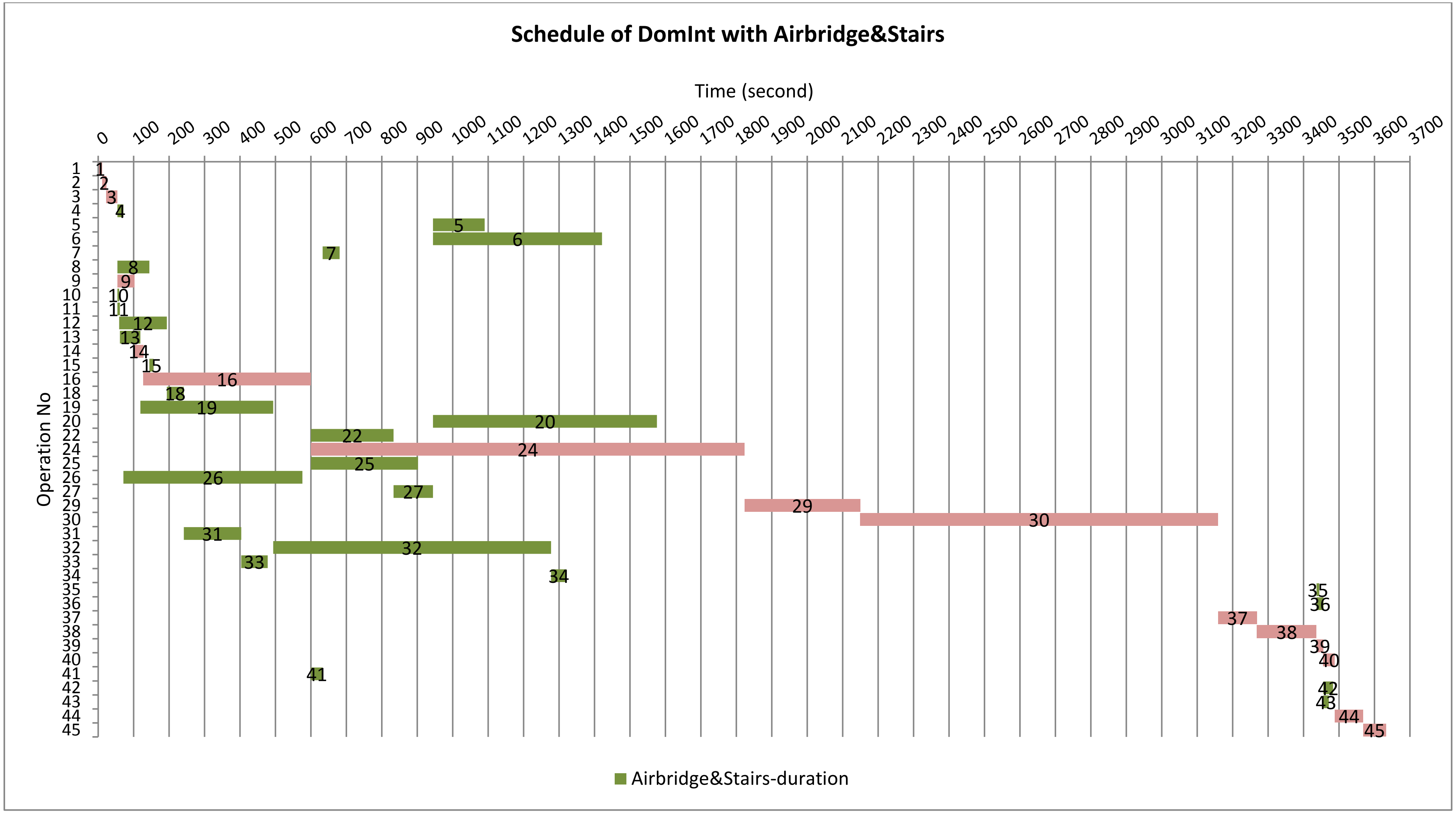


Figure 5.17: Schedule of Domestic to International Turnaround Operations using during Airbridge disembarking and Pax Stairs during boarding of Pax

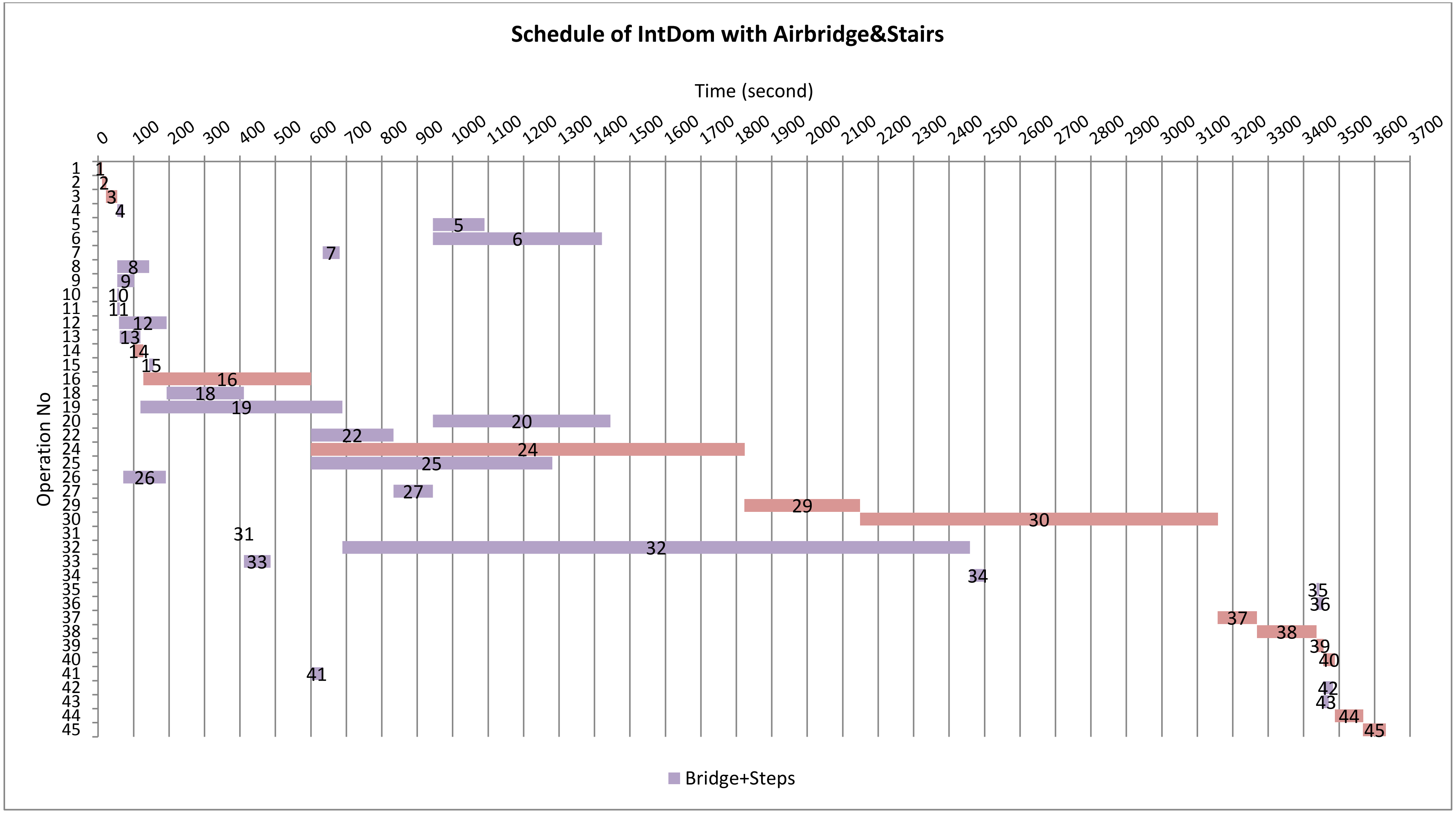


Figure 5.18: Schedule of International to Domestic Turnaround Operations using during Airbridge disembarking and Pax Stairs during boarding of Pax

These final schedules for DomInt and IntDom again presented as Gantt charts and showed the activities as blocks. Start and finish times are expressed in the top axis and id numbers of operations in the vertical axis and on the blocks. Detailed information about start times and names of each operation are presented in Appendix G. According to these charts, unloading and loading baggage, fuelling and catering are different from each other in terms of operation durations which are numbered as 18, 19, 20, 25, 26, 31 and 32. Special to this model, first pax stairs are positioned for passengers to deboard of the plane, and at the end airbridge is positioned for passengers to board on the plane.

5.3. Overall Comparison

In the previous sections, the turnaround times and schedules were presented for each disembarking/boarding style. These results are important for the company in terms of planning their turnaround operations and working on aircraft rotations. From these results, the best scenario so far is to use pax stairs for disembarking and airbridge for boarding. The right allocation of the parking position and vehicles can be arranged to plan the turnaround operations for this scenario. The second best scenario is to use airbridge for both disembarking and boarding of passengers for every flight type. Hence, the operations will be completed with the minimum turnaround time.

Critical path is also important for the company in order to make improvements in the turnaround operations; especially in order to reduce the turnaround time. Many studies have focused on reducing turnaround times within an existing schedule of turnaround operations. Now, with the knowledge of the operations which are in the critical path, the company would apply new strategies for critical operations to reduce turnaround times.

Finally, the last comparison is the big picture of what has been achieved in terms of turnaround times. In Figure 5.19, the comparison of turnaround operations for each flight type and disembarking/boarding styles within each flight type were presented.

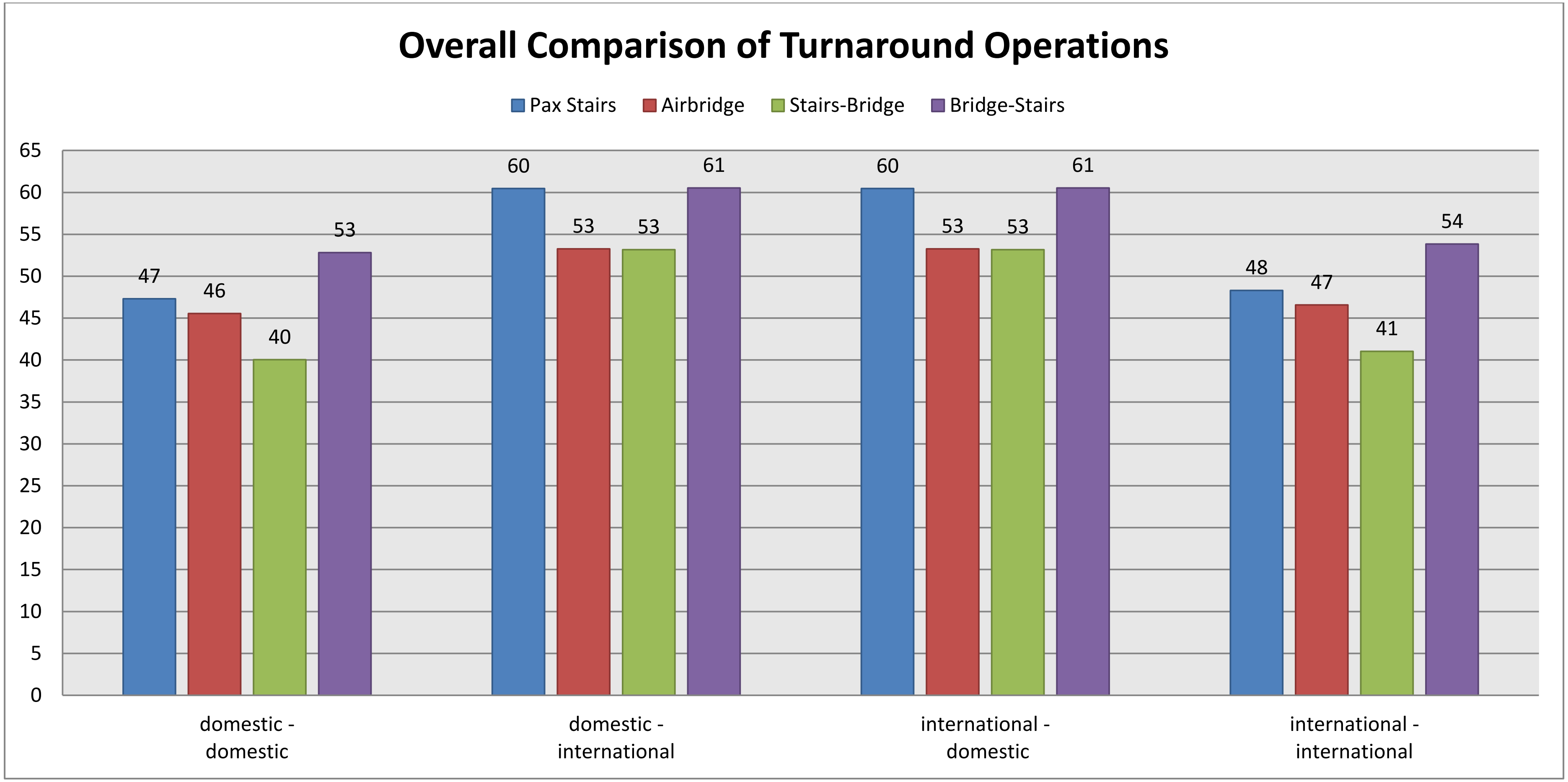


Figure 5.19: Overall Comparison of Turnaround Times

From the above figure, it can be concluded that domestic-domestic and domestic-international flight types' turnaround times are different and that's why in the planning phase, the turnaround times should be planned different for both flight types. This identification is also valid for international-international and international-domestic flight types. On the other hand, the turnaround times for domestic-domestic and international-international are very close to each other while turnaround times of domestic-international and international-domestic are the same.

The turnaround times that the company is using is showed in Figure 5.20. According to this figure, the turnaround times were needed to be rescheduled as the main problem was not being able to complete turnaround operations on time,.

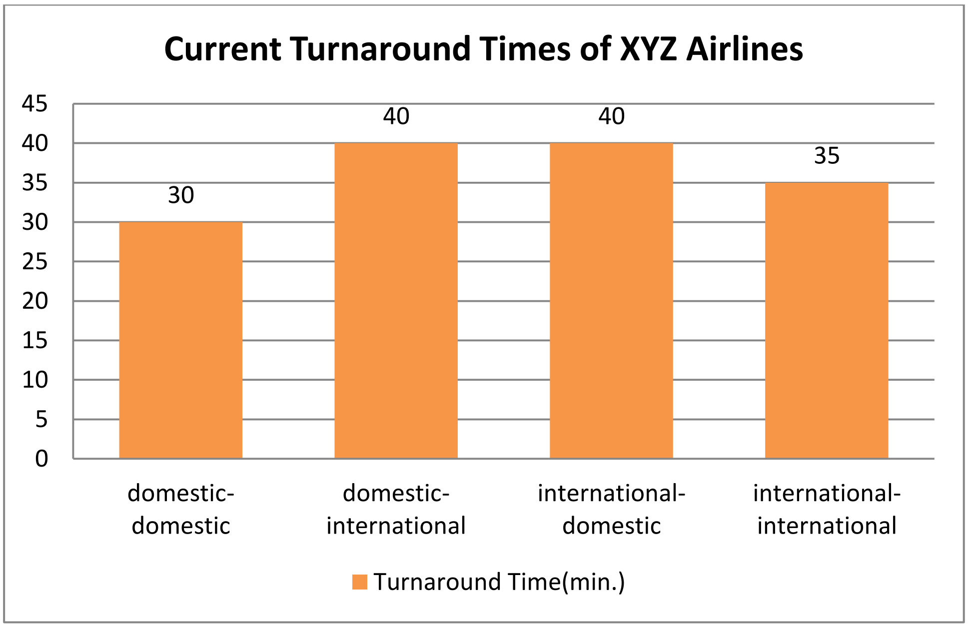


Figure 5.20: Current Turnaround Times of XYZ Airlines

Above figure clearly presents the turnaround time schedules for each flight type. Aircrafts who arrive to the hub from a domestic port and will depart to a domestic port again, are assigned 30 minutes turnaround time. On the other hand, the flight type international-international which is similar to domestic-domestic is assigned 35 minutes turn time. Finally, domestic-international and international-domestic flight types are assigned 40 min. of turnaround time.

Comparison of current turnaround time that XYZ Airline is using and the proposed turnaround time suggested to be used is indicated in Figure 5.21 with the minimized turnaround time scenario.

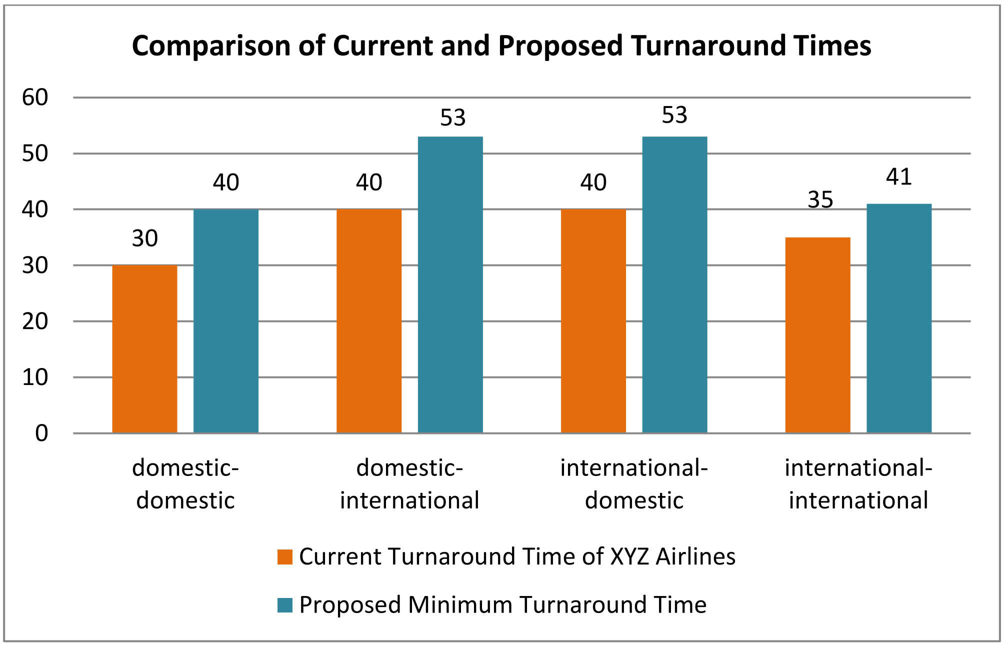


Figure 5.21: Comparison of Existing and Proposed Turnaround Times

According to the above chart; for domestic-domestic flight type, the ideal and the minimum turnaround needs to be 40 minutes according to the parking position and vehicles used. However, the company was planning it as 30minutes which was at least causing 10 minutes delay on average. For domestic-international and international-domestic, the difference is 13 minutes which is more significant. Finally, the closest turnaround time difference between current and proposed turnaround times is 6 minutes which is for IntInt flight type.

The reason why turnaround times are different from current turnaround plan is because the plan was scheduled many years ago without rescheduling of operations and collecting data. Moreover, in their own schedule, most of the operations were not considered such as different options for boarding/disembarking styles, clean water supply, lavatory drainage and most importantly the positioning and removing of vehicles, which also has a great effect on the turnaround time.

5.4. Chapter Summary

This chapter has given the results of the models which are run for each flight type and disembarking/boarding styles (scenarios). According to these results, in total 16 different schedules has been achieved. All these schedules and turnaround times have been presented in section 5.1 and 5.2 in detailed and the critical paths have been indicated. From these comparisons, the best turnaround time from different disembarking/boarding scenarios was concluded as disembarking pax using pax stairs and boarding them using airbridge.

In the last section, the overall comparison of different flight types and scenarios are stated. The result showed that those turnaround times of domestic-domestic and international-international as well as domestic-international and international-domestic are almost same. Final conclusion was made to point out the difference between the current turnaround time and proposed turnaround time. Current turnaround times were found less than the proposed turnaround times in this study. That's why there were many delays occurring due to the deficient scheduling by XYZ Airlines.

CHAPTER 6 – CONCLUSION AND FUTURE WORKS

After all the schedules are presented and compared with each other, objectives which were decided at the beginning of the study have been reached. This chapter gives the conclusion of the whole study from the beginning phase to the final phase explaining what was aimed and how the aim was achieved. Moreover, further works that can be done in the future are discussed in order to extend the study. Finally, critical evaluation of the project including critical evaluation, lessons learnt from this study and project management techniques used to successfully complete the project were discussed in Appendix A.

6.1. Conclusion

This dissertation addressed the problem of optimally scheduling of turnaround operations in XYZ low-cost airline company. The main objective of this study was to develop a linear programming model for four different flight types using mathematical modelling.

First of all, literature was reviewed in the area of turnaround operations in different airlines and applications of mathematical modelling in these areas were discussed. This was the first objective of the study. Secondly, the current operations that low-cost airlines are using in their turnaround processes are explained in detailed and the general flow of operations are presented in chapter 1. Thirdly, the data collection and observation by visiting the hub airport of the company were accomplished. 3 days of data collection including the start and finish time of each operation and the dependencies of operations were identified and recorded for 20 instances. The results were investigated as taking the average of operation durations.

As the next step, an integer linear programming (ILP) model was introduced which is called resource constrained project schedule problem (RCPSP). However since the problem is very difficult to be solved in a limited time, another integer linear programming model (TurnOper_LP) was introduced based on some assumptions. Then, the mathematical model was adapted to the real case of XYZ Airlines. Durations of each turnaround operation, number of operations and precedence relationship of operations were used as an input to the model. The model were run in IBM ILOG CPLEX using OPL for four different flight types (DomDom, DomInt, IntDom, IntInt) and also four different deboarding/boarding styles within each flight type which gave 16 different schedules of turnaround operations as an output.

After interpreting the results, 16 different schedules were created as a Gantt chart and critical path in each result were identified. Common operations in the critical path are the first and last operations which are placing/removing the chocks and connecting/removing GPU. Other most time consuming operations which are critical for all scenarios are disembarking and boarding of passengers. Fuelling becomes critical in DomDom and IntInt flight types however, cleaning replaces fuelling on the critical path for DomInt and IntDom.

At the end, each of the models were compared with each other based on their turnaround times and it was found that, using passenger stairs for disembarking and airbridge for boarding gives the minimum turnaround time for each flight type. For DomDom, the minimum turnaround time was found as 40 minutes, for DomInt and IntDom 53minutes, and for IntInt 41 minutes. These results have been compared with the current turnaround times which are used by the company and concluded that the proposed optimised turnaround times has given approximately 10 more minutes in addition to the current time. With the new turnaround times and schedule, the company is expected to achieve a higher on-time departure performance and almost no delays occurring from the turnaround time.

All the objectives were achieved and problem of the company were solved with an analytical approach. It has been an interesting real life study and still there are many other issues which can be discussed as a further research. These issues and problems are mentioned in the “Future Works” section.

6.2. Recommendation and Future Works

This study has focused on finding an optimal schedule for different flight types for the same aircraft type (Boeing 737-800). This was achieved by modelling the turnaround operations using mathematical modelling. This topic in the research took a lot of attention. Therefore, there is always an interest for continuous improvement in this area. Hence, further researches which can be studied in this area are identified and explained.

First of all, as a further research, the proposed RCPSP can be considered for this problem. Resources in the turnaround operations are limited, that's why considering resource constraint instead of assuming them infinite could give a more realistic schedule. In order to solve the RCPSP, a heuristic method can be developed and solved in a short time. However, since it is solved by a heuristic, it may not give the optimal schedules which can be this study's weakness.

Secondly, the collected data can be considered as stochastic and a stochastic programming model can be developed in order to find the turnaround schedules with probabilistic data. This can provide a more realistic schedule since the airline operations are stochastic and unstable.

Finally, assumptions can be reconsidered and reduced to broaden the model. A cost function can also be added to the model to find an optimal schedule from the trade-off between cost of delay and cost of turnaround operations. By doing this, the effect of increasing number of resources in the turnaround cost can be observed. From this observation it can be concluded that, maybe the increased number of resources can increase the turnaround time however the cost occurred by increasing these number of resources can be much higher than delaying the turnaround. This model can decide the optimal time, cost and schedule of turnaround operations. However solution of this problem can be difficult since it is a RCPSP and there will be additional constraints and variables which will make the model more complex.

REFERENCES

Abara, J. (1989) “Applying integer linear programming to the fleet assignment problem”. *Interfaces* 19 (4), 20–28

Adeleye, S. & Chung, C. (2006) “A Simulation Based Approach Contingency Planning for Aircraft Turnaround Operation System Activities in Airline Hubs”. *Journal of Air Transportation,* 2(1)

Bazargan, M. (2010) *Airline Operations and Scheduling.* Second ed. Surrey: Ashgate Publishing Limited

Blazewicz, J., Lenstra, J., and Kan, A. R. (1983). ‘Scheduling subject to resource constraints: Classification and complexity’. *Discrete Applied Mathematics*, 5, 11–24.

Brucker, P. and Knust, S. (2012). *Complete Scheduling.* Second ed. New York: Springer

Boeing (2013) *B737 Airplane Characteristics for Airport Planning.* [Online] available from: <www.boeing.com/assets/pdf/commercial/airports/acaps/737.pdf> [23 August 2014]

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five designs*. Thousand Oaks, CA: Sage

Dunbar M., Froyland G. and Wu, C. L. (2012) “Robust airline schedule planning: minimizing propagated delay in an integrated routing and crewing framework”. *Transportation Science*, 46(2), 204–16

Fotiadis, T. (2010) A study approach on passengers flow improvement Macedonia International Airport of Thessaloniki [online] EMBA dissertation. International Helenic University < http://www.ihu.edu.gr/gateway/expertise/publications/pub000053.html > [23 August 2014]

Fricke, H. and Schultz, M. (2009) “Delay impacts onto turnaround performance - optimal time buffering for minimizing delay propagation”, in Proceedings of the USA/Europe Air Traffic Management Research and Development Seminar, 2009

Gatersleben, M. R. and Van der Weij, S. W. (1999) ‘Analysis and simulation of passenger flows in an airport terminal’. in Farrington, P. A., Nembhard, H. B., Sturrock, D. T., and Evans, G. W. (ed.). *Proceedings of the 1999 Winter Simulation Conference*, 1226-1231

Gomez, F., Scholz, D. (2009) “Improvements to ground handling operations and their benefits to direct operating cost”. *Proceedings of Hamburg University of Applied Sciences, Deutscher Luft- und Raumfahrtkongress* 2009

Guizzi G., Murino T., Romano E. (2009) “A Discrete Event Simulation to Model Passenger Flow in the Airport Terminal”. *Proceedings of APPLIED COMPUTING CONFERENCE 2009 (ACC '09)*

Han, T., Chung, C., Liang, G. (2006) “Application of fuzzy critical path method to Airport’s cargo ground operation systems” *Journal of Marine Science and Technology,* 14(3), 139-146

Hane, C. A., Barnhart, C., Johnson, E. L., Marsten, R. E., Nemhauser, G. L., Sigismondi, G. (1995). “The fleet assignment problem: Solving a large-scale integer program” *Mathematical Programming,* 70, 211–232

Haouari, M., Aissaoui, N., Mansour, F. Z. (2009) “Network flow-based approaches for integrated aircraft fleeting and routing”. *European Journal of Operational Research*, 193, 591–599

Hillier, F. S., Lieberman G. J. (2001) *Introduction to Operations Research.* 7th edn. New York: McGraw-Hill

Jiang, H., and Barnhart, C. (2013) “Robust airline schedule design in a dynamic scheduling environment”. *Computers &Operations Research*, 40, 831–840

Kolukısa, A. (2011) *Evaluating Aircraft Turnaround Process in the Framework of Airport Design and Airline Behaviour* [online] DPhil dissertation. Universidade do Porto. <http://repositorio-aberto.up.pt/bitstream/10216/61575/1/000149255.pdf > [23 August 2014]

Kunze, T. M., Schultz, and H. Fricke (2011) “Aircraft Turnaround management in a highly automated 4 D flight operations environment”, International Conference on Application and Theory of Automation in Command and Control Systems (ATACCS), Barcelona

Lan, S., Clarke, J.-P. & Barnhart, C. (2006) “Planning for robust airline operations: Optimizing aircraft routings and flight departure times to minimize passenger disruptions”. *Transportation Science*, 40(1), 15–28

Luenberg, D.G., Ye, Y. (2008) *Linear and Nonlinear Programming.* 2nd edn. New York: Springer

Mao, X., Roos, N., and Salden, A. (2009) “Stable multi-project scheduling of airport ground handling services with heterogeneous agents”. in AAMAS 2009, 537–544

Norin, A. (2008) Airport Logistics- Modeling and Optimizing the Turn-Around Process [online] dissertation. Linköping University. <http://liu.diva-portal.org/smash/get/diva2:516859/FULLTEXT01.pdf > [23 August 2014]

Pinedo, M. L. (2005) *Planning and Scheduling in Manufacturing and Services*. New York: Springer Science+Business Media, Inc.

Sanchez, D. R. (2009) *Analysis of Ground Handling Characteristics of Innovative Aircraft Configurations,* Hamburg: Hamburg University of Applied Science

Sanz de Vicente, S. (2010) Ground Handling Simulation with CAST [online] MSME dissertation. Hamburg University of Applied Science. <http://www.fzt.haw-hamburg.de/pers/Scholz/arbeiten/TextSanz.pdf > [23 August 2014]

Saunders, M., Lewis, P. and Thornhill, A. (2007) *Research Methods for Business Students*, 4th ed, Essex: Pearson Education Limited

Schultz, M., and H. Fricke (2011) "Managing passenger handling at airport terminal", USA/Europe Air Traffic Management Research and Development Seminar (ATM), Berlin

Sherali, H. D., Bish, E. K. and Zhu X. (2006) "Airline fleet assignment concepts, models, and algorithms". *European Journal of Operational Research,* 172, 1-30

Trabelsi S. F., Cosenza A. N., Cruz L. G. Z., Mora-Camino, F. (2013) 'An operational approach for ground handling management at airports with imperfect information' in Iglesias, C. H., Pérez Ríos, J. M. (ed.) *Proceedings of the ICIEOM 2013, 19th International Conference on Industrial Engineering and Operations Management.* held 10-12 July 2013. Valladalid: Spain

Van Landeghem H., Beuselinck A. (2002) "Reducing passenger boarding time in airplanes: A simulation based approach". *European Journal of Operational Research* 142, 294-308

Van Leeuwen, P. (2007) A Report on *CAED D2: Modelling the Turnaround Process,* Netherlands: Technical University of Delft

Vidosavljević, A., & Toŝić, V. (2010) '*Modeling of Turnaround Process Using Petri Nets'*. in 2010 ATRS World Conference

Weide, O. D. Ryan, and M. Ehrgott (2009) "An iterative approach to robust and integrated aircraft routing and crew scheduling". *Computers & Operations Research,* 37(5), 833-844

Wu, C. & Caves, R. E. (2004a) "Modelling and optimization of aircraft turnaround time at an airport". *Transportation Planning and Technology,* 27(1), 47-66

Wu, C. & Caves, R. E. (2004b) "Modelling and simulation of aircraft turnaround operations at airports". *Transportation Planning and Technology,* 27(1), 25-46

Wu, C. & Caves, R. E. (2002) "Modelling of aircraft rotation in a multiple airport environment". *Transportation Research Part E,* 265-277

Wu, C (2005) "Inherent delays and operational reliability of airline schedules". *Journal of Air Transport Management,* 11, 273–282

APPENDICES

Appendix A – Critical Evaluation and Project Management

In the development phase of this dissertation, there have been some obstacles. In order to point out what has been learnt from this study and what was done wrong, the progress of dissertation was critically analysed. At the end, lessons learnt from this dissertation were explained and the project management skills used are described.

First of all the strength of this dissertation is being a problem which was not studied with this approach in the literature before. That means it fills the gap of knowledge. This is important for the contribution to the literature with a new method. Secondly, the problem which was studied in this thesis is a real life problem. This is important as it satisfies the applicability of the proposed model which can be put into practice easily. Moreover, observing the outcomes of the schedule and making further improvements can be done by collaborating with the company.

On the other hand, the weaknesses are mainly caused by the limitations of the thesis. Because of lack of time, the integer programming model developed for RCPSP could not be run. That's why assumptions about resources were needed to be made. Since resource constraints are considered infinite, the schedules are not much realistic when it is compared with the real situation. However as resource limits checked for proposed schedules during the verification, the schedules are almost representing the real situation. Another weakness of this project arises from not being able to collect more data which affects to have a better reflection of the real system. This was caused because of the time limitation of the project and being only one person time-watching all the operations and keeping record of them.

In order to manage this project, some project management techniques have been applied. *Time management* were considered before and during to project by defining the milestones and duration of each task that is needed to be done. The data collection dates are agreed well before and agreed on the dates with the company. The Gantt Chart which is prepared to schedule the dissertation steps and durations is showed in Figure A.1. *Risk management* has been applied; risks are identified considering tasks which can delay the project if something goes wrong. These risks were in general: not being able to get a permission to collect data, lack of communication with the company, not much literature about this topic to base this study on and loosing data on computer. After identifying possible risks, some precautions were taken. In order to guarantee to collect data, agreement with the company about the time, date and place were made and restrictions to access some areas were stated by the company in order to avoid misunderstanding. The communication with the company was agreed to be done on phone or via email and the meeting days to contact with the company was known beforehand. About not being able to find enough literature, the research has been conducted on the earlier stages of the dissertation. Risk statement table and risk priority table are presented in Table A.1 and Table A.2 respectively in order to clarify all risks and actions taken to prevent those risks.

Finally, as the last important point**,** *Quality Assurance* of the research was considered. In order to attain high credibility for this research; reliability, validity and generalisability has been achieved. Reliability has been achieved by making more than one observation and collecting enough data from the company. Validity on the other hand was reached by comparing the real data with the achieved data. Since the similarity between them is very high, it can be concluded that the findings are valid. Finally, proposed model can be generalised for any Airlines' turnaround operations since the mathematical model was first developed in a general form and then it was adapted to the XYZ Airline using data collected from the company as an input.

- Time Management (Gantt Chart)

Gantt Chart

	Ta M	Task Name	Duratic	Start	Finish	Pr	Resource Names
1		Problem definition and deciding on the method of solving the problem	20 days	Tue 20/05/14	Mon 16/06/14		
2		Literature Review	27 days	Tue 17/06/14	Wed 23/07/14	1	Computer,Library
3		Observe the current system in the airport	3 days	Mon 07/07/14	Wed 09/07/14		
4		Collect data	3 days	Mon 07/07/14	Wed 09/07/14		Stop watch
5		Draw a flow chart and process map	7 days	Thu 10/07/14	Fri 18/07/14	3,4	Computer
6		Model the system using mathematical modelling	20 days	Tue 24/06/14	Mon 21/07/14	1	Mathematical Modelling Software
7		Mathematical Model is ready	0 days	Mon 21/07/14	Mon 21/07/14	6	
8		Run the model and analyse results	5 days	Tue 22/07/14	Mon 28/07/14	7	Mathematical Modelling Software
9		Conclusion and Recommendations	1 day	Tue 29/07/14	Tue 29/07/14	8	Excel
10		First draft of the report	7 days	Wed 30/07/14	Thu 07/08/14	9	Computer
11		Do refereneces	1 day?	Fri 08/08/14	Fri 08/08/14	10	Computer
12		Proof read	3 days	Mon 11/08/14	Wed 13/08/14	11	
13		Corrections	2 days	Thu 14/08/14	Fri 15/08/14	12	Computer
14		Final Form of the Report	0 days	Sun 17/08/14	Sun 17/08/14	13	

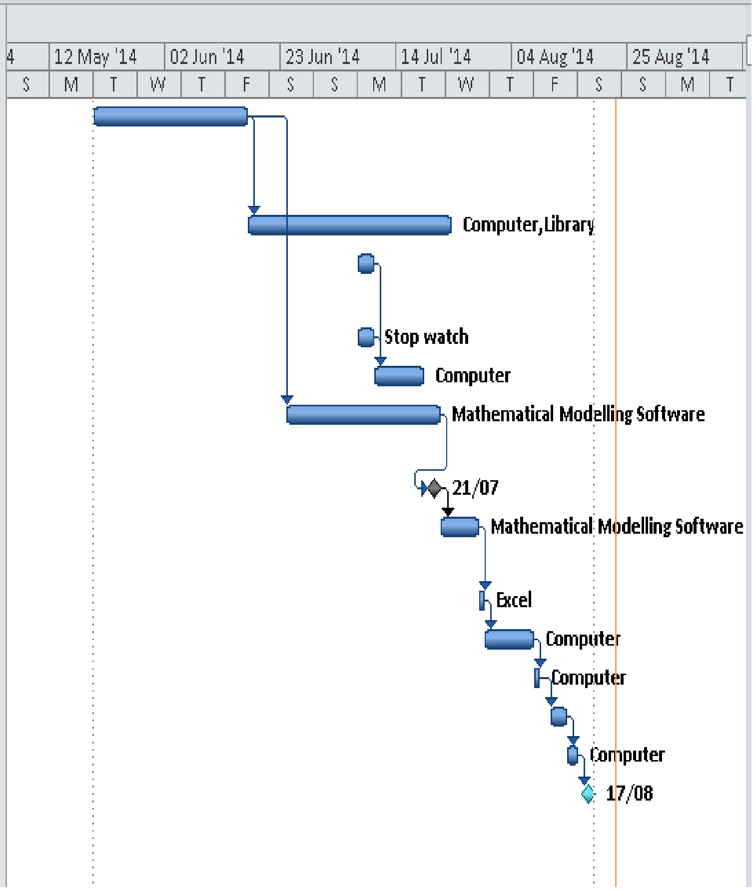


Figure A.1: Project Schedule (Gantt Chart)

- Risk Management Tools

Risk Statement Table

The following table (Table A.1) represents possible risks throughout the dissertation stating the category, description and ID.

Table A.1: Risk Statement Table

Category	Description	Id
Data Collection	• Required approval from the authority is not taken for the observation and data collection at the airport	**1.1**
Budget	• Budget for travel for the data collection exceeds the allowed budget.	**2.1**
Schedule	• One or more weeks late completion of dissertation than its scheduled date • Disagreement on the date for the data collection	**3.1** **3.2**
Resource	• Not enough literature in the area of turnaround operations • Unavailability of required book in the Library	**4.1** **4.2**
Technology	• Failure of downloading mathematical model solver • Crash of the computer and loss of all data	**5.1** **5.2**

Risk Priority Table

The following table (Table A.2) shows the priority scores of each risk and it is calculated by multiplication of Likelihood and Impact over 2. (Priority= (Likelihood + Impact) / 2).

The **rating** is defined as,

Priority Score	**Priority Rating**
0 – 20	Very low
21 – 40	Low
41 – 60	Medium
61 – 80	High
81 – 100	Very High

Table A.2: Risk Priority Table

ID	Likelihood	Impact	Priority Score	Rating	Preventative Actions
1.1	50	90	70	High	To ask for the approval in advance at the beginning of the dissertation
2.1	20	20	20	Low	Prepare the budget and find a sponsor to finance for the expenses during the data collection period
3.1	70	90	80	High	Plan all the milestones and tasks. Prepare a Gantt chart to see the latest completion time of the dissertation. Plan with pessimistic time requirements.
3.2	60	60	60	Medium	Talk with the responsible person in the company and decide on the date.
4.1	50	70	60	Medium	As a first step, before deciding on the topic, search for literature to see if there is enough reviews in proposed topic
4.2	50	30	40	Low	Check at the beginning for the useful books that could be needed for the next stages of the dissertation and book them in advance.
5.1	30	50	40	Low	Check the requirements of the solver at the earlier phase of the dissertation.
5.2	40	100	70	High	Always backup the work daily to a hard-disk and keep it in a good condition.

Appendix B – Research Instrument (Data Collection Tool)

Dom-Dom					
No	**Process**	**Options**	**# Staff**	**Start Time**	**End Time**
1	Stop Enginees				
2	Place chocks				
3	Connect GPU	stairs/ airbridge			
4	Routine Manintenance				
5	Lavatory				
6	Water Service				
7	Parking Position	Place Pax Steps			
		Place Airbridge			
8	Open Cargo doors	*forward			
		aft			
9	Place baggage loader	forward			
		aft			
10	Open Pax doors	front door			
		rear door			
11	Disembark Pax	front door			
		rear door			
12	Unload Baggage/ Cargo	*front baggage			
		front cargo*no2			
		back			
13	Fuelling	w/o fb			
14		with fb			
15	Security Check				
16	Cleaning	Tidy-up			
		Cleaning agents			
17	Catering	Catering Truck			
		Hand loading			
18	Cabin Crew change				
19x	Check-in finished				
20	Load Baggage	forward cargo			
		forward			
		aft			
21	PAX Boarding	Boarding Pass Check			
22		Transportation			
23		Boarding			
24	Remove conveyors	Forward Rear			
25	Close cargo doors	Forward Rear			
26	Head count				
27	Close pax doors				
28	Hand in the Load Sheet and get Captain's approval	Load Sheet			
29	Remove stairs/ airbridge	Stairs / Air bridge			
30	Start Engines				
31	Push-back connection	Towcar			

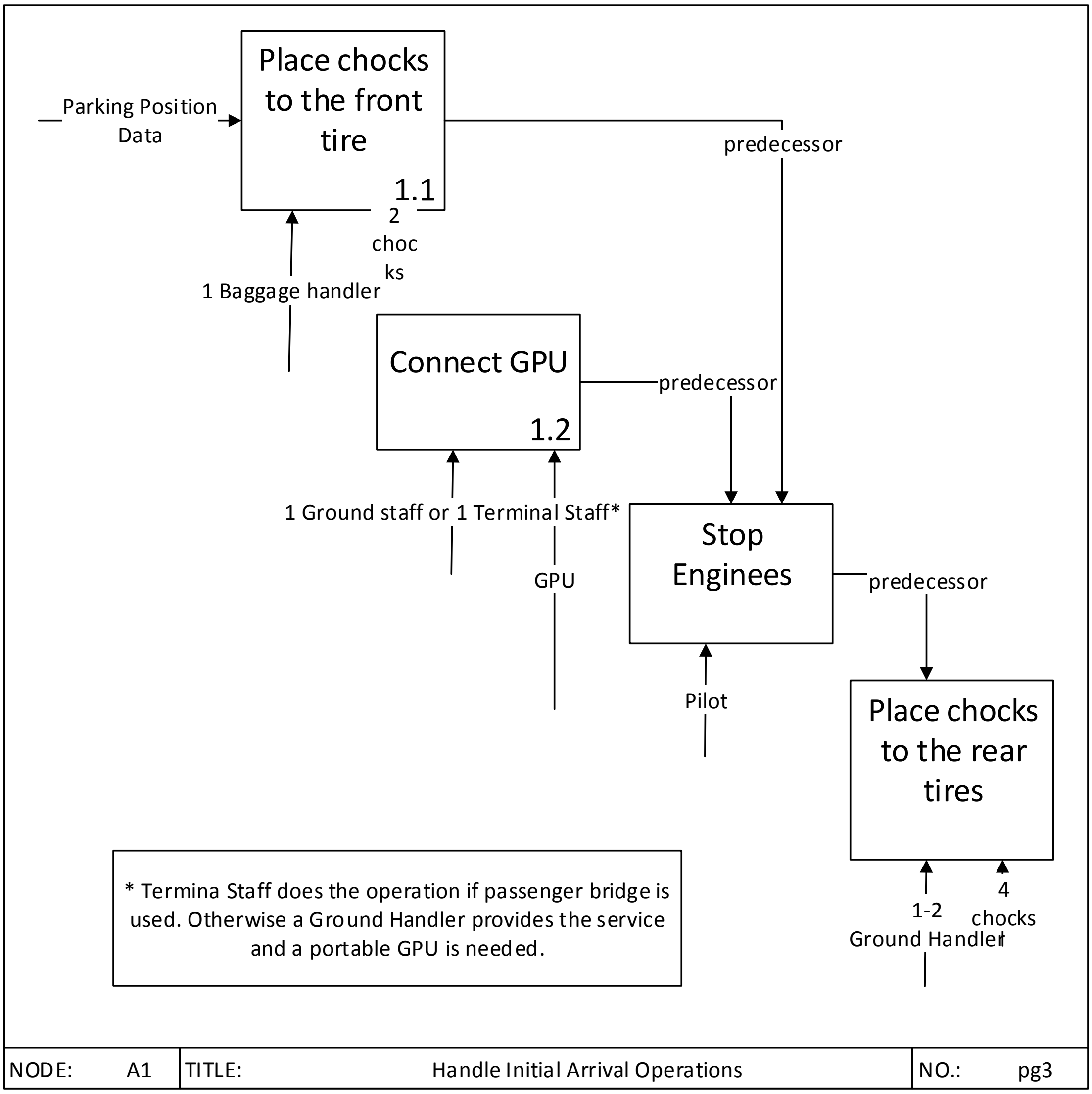
Dom-Int					
No	**Process**	**Options**	**# Staff**	**Start Time**	**End Time**
1	Stop Enginees				
2	Place chocks				
3	Connect GPU	stairs/ airbridge			
4	Routine Manintenance				
5	Lavatory				
6	Water Service				
7	Parking Position	Place Pax Steps			
		Place Airbridge			
8	Open Cargo doors	*forward			
		aft			
9	Place baggage loader(conveyor)	*forward			
		aft			
10	Open Pax doors	front door			
		rear door			
11	Disembark Pax	front door			
		rear door			
12	Unload Baggage/ Cargo	*front baggage			
		front cargo*no2			
		back			
13	Fuelling	w/o fire brigade			
14		with fire brigade			
15	Security Check				
16	Cleaning	Tidy-up		NA	NA
		Cleaning agents			
17	Catering	Catering Truck			
		Hand loading		NA	NA
18	Cabin Crew change				
19x	Check-in finished				
20	Load Baggage	forward cargo			
		forward baggage			
		aft baggage			
21	PAX Boarding	Boarding Pass Check			
22		Transportation			
23		Boarding			
24	Remove conveyors	Forward Rear			
25	Close cargo doors	Forward Rear			
26	Head count				
27	Close pax doors				
28	Hand in the Load Sheet and get Captain's approval	Load Sheet			
29	Remove stairs/ airbridge	Stairs / Air bridge			
30	Start Enginees				
31	Push-back connection	Towcar			

Int-Dom					
No	**Process**	**Options**	**# Staff**	**Start Time**	**End Time**
1	Stop Enginees				
2	Place chocks				
3	Connect GPU	stairs/ airbridge			
4	Routine Manintenance				
5	Lavatory				
6	Water Service				
7	Parking Position	Place Pax Steps			
		Place Airbridge			
8	Open Cargo doors	*forward			
		aft			
9	Place baggage loader(conveyor)	*forward			
		aft			
10	Open Pax doors	front door			
		rear door			
11	Disembark Pax	front door			
		rear door			
12	Unload Baggage/ Cargo	*front baggage			
		front cargo* no2			
		back			
13	Fuelling	w/o fire brigade			
14		with fire brigade			
15	Security Check				
16	Cleaning	Tidy-up		NA	NA
		Cleaning agents			
17	Catering	Catering Truck			
		Hand loading		NA	NA
18	Cabin Crew change				
19x	Check-in finished				
20	Load Baggage	forward cargo			
		forward baggage			
		aft baggage			
21	PAX Boarding	Boarding Pass Check			
22		Transportation			
23		Boarding			
24	Remove conveyors	Forward Rear			
25	Close cargo doors	Forward Rear			
26	Head count				
27	Close pax doors				
28	Hand in the Load Sheet and get Captain's approval	Load Sheet			
29	Remove stairs/ airbridge	Stairs / Air bridge			
30	Start Enginees				
31	Push-back connection	Towcar			

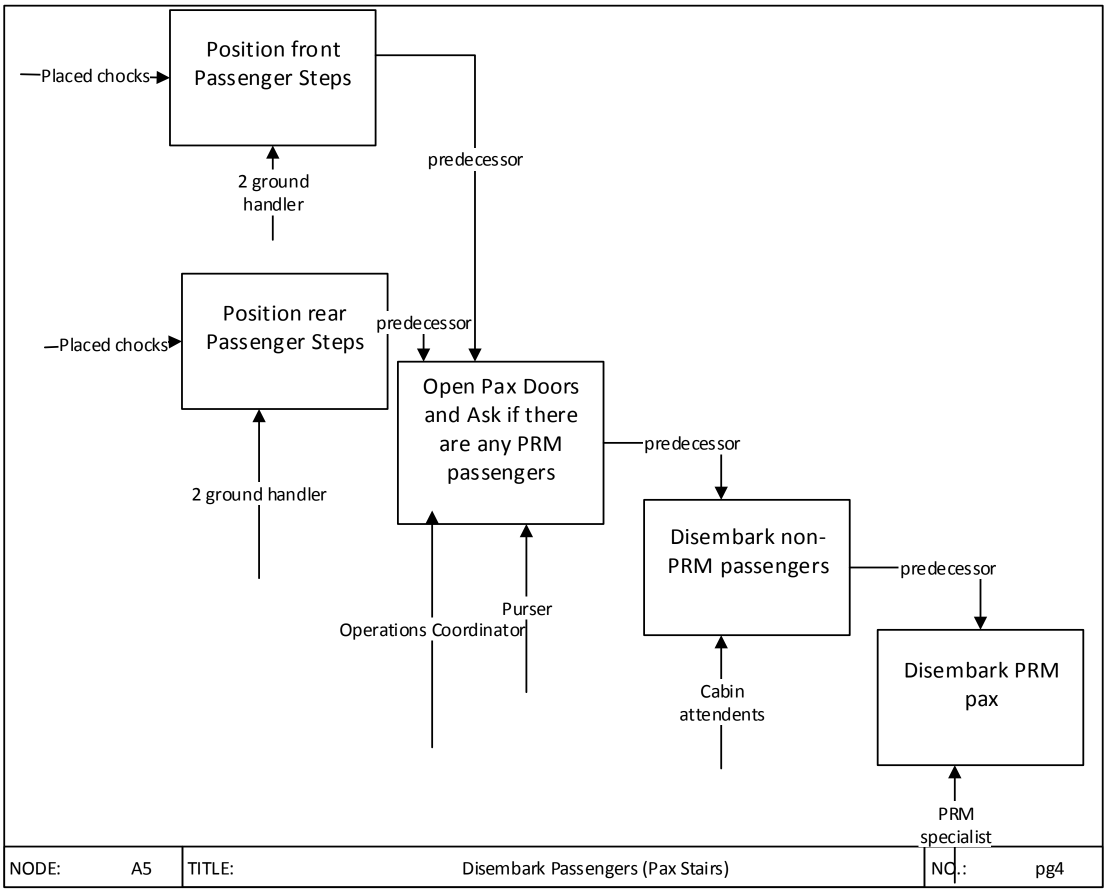
Int-Int					
No	**Process**	**Options**	**# Staff**	**Start Time**	**End Time**
1	Stop Enginees				
2	Place chocks				
3	Connect GPU	stairs/ airbridge			
4	Routine Manintenance				
5	Lavatory				
6	Water Service				
7	Parking Position	Place Pax Steps			
		Place Airbridge			
8	Open Cargo doors	*forward			
		aft			
9	Place baggage loader(conveyor)	*forward			
		aft			
10	Open Pax doors	front door			
		rear door			
11	Disembark Pax	front door			
		rear door			
12	Unload Baggage/ Cargo	*front baggage			
		front cargo*no2			
		back			
13	Fuelling	w/o fire brigade			
14		with fire brigade			
15	Security Check				
16	Cleaning	Tidy-up			
		Cleaning agents			
17	Catering	Catering Truck			
		Hand loading			
18	Cabin Crew change				
19x	Check-in finished				
20	Load Baggage	forward cargo			
		forward baggage			
		aft baggage			
21	PAX Boarding	Boarding Pass Check			
22		Transportation			
23		Boarding			
24	Remove conveyors	Forward Rear			
25	Close cargo doors	Forward Rear			
26	Head count				
27	Close pax doors				
28	Hand in the Load Sheet and get Captain's approval				
29	Remove stairs/ airbridge				
30	Start Enginees				
31	Push-back connection				

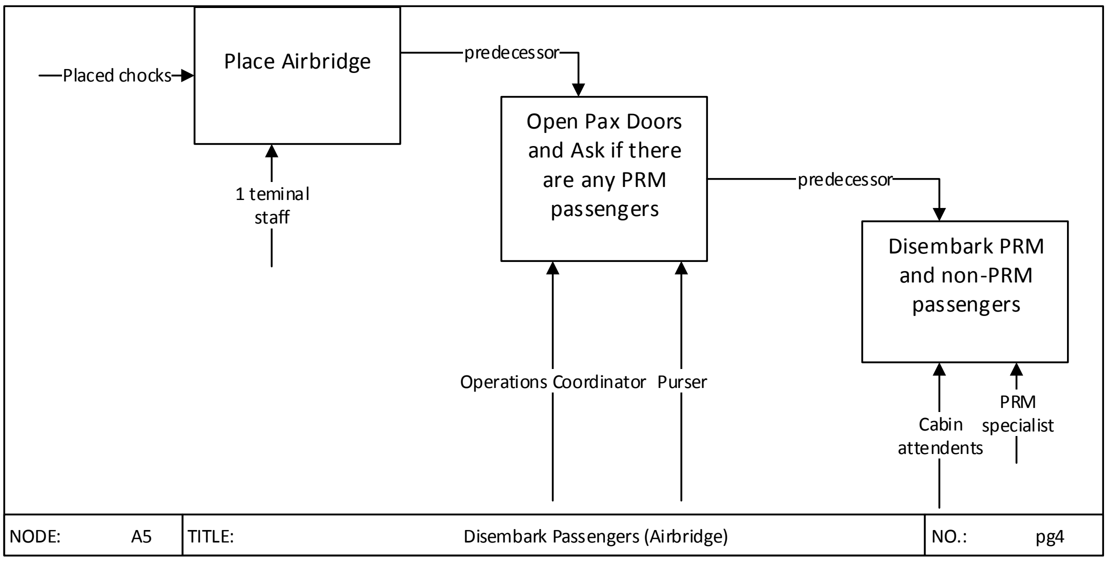
Appendix C – Sub-Processes of the Process Maps

First of all sub-process of Handle Initial Arrival Operations (NODE: A1) is presented below:

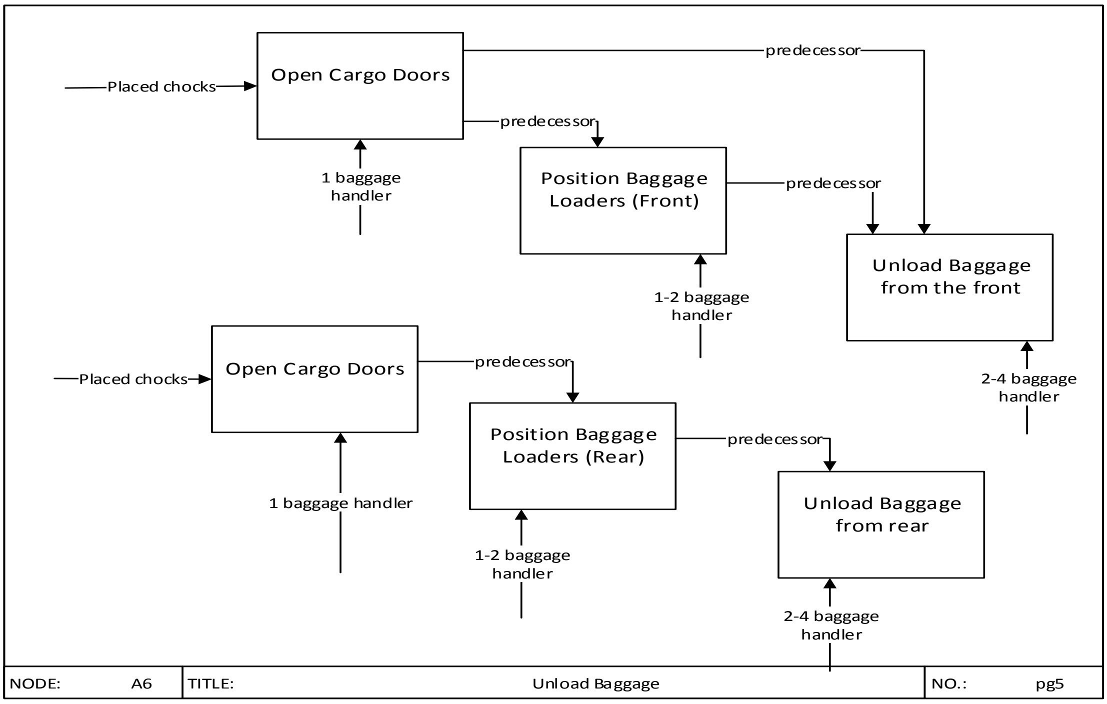


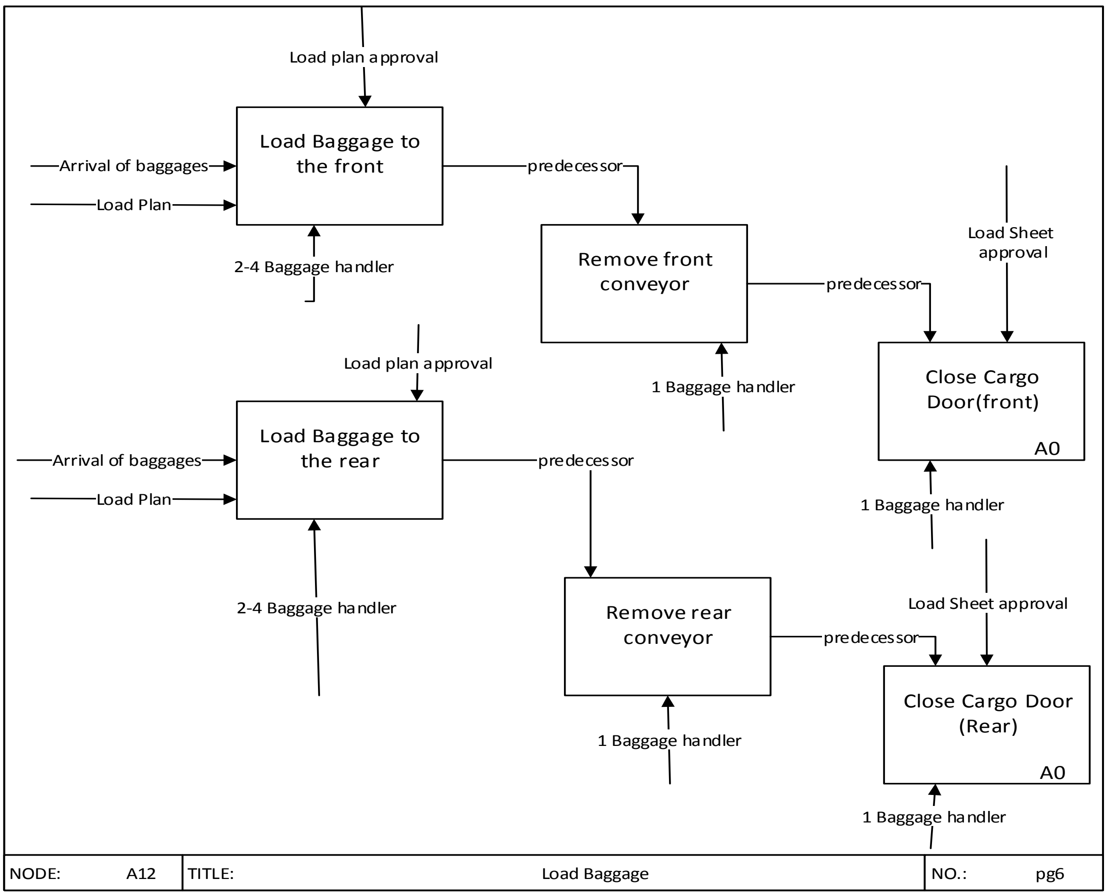
Sub-processes of NODE: A5 (Disembark Pax) are showed in below where passenger stairs are used for disembarking and where airbridge is being used for disembarking.



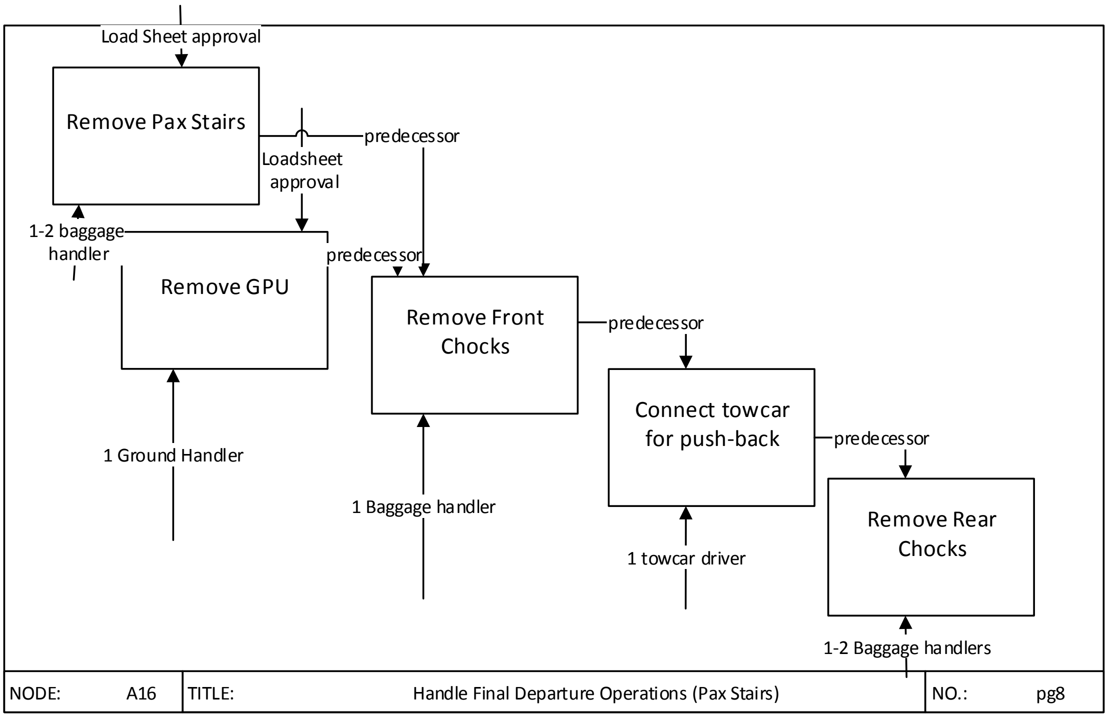


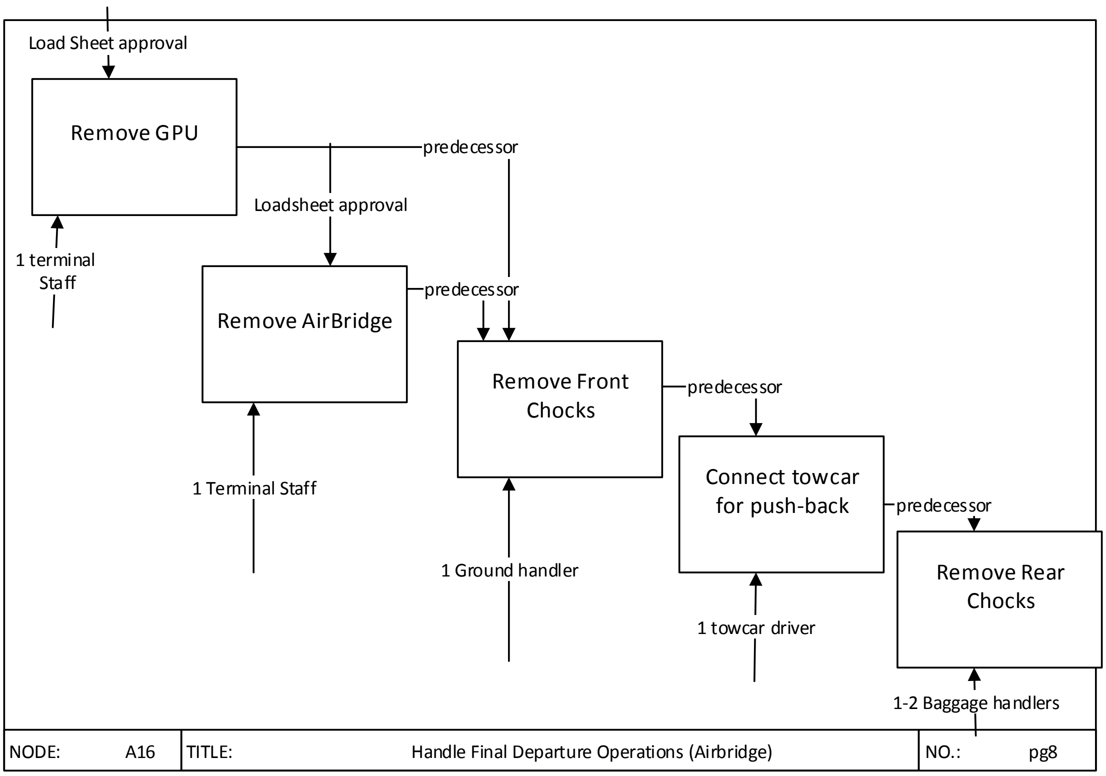
Baggage unloading (A6) and baggage loading (A12) is broken down into the sub-processes showed below respectively.





Finally, sub-process of NODE: A16 is presented for boarding using passenger stairs and airbridge below respectively.





Appendix D – Precedence Matrix

Below matrix states the precedence relationship of activities for Domestic-Domestic flight type with the usage of passenger stairs. According to this matrix, j precedes k. For the operations where the intersection value 1 means there exist a precedence relationship between two operations.

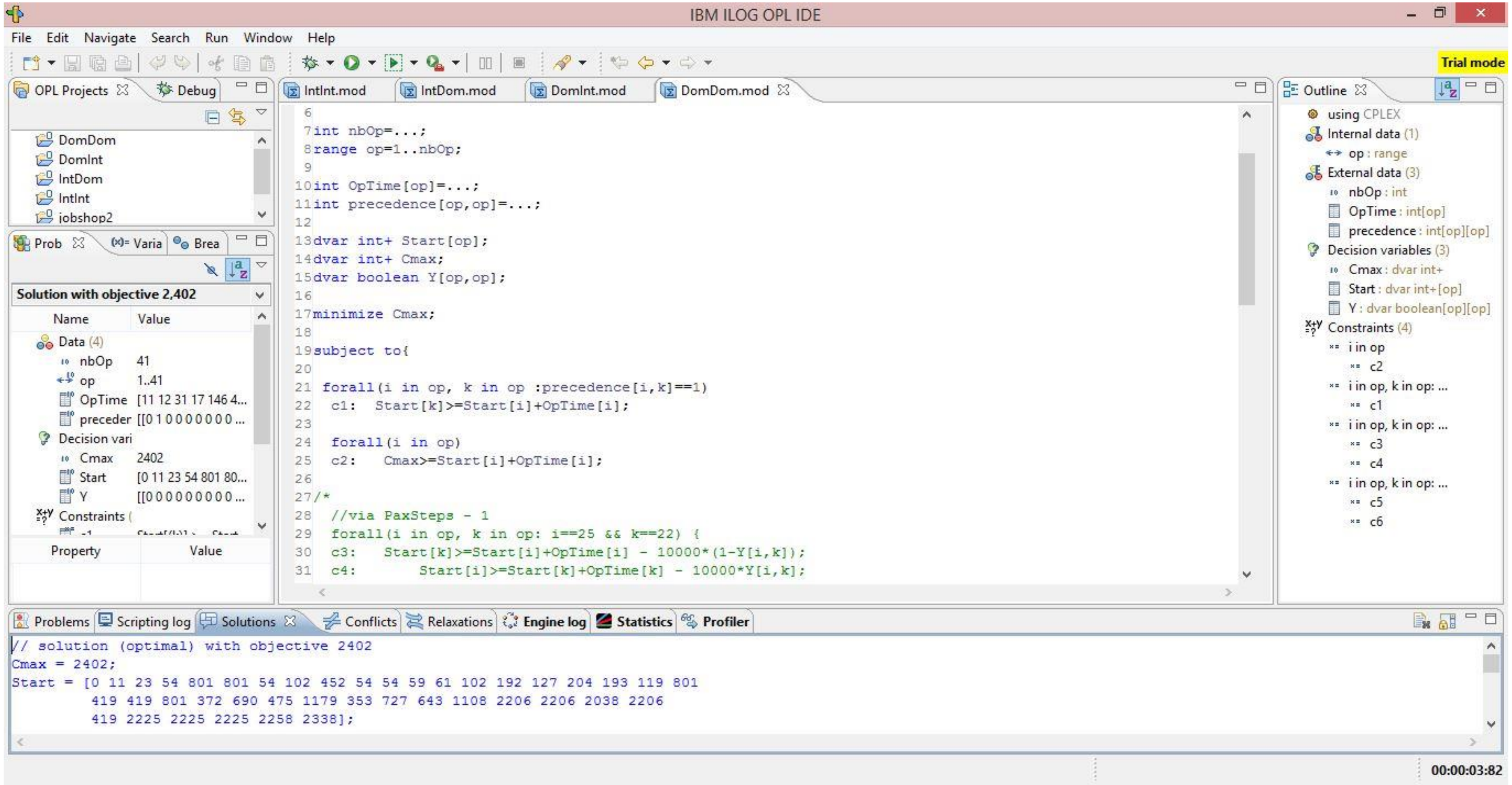
		k																																								
Turnaround Operations	j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	23	25	26	27	28	30	31	32	33	34	35	36	38	39	40	41	42	43	44	45
Place front chocks	1		1																																							
Stop Enginees	2			1																																						
Place rear chocks	3				1			1	1		1	1																														
Connect GPU	4																1	1																								
Lavatory	5																																		1							
Water Service	6																																		1							
Place Pax Steps(front)	7								1						1																											
Place Pax Steps(back)	8															1																										
Place Airbridge	9																										1															
Open cargo doors(forward)	10												1																													
Open cargo doors(aft)	11													1																												
Place baggage loader(forwarc	12																		1																							
Place baggage loader(aft)	13																			1																						
Open front pax doors and ask	14																1																									
Open rear pax door	15																	1																								
Disembark pax from the front	16																				1	1	1	1			1										1					
Disembark pax from the rear (	17																				1	1	1		1												1					
Unload baggage/cargo from t	18																												1													
Unload baggage/cargo from t	19																													1												
Fuelling without fire brigade	20																										1															
Security Check	22																									1																
Tidy-Up	23																									1																
Catering from the front door	25																										1								1							
Catering from the rear door	26																																		1							
Cabin Crew Change	27					1	1														1							1														
Disembark wheelchair pax via	28																				1																					
Pax Boarding	30																																		1							
Load Baggage to forward	31																														1				1							
Load Baggage to Aft	32																															1			1							
Remove forward conveyors	33																																1								1	
Remove rear conveyors	34																																	1							1	
Close forward cargo door	35																																								1	
Close rear cargo doors	36																																								1	
Hand in the Load Sheet and ge	38																																1	1		1						
Close pax doors	39																																					1	1	1		
Remove stairs	40									1																																
Remove airbridge	41																																								1	
Remove GPU	42																																								1	
Remove front chocks	43																																								1	
Push-back connection	44																																									1
Remove rear chocks	45																																									

Appendix E – Duration of Operations for Different Flight Types

		Dom-Dom				Int-Dom				Dom-Int				Int-Int			
Operations\ Dureations	No	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps
Place front chocks	1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Stop Enginees	2	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Place rear chocks	3	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
Connect GPU	4	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Lavatory	5	146	146	146	146	146	146	146	146	146	146	146	146	146	146	146	146
Water Service	6	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477	477
Place Pax Steps(front)	7	48	0	48	48	48	0	48	48	48	0	48	48	48	0	48	48
Place Pax Steps(back)	8	90	0	90	90	90	0	90	90	90	0	90	90	90	0	90	90
Place Airbridge	9	0	48	48	48	0	48	48	48	0	48	48	48	0	48	48	48
Open cargo doors(forward)	10	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Open cargo doors(aft)	11	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Place baggage loader(forward)	12	134	134	134	134	134	134	134	134	134	134	134	134	134	134	134	134
Place baggage loader(aft)	13	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
Open front pax doors and ask purser if there are any PRM pax	14	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Open rear pax door	15	12	0	12	12	12	0	12	12	12	0	12	12	12	0	12	12
Disembark pax from the front door	16	292	473	292	473	292	473	292	473	292	473	292	473	292	473	292	473
Disembark pax from the rear door	17	168	0	168	0	168	0	168	0	168	0	168	0	168	0	168	0
Unload baggage/cargo from the forward door	18	160	160	160	160	218	218	218	218	48	48	48	48	344	344	344	344
Unload baggage/cargo from the aft door	19	608	608	608	608	570	570	570	570	374	374	374	374	445	445	445	445
Fuelling without fire brigade	20	378	378	378	378	501	501	501	501	632	632	632	632	439	439	439	439
Fuelling with fire brigade	21	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420	420
Security Check	22	233	233	233	233	233	233	233	233	233	233	233	233	233	233	233	233
Tidy-Up	23	271	271	271	271	0	0	0	0	0	0	0	0	271	271	271	271
Cleaning	24	0	0	0	0	1223	1223	1223	1223	1223	1223	1223	1223	0	0	0	0
Catering from the front door	25	109	109	109	109	681	681	681	681	302	302	302	302	318	318	318	318
Catering from the rear door	26	89	89	89	89	120	120	120	120	505	505	505	505	310	310	310	310
Cabin Crew Change	27	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111	111
Disembark wheelchair pax via truck	28	326	0	326	0	326	0	326	0	326	0	326	0	326	0	326	0
Board Wheelchair Pax via truck	29	326	0	0	326	326	0	0	326	326	0	0	326	326	0	0	326
Pax Boarding	30	859	1009	859	1009	859	1009	859	1009	859	1009	859	1009	859	1009	859	1009
Load Baggage to forward	31	290	290	290	290	0	0	0	0	162	162	162	162	60	60	60	60
Load Baggage to Aft	32	381	381	381	381	1770	1770	1770	1770	784	784	784	784	849	849	849	849

Operations\ Dureations	No	Dom-Dom				Int-Dom				Dom-Int				Int-Int			
		Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps	Pax Steps	Air Bridge	Steps+Bridge	Bridge+Steps
Remove forward conveyors	33	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Remove rear conveyors	34	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
Close forward cargo door	35	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Close rear cargo doors	36	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Head Count	37	110	0	0	110	110	0	0	110	110	0	0	110	110	0	0	110
Hand in the Load Sheet and get Captain's approval	38	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168	168
Close pax doors	39	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Remove stairs	40	33	0	33	33	33	0	33	33	33	0	33	33	33	0	33	33
Remove airbridge	41	0	33	33	33	0	33	33	33	0	33	33	33	0	33	33	33
Remove GPU	42	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Remove front chocks	43	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Push-back connection	44	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Remove rear chocks	45	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64

Appendix F – Mathematical Modelling Tool (IBM-ILOG-OPL)



Appendix G – Details of Result (Schedules)

- Results for domestic-domestic flight type

Domestic-Domestic							
Operations	No	Pax Steps duration	**Start Time**	Operations	No	Air Bridge duration	**Start Time**
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	801	Lavatory	5	146.00	982
Water Service	6	477.00	801	Water Service	6	477.00	982
Place Pax Steps(front)	7	48.00	54	Place Airbridge	9	48.00	54
Place Pax Steps(back)	8	90.00	102	Open cargo doors(forward)	10	5.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(aft)	11	7.00	54
Open cargo doors(aft)	11	7.00	54	Place baggage loader(forward)	12	134.00	59
Place baggage loader(forward)	12	134.00	59	Place baggage loader(aft)	13	58.00	61
Place baggage loader(aft)	13	58.00	61	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Disembark pax from the front door	16	473.00	127
Open rear pax door	15	12.00	192	Unload baggage/cargo from the forward door	18	160.00	193
Disembark pax from the front door	16	292.00	127	Unload baggage/cargo from the aft door	19	608.00	119
Disembark pax from the rear door	17	168.00	204	Fuelling without fire brigade	20	378.00	982
Unload baggage/cargo from the forward door	18	160.00	193	Security Check	22	233.00	600
Unload baggage/cargo from the aft door	19	608.00	119	Tidy-Up	23	271.00	600
Fuelling without fire brigade	20	378.00	801	Catering from the front door	25	109.00	600
Security Check	22	233.00	419	Catering from the	26	89.00	71

Domestic-Domestic

Operations	No	Pax Steps duration	**Start Time**
Tidy-Up	23	271.00	419
Catering from the front door	25	109.00	801
Catering from the rear door	26	89.00	372
Cabin Crew Change	27	111.00	690
Disembark wheelchair pax via truck	28	326.00	475
Board Wheelchair Pax via truck	29	326.00	1179
Pax Boarding	30	859.00	1505
Load Baggage to forward	31	290.00	353
Load Baggage to Aft	32	381.00	727
Remove forward conveyors	33	75.00	643
Remove rear conveyors	34	44.00	1108
Close forward cargo door	35	8.00	2642
Close rear cargo doors	36	20.00	2642
Head Count	37	110.00	2364
Hand in the Load Sheet and get Captain's approval	38	168.00	2474
Close pax doors	39	19.00	2642
Remove stairs	40	33.00	2661
Remove GPU	42	28.00	2661
Remove front chocks	43	16.00	2661
Push-back connection	44	80.00	2694
Remove rear chocks	45	64.00	2774
Total	**41**		**2838**

Operations	No	Air Bridge duration	**Start Time**
rear door			
Cabin Crew Change	27	111.00	871
Pax Boarding	30	1009.00	1360
Load Baggage to forward	31	290.00	353
Load Baggage to Aft	32	381.00	727
Remove forward conveyors	33	75.00	643
Remove rear conveyors	34	44.00	1108
Close forward cargo door	35	8.00	2537
Close rear cargo doors	36	20.00	2537
Hand in the Load Sheet and get Captain's approval	38	168.00	2369
Close pax doors	39	19.00	2537
Remove airbridge	41	33.00	2556
Remove GPU	42	28.00	2556
Remove front chocks	43	16.00	2556
Push-back connection	44	80.00	2589
Remove rear chocks	45	64.00	2669
Total	**35**		**2733**

Domestic-Domestic							
Operations	No	Steps+Bridge duration	**Start Time**	Operations	No	Bridge+ Steps duration	**Start Time**
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	801	Lavatory	5	146.00	982
Water Service	6	477.00	801	Water Service	6	477.00	982
Place Pax Steps(front)	7	48.00	54	Place Pax Steps(front)	7	48.00	633
Place Pax Steps(back)	8	90.00	102	Place Pax Steps(back)	8	90.00	54
Place Airbridge	9	48.00	452	Place Airbridge	9	48.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(forward)	10	5.00	54
Open cargo doors(aft)	11	7.00	54	Open cargo doors(aft)	11	7.00	54
Place baggage loader(forward)	12	134.00	59	Place baggage loader(forward)	12	134.00	59
Place baggage loader(aft)	13	58.00	61	Place baggage loader(aft)	13	58.00	61
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open rear pax door	15	12.00	192	Open rear pax door	15	12.00	144
Disembark pax from the front door	16	292.00	127	Disembark pax from the front door	16	473.00	127
Disembark pax from the rear door	17	168.00	204	Unload baggage/cargo from the forward door	18	160.00	193
Unload baggage/cargo from the forward door	18	160.00	193	Unload baggage/cargo from the aft door	19	608.00	119
Unload baggage/cargo from the aft door	19	608.00	119	Fuelling without fire brigade	20	378.00	982

Domestic-Domestic							
Operations	No	Steps+Bridge duration	**Start Time**	Operations	No	Bridge+ Steps duration	**Start Time**
Fuelling without fire brigade	20	378.00	801	Security Check	22	233.00	600
Security Check	22	233.00	419	Tidy-Up	23	271.00	600
Tidy-Up	23	271.00	419	Catering from the front door	25	109.00	600
Catering from the front door	25	109.00	801	Catering from the rear door	26	89.00	71
Catering from the rear door	26	89.00	372	Cabin Crew Change	27	111.00	871
Cabin Crew Change	27	111.00	690	Board Wheelchair Pax via truck	29	326.00	1360
Disembark wheelchair pax via truck	28	326.00	475	Pax Boarding	30	1009.00	1686
Pax Boarding	30	859.00	1179	Load Baggage to forward	31	290.00	353
Load Baggage to forward	31	290.00	353	Load Baggage to Aft	32	381.00	727
Load Baggage to Aft	32	381.00	727	Remove forward conveyors	33	75.00	643
Remove forward conveyors	33	75.00	643	Remove rear conveyors	34	44.00	1108
Remove rear conveyors	34	44.00	1108	Close forward cargo door	35	8.00	2973
Close forward cargo door	35	8.00	2206	Close rear cargo doors	36	20.00	2973
Close rear cargo doors	36	20.00	2206	Head Count	37	110.00	2695
Hand in the Load Sheet and get Captain's approval	38	168.00	2038	Hand in the Load Sheet and get Captain's approval	38	168.00	2805
Close pax doors	39	19.00	2206	Close pax doors	39	19.00	2973
Remove stairs	40	33.00	419	Remove stairs	40	33.00	2992
Remove airbridge	41	33.00	2225	Remove airbridge	41	33.00	600
Remove GPU	42	28.00	2225	Remove GPU	42	28.00	2992
Remove front chocks	43	16.00	2225	Remove front chocks	43	16.00	2992
Push-back connection	44	80.00	2258	Push-back connection	44	80.00	3025
Remove rear chocks	45	64.00	2338	Remove rear chocks	45	64.00	3105
Total	**41**		**2402**	**Total**	**41**		**3169**

- Results for international-international flight type

International-International							
Operations	No	Pax Steps	**Start Time**	Operations	No	Air Bridge	**Start Time**
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	801	Lavatory	5	146.00	982
Water Service	6	477.00	801	Water Service	6	477.00	982
Place Pax Steps(front)	7	48.00	54	Place Airbridge	9	48.00	54
Place Pax Steps(back)	8	90.00	102	Open cargo doors(forward)	10	5.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(aft)	11	7.00	54
Open cargo doors(aft)	11	7.00	54	Place baggage loader(forward)	12	134.00	59
Place baggage loader(forward)	12	134.00	59	Place baggage loader(aft)	13	58.00	61
Place baggage loader(aft)	13	58.00	61	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Disembark pax from the front door	16	473.00	127
Open rear pax door	15	12.00	192	Unload baggage/cargo from the forward door	18	344.00	193
Disembark pax from the front door	16	292.00	127	Unload baggage/cargo from the aft door	19	445.00	119
Disembark pax from the rear door	17	168.00	204	Fuelling without fire brigade	20	439.00	982
Unload baggage/cargo from the forward door	18	344.00	193	Security Check	22	233.00	600
Unload baggage/cargo from the aft door	19	445.00	119	Tidy-Up	23	271.00	600
Fuelling without fire brigade	20	439.00	801	Catering from the front door	25	318.00	600
Security Check	22	233.00	419	Catering from the rear door	26	310.00	71
Tidy-Up	23	271.00	419	Cabin Crew Change	27	111.00	871

International-International							
Operations	No	Pax Steps	**Start Time**	Operations	No	Air Bridge	**Start Time**
Catering from the front door	25	318.00	745	Pax Boarding	30	1009.00	1421
Catering from the rear door	26	310.00	372	Load Baggage to forward	31	60.00	537
Cabin Crew Change	27	111.00	690	Load Baggage to Aft	32	849.00	564
Disembark wheelchair pax via truck	28	326.00	419	Remove forward conveyors	33	75.00	597
Board Wheelchair Pax via truck	29	326.00	1240	Remove rear conveyors	34	44.00	1413
Pax Boarding	30	859.00	1566	Close forward cargo door	35	8.00	2598
Load Baggage to forward	31	60.00	537	Close rear cargo doors	36	20.00	2598
Load Baggage to Aft	32	849.00	564	Hand in the Load Sheet and get Captain's approval	38	168.00	2430
Remove forward conveyors	33	75.00	597	Close pax doors	39	19.00	2598
Remove rear conveyors	34	44.00	1413	Remove airbridge	41	33.00	2617
Close forward cargo door	35	8.00	2703	Remove GPU	42	28.00	2617
Close rear cargo doors	36	20.00	2703	Remove front chocks	43	16.00	2617
Head Count	37	110.00	2425	Push-back connection	44	80.00	2650
Hand in the Load Sheet and get Captain's approval	38	168.00	2535	Remove rear chocks	45	64.00	2730
Close pax doors	39	19.00	2703	**Total**	**35**	0	**2794**
Remove stairs	40	33.00	2722				
Remove GPU	42	28.00	2722				
Remove front chocks	43	16.00	2722				
Push-back connection	44	80.00	2755				
Remove rear chocks	45	64.00	2835				
Total	**41**	0	**2899**				

International-International							
Operations	No	Steps+Bridge	**Start Time**	Operations	No	Bridge+Steps	**Start Time**
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	801	Lavatory	5	146.00	982
Water Service	6	477.00	801	Water Service	6	477.00	982
Place Pax Steps(front)	7	48.00	54	Place Pax Steps(front)	7	48.00	633
Place Pax Steps(back)	8	90.00	102	Place Pax Steps(back)	8	90.00	54
Place Airbridge	9	48.00	452	Place Airbridge	9	48.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(forward)	10	5.00	54
Open cargo doors(aft)	11	7.00	54	Open cargo doors(aft)	11	7.00	54
Place baggage loader(forward)	12	134.00	59	Place baggage loader(forward)	12	134.00	59
Place baggage loader(aft)	13	58.00	61	Place baggage loader(aft)	13	58.00	61
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open rear pax door	15	12.00	192	Open rear pax door	15	12.00	144
Disembark pax from the front door	16	292.00	127	Disembark pax from the front door	16	473.00	127
Disembark pax from the rear door	17	168.00	204	Unload baggage/cargo from the forward door	18	344.00	193
Unload baggage/cargo from the forward door	18	344.00	193	Unload baggage/cargo from the aft door	19	445.00	119
Unload baggage/cargo from the aft door	19	445.00	119	Fuelling without fire brigade	20	439.00	982
Fuelling without fire brigade	20	439.00	801	Security Check	22	233.00	600

International-International							
Operations	No	Steps+Bridge	**Start Time**	Operations	No	Bridge+Steps	**Start Time**
Security Check	22	233.00	419	Tidy-Up	23	271.00	600
Tidy-Up	23	271.00	419	Catering from the front door	25	318.00	600
Catering from the front door	25	318.00	745	Catering from the rear door	26	310.00	71
Catering from the rear door	26	310.00	372	Cabin Crew Change	27	111.00	871
Cabin Crew Change	27	111.00	690	Board Wheelchair Pax via truck	29	326.00	1421
Disembark wheelchair pax via truck	28	326.00	419	Pax Boarding	30	######	1747
Pax Boarding	30	859.00	1240	Load Baggage to forward	31	60.00	537
Load Baggage to forward	31	60.00	537	Load Baggage to Aft	32	849.00	564
Load Baggage to Aft	32	849.00	564	Remove forward conveyors	33	75.00	597
Remove forward conveyors	33	75.00	597	Remove rear conveyors	34	44.00	1413
Remove rear conveyors	34	44.00	1413	Close forward cargo door	35	8.00	3034
Close forward cargo door	35	8.00	2267	Close rear cargo doors	36	20.00	3034
Close rear cargo doors	36	20.00	2267	Head Count	37	110.00	2756
Hand in the Load Sheet and get Captain's approval	38	168.00	2099	Hand in the Load Sheet and get Captain's approval	38	168.00	2866
Close pax doors	39	19.00	2267	Close pax doors	39	19.00	3034
Remove stairs	40	33.00	419	Remove stairs	40	33.00	3053
Remove airbridge	41	33.00	2286	Remove airbridge	41	33.00	600
Remove GPU	42	28.00	2286	Remove GPU	42	28.00	3053
Remove front chocks	43	16.00	2286	Remove front chocks	43	16.00	3053
Push-back connection	44	80.00	2319	Push-back connection	44	80.00	3086
Remove rear chocks	45	64.00	2399	Remove rear chocks	45	64.00	3166
Total	**41**		**2463**	**Total**	**41**		**3230**

- Results for Domestic-International flight type

Domestic-International							
Operations	No	Pax Steps	Start Time	Operations	No	Air Bridge	Start Time
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	763	Lavatory	5	146.00	944
Water Service	6	477.00	763	Water Service	6	477.00	944
Place Pax Steps(front)	7	48.00	54	Place Airbridge	9	48.00	54
Place Pax Steps(back)	8	90.00	102	Open cargo doors(forward)	10	5.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(aft)	11	7.00	54
Open cargo doors(aft)	11	7.00	54	Place baggage loader(forward)	12	134.00	59
Place baggage loader(forward)	12	134.00	59	Place baggage loader(aft)	13	58.00	61
Place baggage loader(aft)	13	58.00	61	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Disembark pax from the front door	16	473.00	127
Open rear pax door	15	12.00	192	Unload baggage/cargo from the forward door	18	48.00	193
Disembark pax from the front door	16	292.00	127	Unload baggage/cargo from the aft door	19	374.00	119
Disembark pax from the rear door	17	168.00	204	Fuelling without fire brigade	20	632.00	944
Unload baggage/cargo from the forward door	18	48.00	193	Security Check	22	233.00	600
Unload baggage/cargo from the aft door	19	374.00	119	Cleaning	24	1223.00	600
Fuelling without fire brigade	20	632.00	1336	Catering from the front door	25	302.00	600
Security Check	22	233.00	419	Catering from the rear door	26	505.00	71
Cleaning	24	1223.00	745	Cabin Crew Change	27	111.00	833

Domestic-International

Operations	No	Pax Steps	Start Time
Catering from the front door	25	302.00	745
Catering from the rear door	26	505.00	1047
Cabin Crew Change	27	111.00	652
Disembark wheelchair pax via truck	28	326.00	419
Board Wheelchair Pax via truck	29	326.00	1968
Pax Boarding	30	859.00	2294
Load Baggage to forward	31	162.00	241
Load Baggage to Aft	32	784.00	493
Remove forward conveyors	33	75.00	403
Remove rear conveyors	34	44.00	1277
Close forward cargo door	35	8.00	3431
Close rear cargo doors	36	20.00	3431
Head Count	37	110.00	3153
Hand in the Load Sheet and get Captain's approval	38	168.00	3263
Close pax doors	39	19.00	3431
Remove stairs	40	33.00	3450
Remove GPU	42	28.00	3450
Remove front chocks	43	16.00	3450
Push-back connection	44	80.00	3483
Remove rear chocks	45	64.00	3563
Number of Operations	**41**		**3627**

Operations	No	Air Bridge	Start Time
Pax Boarding	30	1009.00	1823
Load Baggage to forward	31	162.00	241
Load Baggage to Aft	32	784.00	493
Remove forward conveyors	33	75.00	403
Remove rear conveyors	34	44.00	1277
Close forward cargo door	35	8.00	3000
Close rear cargo doors	36	20.00	3000
Hand in the Load Sheet and get Captain's approval	38	168.00	2832
Close pax doors	39	19.00	3000
Remove airbridge	41	33.00	3019
Remove GPU	42	28.00	3019
Remove front chocks	43	16.00	3019
Push-back connection	44	80.00	3052
Remove rear chocks	45	64.00	3132
Number of Operations	**35**		**3196**

Domestic-International							
Operations	No	Steps+Bridge	Start Time	Operations	No	Bridge +Steps	Start Time
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	763	Lavatory	5	146.00	944
Water Service	6	477.00	763	Water Service	6	477.00	944
Place Pax Steps(front)	7	48.00	54	Place Pax Steps(front)	7	48.00	633
Place Pax Steps(back)	8	90.00	102	Place Pax Steps(back)	8	90.00	54
Place Airbridge	9	48.00	452	Place Airbridge	9	48.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(forward)	10	5.00	54
Open cargo doors(aft)	11	7.00	54	Open cargo doors(aft)	11	7.00	54
Place baggage loader(forward)	12	134.00	59	Place baggage loader(forward)	12	134.00	59
Place baggage loader(aft)	13	58.00	61	Place baggage loader(aft)	13	58.00	61
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open rear pax door	15	12.00	192	Open rear pax door	15	12.00	144
Disembark pax from the front door	16	292.00	127	Disembark pax from the front door	16	473.00	127
Disembark pax from the rear door	17	168.00	204	Unload baggage/cargo from the forward door	18	48.00	193
Unload baggage/cargo from the forward door	18	48.00	193	Unload baggage/cargo from the aft door	19	374.00	119
Unload baggage/cargo from the aft door	19	374.00	119	Fuelling without fire brigade	20	632.00	944
Fuelling without fire brigade	20	632.00	1336	Security Check	22	233.00	600
Security Check	22	233.00	419	Cleaning	24	1223.00	600

Domestic-International							
Operations	No	Steps+Bridge	Start Time	Operations	No	Bridge +Steps	Start Time
Cleaning	24	1223.00	745	Catering from the front door	25	302.00	600
Catering from the front door	25	302.00	1666	Catering from the rear door	26	505.00	71
Catering from the rear door	26	505.00	1968	Cabin Crew Change	27	111.00	833
Cabin Crew Change	27	111.00	652	Board Wheelchair Pax via truck	29	326.00	1823
Disembark wheelchair pax via truck	28	326.00	419	Pax Boarding	30	1009.00	2149
Pax Boarding	30	859.00	1968	Load Baggage to forward	31	162.00	241
Load Baggage to forward	31	162.00	241	Load Baggage to Aft	32	784.00	493
Load Baggage to Aft	32	784.00	493	Remove forward conveyors	33	75.00	403
Remove forward conveyors	33	75.00	403	Remove rear conveyors	34	44.00	1277
Remove rear conveyors	34	44.00	1277	Close forward cargo door	35	8.00	3436
Close forward cargo door	35	8.00	2995	Close rear cargo doors	36	20.00	3436
Close rear cargo doors	36	20.00	2995	Head Count	37	110.00	3158
Hand in the Load Sheet and get Captain's approval	38	168.00	2827	Hand in the Load Sheet and get Captain's approval	38	168.00	3268
Close pax doors	39	19.00	2995	Close pax doors	39	19.00	3436
Remove stairs	40	33.00	419	Remove stairs	40	33.00	3455
Remove airbridge	41	33.00	3014	Remove airbridge	41	33.00	600
Remove GPU	42	28.00	3014	Remove GPU	42	28.00	3455
Remove front chocks	43	16.00	3014	Remove front chocks	43	16.00	3455
Push-back connection	44	80.00	3047	Push-back connection	44	80.00	3488
Remove rear chocks	45	64.00	3127	Remove rear chocks	45	64.00	3568
Number of Operations	**41**		**3191**	**Number of Operations**	**41**		**3632**

- Results for International-Domestic flight type

International-Domestic							
Operations	No	Pax Steps	**Start Time**	Operations	No	Air Bridge	**Start Time**
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	763	Lavatory	5	146.00	944
Water Service	6	477.00	763	Water Service	6	477.00	944
Place Pax Steps(front)	7	48.00	54	Place Airbridge	9	48.00	54
Place Pax Steps(back)	8	90.00	102	Open cargo doors(forward)	10	5.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(aft)	11	7.00	54
Open cargo doors(aft)	11	7.00	54	Place baggage loader(forward)	12	134.00	59
Place baggage loader(forward)	12	134.00	59	Place baggage loader(aft)	13	58.00	61
Place baggage loader(aft)	13	58.00	61	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Disembark pax from the front door	16	473.00	127
Open rear pax door	15	12.00	192	Unload baggage/cargo from the forward door	18	218.00	193
Disembark pax from the front door	16	292.00	127	Unload baggage/cargo from the aft door	19	570.00	119
Disembark pax from the rear door	17	168.00	204	Fuelling without fire brigade	20	501.00	944
Unload baggage/cargo from the forward door	18	218.00	193	Security Check	22	233.00	600
Unload baggage/cargo from the aft door	19	570.00	119	Cleaning	24	1223.00	600
Fuelling without fire brigade	20	501.00	1467	Catering from the front door	25	681.00	600
Security Check	22	233.00	419	Catering from the rear door	26	120.00	71

International-Domestic

Operations	No	Pax Steps	**Start Time**
Cleaning	24	1223.00	745
Catering from the front door	25	681.00	745
Catering from the rear door	26	120.00	372
Cabin Crew Change	27	111.00	652
Disembark wheelchair pax via truck	28	326.00	419
Board Wheelchair Pax via truck	29	326.00	1968
Pax Boarding	30	859.00	2294
Load Baggage to forward	31	0.00	411
Load Baggage to Aft	32	1770.00	689
Remove forward conveyors	33	75.00	411
Remove rear conveyors	34	44.00	2459
Close forward cargo door	35	8.00	3431
Close rear cargo doors	36	20.00	3431
Head Count	37	110.00	3153
Hand in the Load Sheet and get Captain's approval	38	168.00	3263
Close pax doors	39	19.00	3431
Remove stairs	40	33.00	3450
Remove GPU	42	28.00	3450
Remove front chocks	43	16.00	3450
Push-back connection	44	80	3483
Remove rear chocks	45	64	3563
Number of Operations	**41**		**3627**

Operations	No	Air Bridge	**Start Time**
Cabin Crew Change	27	111.00	833
Pax Boarding	30	1009.00	1823
Load Baggage to forward	31	0.00	411
Load Baggage to Aft	32	1770.00	689
Remove forward conveyors	33	75.00	411
Remove rear conveyors	34	44.00	2459
Close forward cargo door	35	8.00	3000
Close rear cargo doors	36	20.00	3000
Hand in the Load Sheet and get Captain's approval	38	168.00	2832
Close pax doors	39	19.00	3000
Remove airbridge	41	33.00	3019
Remove GPU	42	28.00	3019
Remove front chocks	43	16.00	3019
Push-back connection	44	80	3052
Remove rear chocks	45	64	3132
Number of Operations	**35**		**3196**

International-Domestic							
Operations	No	Steps+ Bridge	**Start Time**	Operations	No	Bridge+ Steps	**Start Time**
Place front chocks	1	11.00	0	Place front chocks	1	11.00	0
Stop Enginees	2	12.00	11	Stop Enginees	2	12.00	11
Place rear chocks	3	31.00	23	Place rear chocks	3	31.00	23
Connect GPU	4	17.00	54	Connect GPU	4	17.00	54
Lavatory	5	146.00	763	Lavatory	5	146.00	944
Water Service	6	477.00	763	Water Service	6	477.00	944
Place Pax Steps(front)	7	48.00	54	Place Pax Steps(front)	7	48.00	633
Place Pax Steps(back)	8	90.00	102	Place Pax Steps(back)	8	90.00	54
Place Airbridge	9	48.00	452	Place Airbridge	9	48.00	54
Open cargo doors(forward)	10	5.00	54	Open cargo doors(forward)	10	5.00	54
Open cargo doors(aft)	11	7.00	54	Open cargo doors(aft)	11	7.00	54
Place baggage loader(forward)	12	134.00	59	Place baggage loader(forward)	12	134.00	59
Place baggage loader(aft)	13	58.00	61	Place baggage loader(aft)	13	58.00	61
Open front pax doors and ask purser if there are any PRM pax	14	25.00	102	Open front pax doors and ask purser if there are any PRM pax	14	25.00	102
Open rear pax door	15	12.00	192	Open rear pax door	15	12.00	144
Disembark pax from the front door	16	292.00	127	Disembark pax from the front door	16	473.00	127
Disembark pax from the rear door	17	168.00	204	Unload baggage/cargo from the forward door	18	218.00	193
Unload baggage/cargo from the forward door	18	218.00	193	Unload baggage/cargo from the aft door	19	570.00	119
Unload baggage/cargo from the aft door	19	570.00	119	Fuelling without fire brigade	20	501.00	944
Fuelling without fire brigade	20	501.00	1467	Security Check	22	233.00	600
Security Check	22	233.00	419	Cleaning	24	1223.0 0	600

International-Domestic							
Operations	No	Steps+ Bridge	**Start Time**	Operations	No	Bridge+ Steps	**Start Time**
Cleaning	24	1223.00	745	Catering from the front door	25	681.00	600
Catering from the front door	25	681.00	745	Catering from the rear door	26	120.00	71
Catering from the rear door	26	120.00	372	Cabin Crew Change	27	111.00	833
Cabin Crew Change	27	111.00	652	Board Wheelchair Pax via truck	29	326.00	1823
Disembark wheelchair pax via truck	28	326.00	419	Pax Boarding	30	1009.00	2149
Pax Boarding	30	859.00	1968	Load Baggage to forward	31	0.00	411
Load Baggage to forward	31	0.00	411	Load Baggage to Aft	32	1770.00	689
Load Baggage to Aft	32	1770.00	689	Remove forward conveyors	33	75.00	411
Remove forward conveyors	33	75.00	411	Remove rear conveyors	34	44.00	2459
Remove rear conveyors	34	44.00	2459	Close forward cargo door	35	8.00	3436
Close forward cargo door	35	8.00	2995	Close rear cargo doors	36	20.00	3436
Close rear cargo doors	36	20.00	2995	Head Count	37	110.00	3158
Hand in the Load Sheet and get Captain's approval	38	168.00	2827	Hand in the Load Sheet and get Captain's approval	38	168.00	3268
Close pax doors	39	19.00	2995	Close pax doors	39	19.00	3436
Remove stairs	40	33.00	419	Remove stairs	40	33.00	3455
Remove airbridge	41	33.00	3014	Remove airbridge	41	33.00	600
Remove GPU	42	28.00	3014	Remove GPU	42	28.00	3455
Remove front chocks	43	16.00	3014	Remove front chocks	43	16.00	3455
Push-back connection	44	80	3047	Push-back connection	44	80	3488
Remove rear chocks	45	64	3127	Remove rear chocks	45	64	3568
Number of Operations	**41**		**3191**	**Number of Operations**	**41**		**3632**