공학석사학위논문

Flight Rescheduling of Airline under Ground Delay Program Considering Delay Propagation in Multi-Airport

다중공항에서 지상 지연 프로그램 발생시 지연전파를 고려한 항공사의 운항 일정 변경

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Abstract

Flight Rescheduling of Airline under Ground Delay Program Considering Delay Propagation in Multi-Airport

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The purpose of this thesis is to reschedule flights from the airline company's perspective to correspond to the airport's changed capacity in the event of a ground delay program (GDP), one of the important means of controlling air traffic. We considered delay propagation not only within the same airport but within other airports by extending the setup to include several airports rather than a single airport. We also included realistic costs from planned schedules of the aircraft and crew. When a GDP is issued, airlines are given a short time to reschedule flights in time for the changed slot. Each airport has its own capacity, especially the airport acceptance rate (AAR), which is a capacity that can accommodate incoming aircraft. We formulated a mixed-integer linear programming (MILP) model to reschedule flights. To handle the uncertainty of future scheduling, two versions of the MILP model may be applied. With scenarios in which the AAR changes again, an optimal model that obtains a minimizing total relevant cost in each scenario solution and a stochastic model solution that obtains a minimizing expectation of the total relevant cost of all scenarios are presented and compared.

Keywords: Mixed-integer linear programming; Stochastic programming; Rescheduling; Ground delay program; Air traffic control;

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Contents

Abstract i

Contents ii

List of Tables iv

List of Figures v

Chapter 1 Introduction 1

Chapter 2 Literature review 3

Chapter 3 Mathematical model 5

3.0 Model description 5

3.1 Multi-airport Scenario-based Optimal Rescheduling Problem 10

3.2 Multi-airport Scenario-based Stochastic Rescheduling Problem 13

Chapter 4 Computational experiments 14

4.0 Settings 14

4.1 Experiment 1 16

4.2 Experiment 2 18

4.3 Experiment 3 19

4.4 Experiment 4 20

Chapter 5 Conclusions 25

Appendix 27

Appendix A. 27

Appendix B. 28

Bibliography 31

국문초록 35

List of Tables

Table 4.1 Parameters 15

Table 4.2 TRC($) of MSOR, SSOR, TRC+penalty fee($) of SSOR and its gap with MSOR 17

Table 4.3 TRC($) and computation times(sec.) by the number of scenarios for MSOR and MSSR 18

Table 4.4 TRC($), the number of cancelled flights, buffer time violations, and crew misconnections for each scenario 19

Table 4.5 Solutions and delay time(min.) of MSOR and MSSR for cancel cost=120$, 160$, 200$, 400$ when delay cost=7$ ... 24

List of Figures

Figure 1.1 Flights of each airline planned in timeslots 1

Figure 1.2 Example of possible scenarios at the point when the GDP first occurred 3

Figure 3.1 Eight cases for the multi-airport problem....................... 6

Figure 3.2 Timeslot assignment difference at arrival airport between single airport model and multi-airport model.................. 7

Figure 3.3 Example of crew misconnection with minimum turnaround time of crew 9

Figure 3.4 Examples of buffer time with minimum turnaround time of aircraft.. 9

Figure 4.1 Rescheduling using the RBS method 15

Figure 4.2 Example of different timeslot assignment between SSOR and MSOR.. 17

Figure 4.3 Total delay time(min.) by delay cost per cancel cost 21

Figure 4.4 The number of cancelled flights by delay cost per cancel cost 21

Figure 4.5 TRC($) by scenario per (buffer time,urgent cost) 22

Figure 4.6 The number of buffer time violations by scenario per (buffer time, urgent cost) 23

Chapter 1. Introduction

Air transportation is increasingly an important part of the overall transportation. However, due to the characteristic of the aviation industry, it is necessary to plan flights carefully and control the flow of air traffic, compared to other means of transportation. Each airport has its own capacity, especially the airport acceptance rate (AAR), which is a capacity that can accommodate incoming aircraft considering runways, gates, and baggage lines. This rate is determined by the air route traffic control center, which calculates the time interval between aircraft arriving and entering the airport, which is called the timeslot when the aircraft can enter. Airlines or other aircraft operators are assigned timeslots they want in advance, according to the International Air Transport Association (IATA) conference by the South Korea Airport Schedule Office (KASO), so that flights can be organized at the corresponding time, as shown in Figure 1.1. Vertical bars represent the time slot.

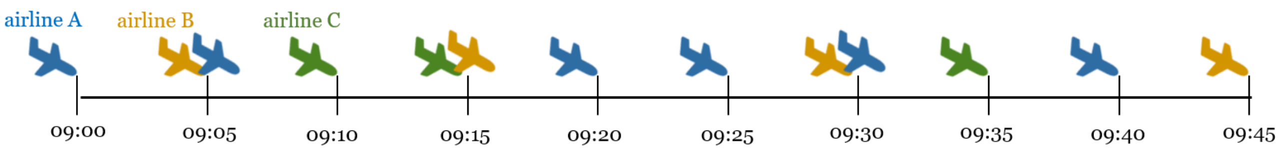

Figure 1.1: Flights of each airline planned in timeslots

Nonetheless, the AAR may decrease when weather conditions deteriorate or when there is a need to clear the airway as neighboring countries conduct military training. The ground delay program (GDP) is one of the important ways to control air traffic in this case. When the AAR decreases because of some reason, reducing the number of incoming aircrafts per hour changes the time of slots accordingly, and adjusting already departed flights to the changed timeslot causes waiting in the air. This has many disadvantages, such as fuel consumption, airway congestion, and safety problems. Therefore, having flights wait at the origin airport on the ground before departing is desirable, which is called the GDP. When the GDP is issued, flights planned to arrive at the GDP airport must be readjusted, and the most standard method used is the "first-scheduled, first-served rule" which receives slots in the order originally planned. As centralized framework, the GDP decision maker can control schedule for the overall efficiency of the airport, addressing such issues as minimizing total delay time or promising equity among interested parties. Various rules and heuristics to help make decisions have been studied in this centralized framework. Even so, Yan et al. [31] summarized the advantages that can be acquired when considering the operational aspects of the airline, not the central authority. When the GDP is implemented, airlines are given a short time to readjust their flights. An et al. [1] introduced several methods, such as compression and timeslot substitution, in which airlines cooperate with one another. However, it would be relatively inexpensive and easy to make adjustments within a given airline's own flights before working with other airlines. As airlines should consider various factors and costs, such as an aircraft being used on multiple flights or crews having to be transferred to another flight, it is challenging to decide which flight to delay or cancel and how much to delay them. In addition, most existing studies solved the problem within a single airport. This leads to infeasibility in reality, because delay from other airports or other flights could be ignored. Even though some single airport rescheduling models consider delay propagation, they consider only how the delay of arrival at the target airport could extend to departures in the same airport.

In this thesis, a mathematical model is established to reschedule flights from multi-airport from the perspective of airline when the GDP is issued. The benefit of solving a problem in such a multi-airport setup is that it can consider the delay propagation twice. As short-distance flights such as domestic flights have increased due to improved accessibility of aviation, one aircraft could be used on two flights a day in many airlines. Therefore, considering that only an arrival delay is propagated as one departure delay cannot guarantee the feasibility when used in reality. Not only the delay in the same airport but the delay from other airports should be examined.

Also, we consider costs and circumstances of airlines to be more practicable. Such costs examined in this paper include not only the cost of flight delays and cancellations but also the cost of failure to transfer the crews and the cost of not guaranteeing a buffer time between connected flights. From the airline's point of view, when a schedule has to be adjusted according to the initial GDP issued, it might be worth considering the possibility that the GDP is not a permanent method. Figure 1.2 shows that the GDP could be withdrawn or issued once or even more times later in a given time frame, and shows that the flow rate will change accordingly. Rescheduling according to information available only in the present, without preparation for possible changes, is costly. Therefore, a scenario-based method is used to minimize the expected cost by creating scenarios with the currently updated information about the GDP.

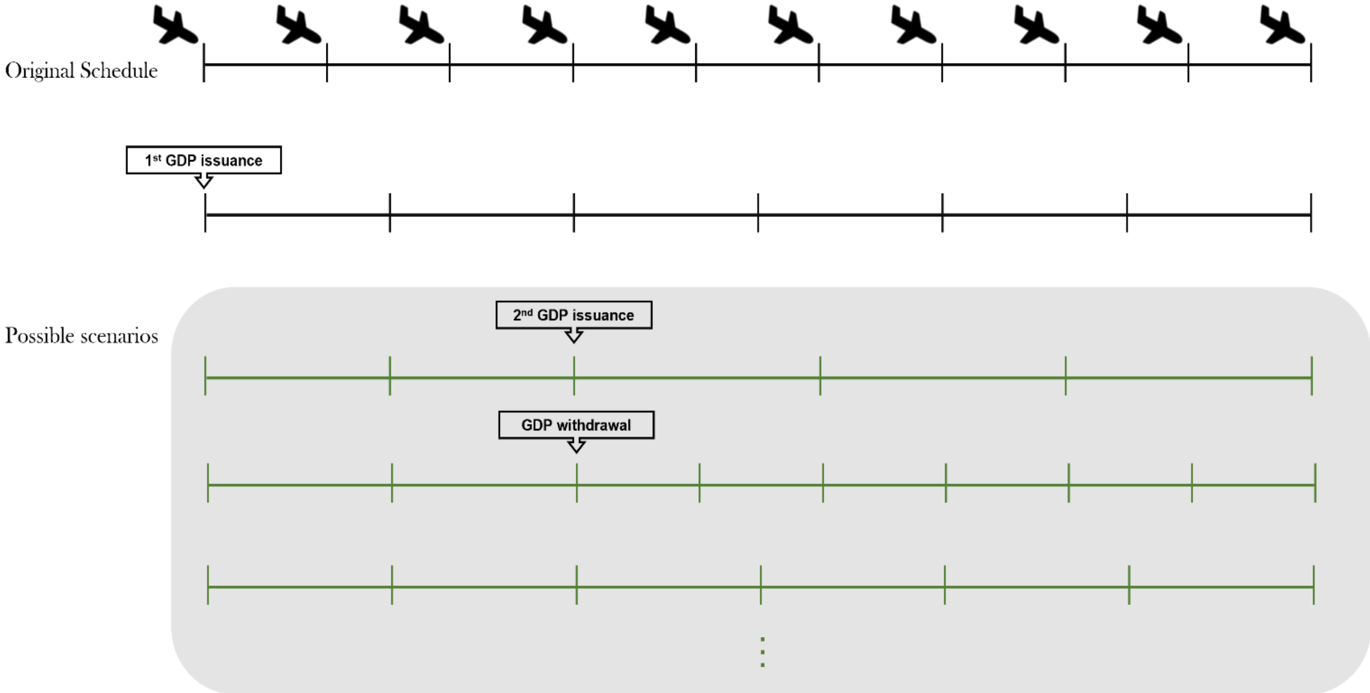

Figure 1.2: Example of possible scenarios at the point when the GDP first occurred

The remainder of this thesis is organized as follows: In chapter 2, we review studies related to the GDP and recovery from disruptions in airports. Then, we describe problems in detail, along with mathematical formulations of our model, in chapter 3. Chapter 4 details the computations of four experiments showing the validation of models in various aspects. Results and analyses of experiments are suggested in the same chapter. Last, conclusions are presented in chapter 5.

Chapter 2. Literature Review

A static and deterministic Ground Holding Program(GHP) problem in a single airport was introduced first in Odoni [20]. Terrab [24] and Richetta [21] also suggested a deterministic single airport GHP in formulations of capacitated network formulation and minimum cost assignment formulation. With uncertainty in the

AAR, stochastic versions of the GHP were followed. Then dynamic stochastic versions in a single airport were studied by Richetta et al. [20] and Mukherjee et al. [17]. Luo et al. [16] studied schedule disruption by the GDP in a single airport. They presented an algorithm to minimize the total delay time solved within the polynomial time in a specific case. Jarrah et al. [13] dealt with the shortage of flights or aircraft, permitting swapping aircraft among flights. Also, Cox et al. [10] reviewed six optimization models of a single airport's GHP and compared strengths and weaknesses of each previously studied model. Subsequently, they proposed a model to optimize a plan of GHP using Markov decision process [9]. Various studies have been conducted to ensure robustness in scheduling problems. Ball et al. [3] offered a stochastic GHP that determined the number of timeslots. Terrab et al. [23] experimented with the GHP in a deterministic case and a stochastic case, and suggested insights comparing a mathematical model with dynamic programming and a heuristic. Ng et al. [19] tried to handle uncertainty using the min-max regret approach. Liu et al. [15] involved scenarios with possible capacities. To reschedule more realistically, [15] used a scenario tree method that dynamically solves the problem by updating a probability of scenarios as realizing information.

Filar et al. [11] summarized papers on the recovery of airlines and airports from disruption. They categorized objectives of tactical air traffic management into three types —fuel consumption, late arrival and departure, and noise nuisance— and stated the GHP is one of important workarounds. Vranas et al. [25] and Bertsimas et al. [6] proposed integer programming models to assign ground-holding delays optimally in a network of airports, which included transmission of delays between successive flights with coupling constraints. Vranas et al. [26] then extended the multi-airport problem to dynamic version. A stochastic version was briefly introduced as well. They used discrete time horizon where decisions were made about how many unit periods to wait. Brunette et al. [7] presented a static and deterministic MILP model in a multi-airport setup, but only included single connections, not multiple connections. Additionally, they proposed heuristic.

Because computation time is too long, heuristics were also introduced. Navazio et al. [18] suggested a heuristic based on the limited resource critical path method, which obtained suboptimal result. Navazio et al. [18] also considered multi-connections which means there are several preceding flights of passengers who have to take a subsequent flight. Several heuristics applied the priority rule using the marginal cost in scheduling [2, 18, 23].

Most studies focused on a centralized framework. Yan [31] assessed the benefits of decentralized framework that reflects airline-driven objectives. Yan et al. [32] solved a problem with an objective function to maximize the profit of an airline, taking into account delay and cancellation simultaneously, but not crew members or passengers. Bard et al. [5] solved a timeslot reallocation problem with dynamic programming from the airlines' point of view. Brunner [8] proposed a mathematical model to minimize airline driven costs including passenger and crew connections. Woo et al. [28] presented a model to help airlines reschedule when the GDP was issued. Considering the transfer of aircraft and crew, they attempted to be more realistic, as the longer the delay time, the larger the cost. In addition, in order to prepare for uncertain situations from a present perspective, stochastic programming was solved and its value was evaluated. Wu et al. [30] introduced and analyzed delay propagation that sequential flights can have. However, as with other studies dealing with delay propagation, only propagation at the same airport was described. Kafle et al. [14] investigated a role of a buffer time in delay propagation. Slack time, explained in [18] and [27], is a delay absorption tool. This is slightly different from the concept of buffer time in this thesis. To the best of our knowledge, there has been no study yet undertaken to reschedule in more than one airport simultaneously when the GDP is issued, taking into account not only the delay propagation of one airport but also the propagation from another airport. Furthermore, buffer time is introduced in this thesis to lend insight to operations, in addition to considering airline's limited assets. For robustness, not only the optimal version but also the stochastic programming method is adopted.

Chapter 3. Mathematical model

3.0 Model Description

We assume that departure capacity for outbound flights is infinite, while arrival capacity, the airline acceptance rate (AAR), for inbound flights is finite. This assumption will not go too far in reality. Therefore, a specific timeslot is not required for departures. Moreover, one aircraft can be used for dup to two flights for short-distance flights such as domestic flights. For instance, an aircraft often makes a round trip between Gimpo and Jeju in one day. When the GDP is issued, timeslots also will be changed, in keeping with the changed flow rate of the airport. Airlines have time to readjust their flights relatively autonomously among the timeslots assigned to themselves.

In an airport set, some airports may be unaffected by the GDP, and several airports may be under the influence of the GDP. If there are multiple airports with the GDP implemented at once, there are eight situations to consider per airport. Let there be airport $m1, m2, m3 \in M \text{ which is an airport set under GDP}$ and $v \notin M$. For inbound $flight\ i$ in airport $m1$, there are four cases, as follows: (1) aircraft departing at v arrives and finishes its flight on that day; (2) aircraft departing at $m2$ arrives and finishes its flight on that day; (3) aircraft departing at v arrives and leaves for another airport on that day; (4) aircraft departing at $m2$ arrives and leaves for another airport on that day. For outbound $flight\ j$ in airport $m1$, there are four cases, as follows: (5) aircraft leaves for v; (6) aircraft arriving from $m2$ leaves for v; (7) aircraft leaves for $m2$; (8) aircraft arriving from $m2$ leaves for $m3$. Each case is depicted in Figure 3.1. Yet, we did not have to include case (5), because we assume departure capacity in the airport is infinite. Previous papers related to the GDP with delay propagation usually deal with cases (1) and (3).

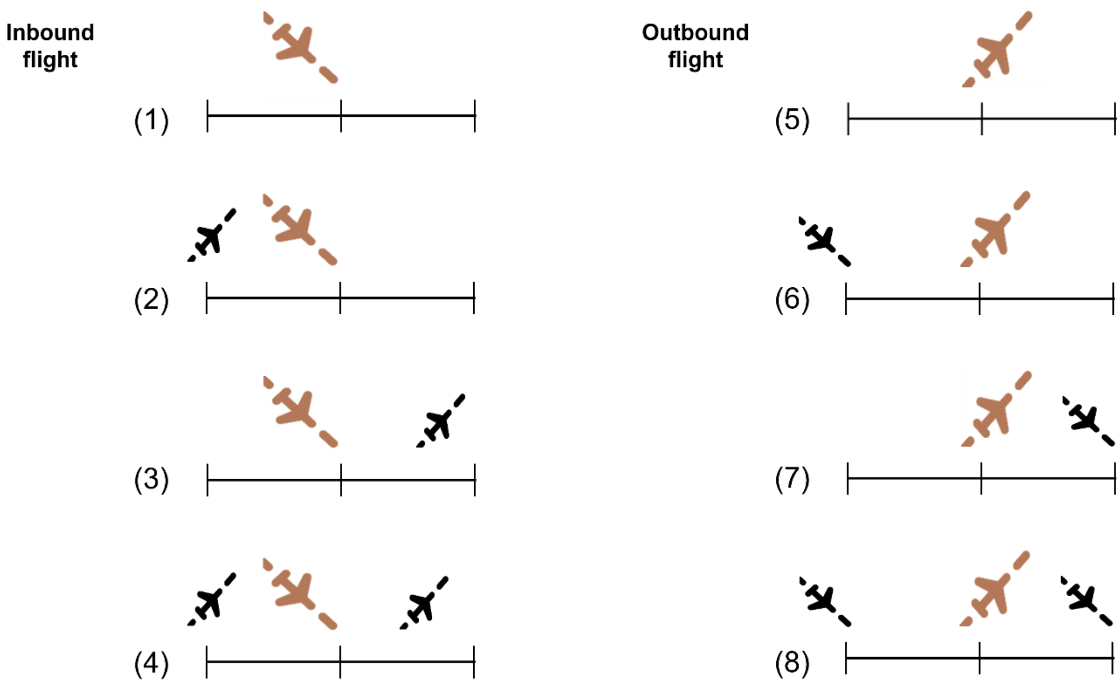

Figure 3.1: Eight cases for the multi-airport problem

When rescheduling flights in the GDP, it is intrinsic that the origin airport of each flight is in a normal state; thus, there is no delay except delaying on purpose for the GDP to arrive in accordance with the timeslot assigned. However, if multiple airports are rescheduled at the same time, departure airports as well as the arrival airports of flights can be considered. For example, in case (8), timeslots will be assigned for inbound $flight\ i$ at airport $m3$ which is under the GDP. However, after arriving late of the preceding $flight\ i$ because of the GDP in airport $m1$, it departs as $flight\ j$ as late as the propagated delay time. Airport $m3$ has to allocate timeslot for $flight\ j$ to reflect this delay in departure. This is illustrated in Figure 3.2.

If the actual arrival time is later than the pre-allocated timeslot, such as timeslot A, the existing plan is infeasible, so it is necessary to readjust or cancel the flight at the time when the departure delay occurs. Furthermore, If the actual arrival time of the flight is much faster than the conservative pre-allocated timeslot such as timeslot B because the exact delay information is not known, airborne delay inevitably occurs. Either way, resulting costs are high for an airline. Yet, in the multi-airport model, timeslots are assigned in consideration of cases in which departing aircrafts already absorb delay from preceding flights and leave late.

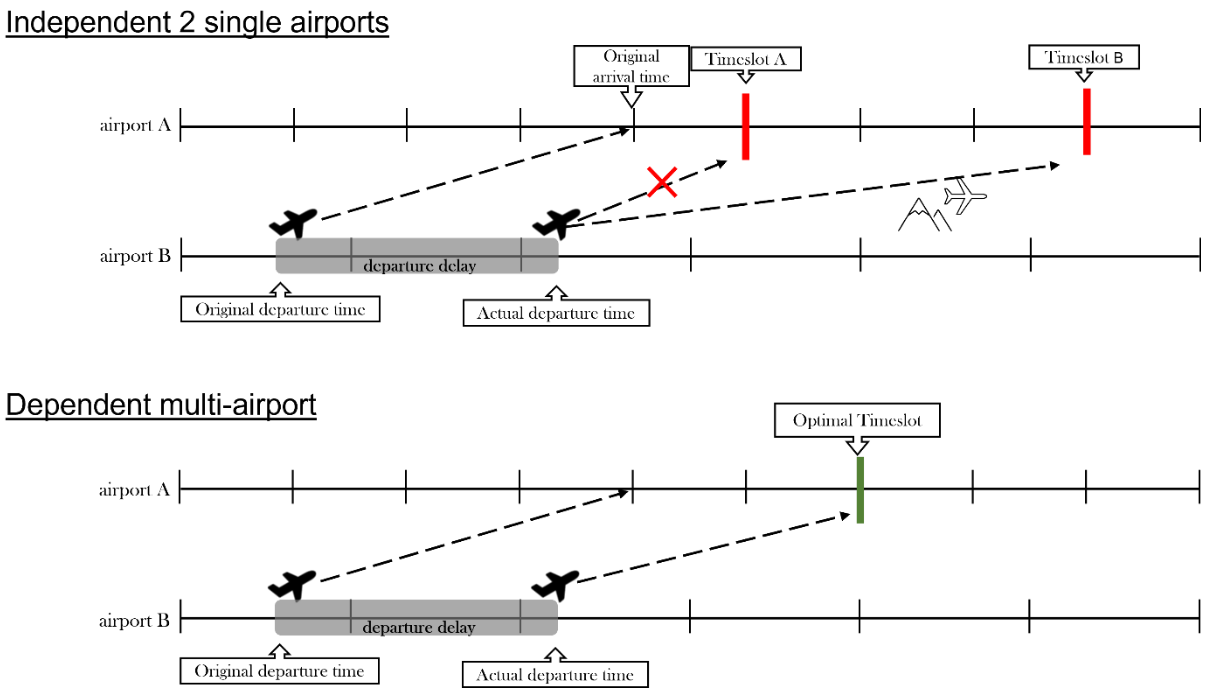

Figure 3.2: Timeslot assignment difference at arrival airport between single airport model and multi-airport model

Aircraft connections are classified in two categories. If the preceding $flight\ i$ arrives and is connected to depart as succeeding $flight\ j$ from the same airport, it is expressed as L1(i,j). If $flight\ j$ departs and arrives as *flight n* at another airport in the airport set, it is expressed as L2(j,n). In this case, since it is one journey, they have the same flight name, but different indexes were used in this thesis for the convenience of experiments. If a crew is connected to depart for succeeding $flight\ j$ from the same airport after getting off the preceding $flight\ i$, express it as R(i,j). For L1, if $flight\ i$ is cancelled j is also cancelled. In the case of L2(j,n), if one of the two is cancelled, the other is cancelled as well. Whether $flight\ i\ or\ j$ is cancelled in R(i,j), a crew fails to transfer. Each flight has a maximum allowed delay time.

From the perspective of central authority, which determines the GDP, the airport is viewed as a whole, so it will try to minimize total delay time, balance stakeholders, or put passenger convenience first. On the other hand, from the perspective of an airline, minimizing total delay time is important, how much it affects the crew's work schedule and whether aircrafts are used for other flights is also important. If an aircraft is used again after the arrival, the departure time will be planned at appropriate intervals, regarding taxi-in/out times, aircraft maintenance and cabin cleaning from the arrival time of the aircraft. The time for these essentials is called the minimum turnaround time of the aircraft, and it must be observed even if the departure is delayed, because it is necessary for the operation of the aircraft no matter what. On the other hand, crews also have minimum turnaround time if crews are connected to another flight. However, contrary to the minimum turnaround time of aircraft which an arrival delay will unconditionally be propagated as a departure delay to ensure as long as it is not cancelled, it may be more cost-effective for crews not to transfer rather than for departure delays to result to ensure minimum turnaround time of crew. In this thesis, there is one more time interval that is different from the minimum turnaround time. Let's say that the airline has set a time for safer operations, which is called buffer time. This, specifically, is the buffering time for risk-averse operations, because there are many kinds of planned time buffers, such as passenger boarding time and assigned gate availability time. If this time is not guaranteed, an urgent operation condition will need to be addressed, such as ensuring additional staff are on hand or changing the order of the assigned gate. Such exigencies will need to be addressed to avoid causing departure delays as much as possible. Buffer time violations result in failures to ensure specific time within the planned time interval because of an arrival delay of preceding flights before the given aircraft leaves for the next flight. As a result, there will be an additional cost for urgent operations caused by original plan breakdowns, even if such plan breakdowns are not immediately propagated to departure delays of successive flights. Figure 3.3 and Figure 3.4 describe the situation related to the minimum crew turnaround, aircraft turnaround time, and buffer time.

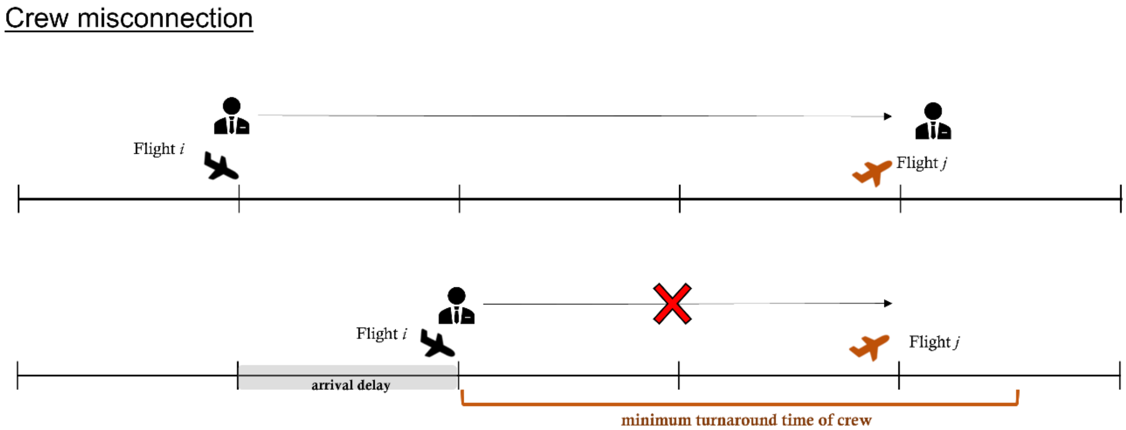

Figure 3.3: Example of crew misconnection with minimum turnaround time of crew

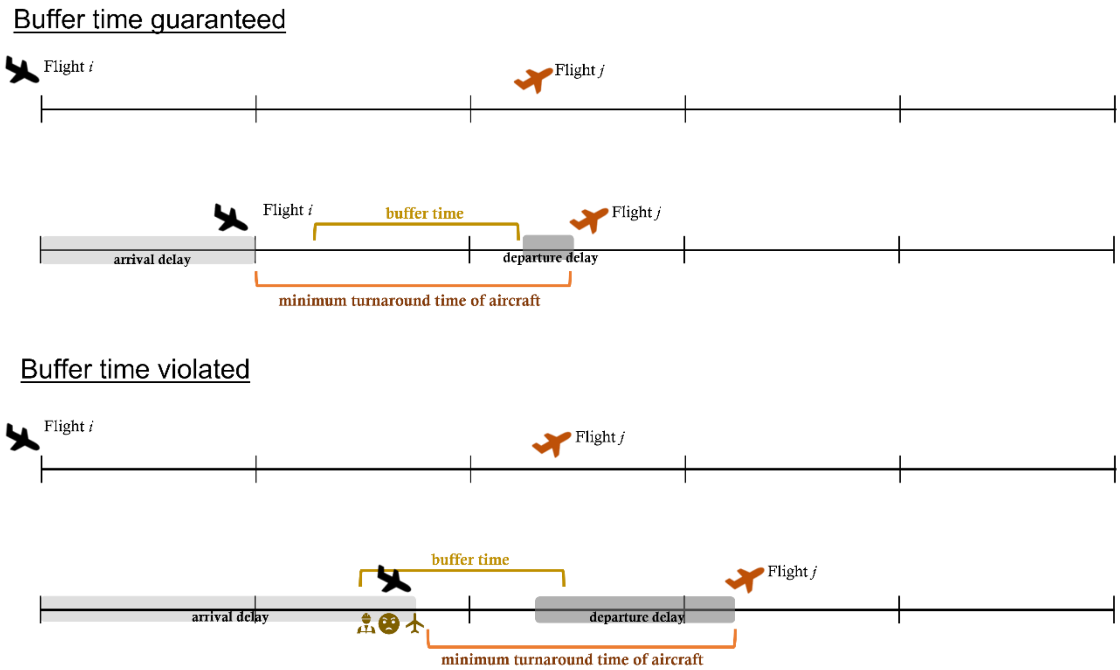

Figure 3.4: Examples of buffer time with minimum turnaround time of aircraft

Assuming that the GDP has been issued, all inbound flights have to be assigned timeslots or cancelled. How much to delay is determined by which timeslot the flight will be assigned. It is also important to consider the possibility that the AAR will change again at some point in the future. For example, factors that caused GDP can disappear, and the AAR may be restored to its original rate, or it may get worse with the AAR decreased again. Otherwise, nothing will change from the first

GDP. Flights should be readjusted to meet the GDP, but it is not known what will happen again later. Therefore, to prepare for this, the model is verified by creating scenarios that may occur with base scenario, in which the GDP has been executed once. We assumed that the probability of each scenario occurring is uniform. That is, 1/(the number of scenarios). There are two ways to use scenarios. First, one may obtain the optimal value for each scenario in advance, proceed according to the base scenario, and when the scenario is actually realized, change the schedule again according to the solution obtained before. Second, one may obtain the value that optimizes the expected value of all scenarios. No matter what scenario is realized, it may be not the optimal for that scenario, but it can proceed without further changes.

3.1 Multi-airport Scenario-based Optimal Rescheduling Problem

The mathematical model is formulated as mixed-integer linear programming. Here are notations used in model. First, we showed optimal version. We named this Multi-airport Scenario-based Optimal Rescheduling (MSOR) Problem.

Sets

S: set of scenarios

M: set of airports

I : set of flights

I^a: set of inbound flights (I^a_m: subset of I^a whose arrival airport is m)

I^d: set of outbound fligts (I^b_m : subset of I^a whose departure airport is m)

$k \in K_m$: set of timeslots of airport $m \in M$

Parameters

arr_i: scheduled arivial time of flight i

dep_j: scheduled departure time of flight j

$\delta^{aircraft}$: minimum turnaround time of aircraft to connecting flight

δ^{crew} : minimum turnaround time of crew to connecting flight

Δ : buffer time for preventing urgent situation of aircraft

fly_{ij} : flying time of flight between origin and destination

R_{ij} : 1, if a crew is connecting between flight i and j; otherwise 0

$L1_{ij}$: 1, if the same aircraft of arriving flight i is used for the departing flight j ; otherwise 0

$L2_{jn}$: 1, if the same aircraft of departing flight j arrives on a flight n at another airport; otherwise 0

t_{ms}^{k} : time of timeslot k when flights can arrive at airport m in scenario s

τ_{ms}: time when a subsequent GDP will be issued at airport m in scenario s

$\overline{d_i^a}$: maximum allowed arrival delay of flight i

$\overline{d_j^d}$: maximum allowed arrival delay of flight j

c^{delay} : flight delay cost

c^{cancel} : flight cancellation cost

c^{crew}: crew misconnection cost

c^{urgent}: urgent operation cost

Decision Variables

d_{is}^{a} : arrival delay time of flight i in scenario s

d_{js}^{d} : departure delay time of flight j in scenario s

x_{is}^{k}: 1, if flight i is assigned to timeslot k in scenario s; otherwise 0

y_{ijs}: 1, if crews of flight i connecting to flight j fail to transfer in scenario s; otherwise 0

u_{ijs}:1, if a buffer time between flight i and j is not guaranteed due to delay ; otherwise 0

z_{is}^{a} : 1, if inbound flight i is cancelled in scenario s

z_{js}^{d} : 1, if outbound flight j is cancelled in scenario s

w_{is}^{a} : auxiliary continuous variable for arrival delay

w_{js}^{d} : auxiliary continuous variable for departure delay

The mathematical formulation of MSOR problem is as follows.

$$min.\quad E_{s\in S}[\Sigma_{m\in M}\{c^{delay}\left(\Sigma_{i\in I_m^a}(d_{is}^a-w_{is}^a)+\Sigma_{j\in I_m^d}(d_{js}^d-w_{js}^d)\right)+\Sigma_{i\in I_m^a,j\in I_m^d}(c^{crew}R_{ij}y_{ijs}+c^{urgent}L1_{ij}u_{ijs}\Big)+c^{cancel}(\Sigma_{i\in I_m^a}z_{is}^a+\Sigma_{j\in I_m^d}z_{js}^d)\}] \quad (1.1)$$

s.t.

$$x_{is}^{k}=0 \qquad \forall m\in M, s\in S, k\in K_m : t_{ms}^{k}\leq arr_i \quad (1.2)$$

$$\sum_{i\in I_m^a} x_{is}^{k}\leq 1 \qquad \forall m\in M, s\in S, k\in K_m \quad (1.3)$$

$$\left(\sum_{k\in K_m} x_{is}^{k}\right)+z_{is}^{a}=1 \qquad \forall m\in M, s\in S, i\in I_m^a \quad (1.4)$$

$$d_{is}^{a} = \sum_{k \in K_m : arr_i \le t_{ms}^{k}} (t_{ms}^{k} - arr_i) x_{is}^{k} \qquad \forall m \in M, s \in S, i \in I_m^a \tag{1.5}$$

$$d_{js}^{d} \ge arr_i + d_{is}^{a} + \delta^{plane} - dep_j \qquad \forall m \in M, s \in S, i \in I_m^a, j \in I_m^d : L1_{ij} = 1 \tag{1.6}$$

$$d_{ns}^{a} \ge dep_j + d_{js}^{d} + fly_{ij} - arr_n \qquad \forall m \in M, s \in S, n \in I^a \backslash I_m^a, j \in I_m^d : L2_{jn} = 1 \tag{1.7}$$

$$-\overline{d_i^a}\, u_{ijs} \le \{(dep_j - arr_i) - d_{is}^{a}\} - \Delta \le \overline{d_i^a}\,(1 - u_{ijs}) \quad \forall m \in M, s \in S, i \in I_m^a, j \in I_m^d : L1_{ij} = 1 \tag{1.8}$$

$$arr_i + d_{is}^{a} + \delta^{crew} \le dep_j + d_{js}^{d} + \overline{d_i^a} y_{ijs} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d :\ R_{ij} = 1 \tag{1.9}$$

$$w_{is}^{a} \le \overline{d_i^a} z_{is}^{a} \qquad \forall m \in M, s \in S, i \in I_m^a \tag{1.10}$$

$$w_{is}^{a} \le d_{is}^{a} \qquad \forall m \in M, s \in S, i \in I_m^a \tag{1.11}$$

$$w_{js}^{d} \le \overline{d_j^d} z_{js}^{d} \qquad \forall m \in M, s \in S, j \in I_m^d \tag{1.12}$$

$$w_{js}^{d} \le d_{js}^{d} \qquad \forall m \in M, s \in S, j \in I_m^d \tag{1.13}$$

$$z_{is}^{a} \le y_{ijs},\ z_{js}^{d} \le y_{ijs} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d : R_{ij} = 1 \tag{1.14}$$

$$z_{is}^{a} \le z_{js}^{d} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d : L1_{ij} = 1 \tag{1.15}$$

$$z_{js}^{d} = z_{ns}^{a} \qquad \forall m \in M, s \in S,\ j \in I_m^d, n \in I^a \backslash I_m^a : L2_{jn} = 1 \tag{1.16}$$

$$0 \le d_{is}^{a} \le \overline{d_i^a},\ 0 \le d_{js}^{d} \le \overline{d_j^d} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d \tag{1.17}$$

$$x_{is}^{k}, y_{ijs},\ u_{ijs}, z_{is}^{a},\ z_{js}^{d} \in \{0,1\} \qquad \forall m \in M, s \in S, i, j \in I \tag{1.18}$$

The objective function (1.1) is to minimize total relevant cost (TRC) of an airline. It uses the expectation of cost of all scenarios. However, as we use uniform distribution in occurrence of each scenario, to minimize expectation cost means to minimize cost of each scenario. It includes the total delay cost, the crew misconnection cost, the urgent operation cost and cancellation cost. As c^{delay} is cost per minute, total delay cost is proportional to the delay time. Other costs, on the other hand, are incurred at once, depending on the decision. In constraints (1.2), flights cannot be allocated to a timeslot at a time earlier than the original planned time. Constraints (1.3) allow up to one flight to be assigned to one timeslot. Constraints (1.4) state all inbound flights should be assigned to one timeslot or cancelled. Constraints (1.5) define arrival delay time as being a difference between the allocated timeslot and the original planned time. Constraints (1.6) ensure that subsequent $flight\ j$ is delayed in departure so that it departs later than actual arrival time of the preceding $flight\ i$ plus minimum turnaround time required for the same aircraft. In constraints (1.7), if the origin of inbound $flight\ n$ is also in GDP airport set, $flight\ n$ can be delayed so that it arrives later than an actual departure time plus flying time of the flight. Constraints (1.8) indicate the cost occurs because of the malfunction of the planned operation if the buffer time is not guaranteed due to the delay of the preceding flight. Constraints (1.9) imply that in case the gap between the actual arrival time and the actual departure time is less than the minimum turnaround time of the crew, the crew could fail to transfer. Constraints (1.10) – (1.13) make the delay time be zero when a flight is cancelled. Constraints (1.14) state crews fail to transfer even if only one of the crew's planned $flight\ i\ or\ j$ is cancelled. Constraints (1.15) force a follow-up $flight\ j$ which uses the same aircraft to be cancelled if a preceding $flight\ i$ is cancelled. Constraints (1.16) require that as long as flights are connected as parameter L2, they are the same flight not only the same aircraft, so the cancellation must be the same. Constraints (1.17) restrict maximum allowed delay of each flight.

3.2 Multi-airport Scenario-based Stochastic Rescheduling Problem

We present stochastic version called Multi-airport Scenario-based Stochastic Rescheduling (MSSR) problem. The stochastic version is designed to provide robust timeslot allocation that can be applied to all the created scenarios, in order to prepare for the uncertainty that the GDP will change again later. The strength of the MSSR over the MSOR is that if the GDP state changes once more, airlines can have no opportunity to change the plan again. The MSSR allows airlines to minimize losses in your initial plan in preparation for such a situation. The decision variables of the MSOR $x_{is}^k, z_{is}^a, z_{js}^d$ are changed to x_i^k, z_i^a, z_j^d which do not depend on the scenario. Everything else is the same as in the MSOR.

$$min.\quad E_{s\in S}[\Sigma_{m\in M}\{c^{delay}\left(\Sigma_{i\in I_m^a}(d_{is}^a - w_{is}^a) + \Sigma_{j\in I_m^d}(d_{js}^d - w_{js}^d)\right) + \Sigma_{i\in I_m^a, j\in I_m^d}(c^{crew}R_{ij}y_{ijs} + c^{urgent}L1_{ij}u_{ijs}\Big) + c^{cancel}(\Sigma_{i\in I_m^a} z_i^a + \Sigma_{j\in I_m^d} z_j^d)\}] \tag{2.1}$$

s.t.

$$x_i^k = 0 \qquad \forall m \in M, s \in S, k \in K_m : t_{ms}^k \leq arr_i \tag{2.2}$$

$$\sum_{i \in I_m^a} x_i^k \leq 1 \qquad \forall m \in M, s \in S, k \in K_m \tag{2.3}$$

$$\left(\sum_{k \in K_m} x_i^k\right) + z_i^a = 1 \qquad \forall m \in M, s \in S, i \in I_m^a \tag{2.4}$$

$$d_{is}^a = \sum_{k \in K_m : arr_i \leq t_{ms}^k} (t_{ms}^k - arr_i) x_i^k \qquad \forall m \in M, s \in S, i \in I_m^a \tag{2.5}$$

$$d_{js}^d \geq arr_i + d_{is}^a + \delta^{plane} - dep_j \qquad \forall m \in M, s \in S, i \in I_m^a, j \in I_m^d : L1_{ij} = 1 \tag{2.6}$$

$$d_{ns}^a \geq dep_j + d_{js}^d + fly_{ij} - arr_n \qquad \forall m \in M, s \in S, n \in I^a \backslash I_m^a, j \in I_m^d : L2_{jn} = 1 \tag{2.7}$$

$$-\overline{d_i^a}\, u_{ijs} \leq \{(dep_j - arr_i) - d_{is}^a\} - \Delta \leq \overline{d_i^a}\,(1 - u_{ijs}) \quad \forall m \in M, s \in S, i \in I_m^a, j \in I_m^d : L1_{ij} = 1 \tag{2.8}$$

$$arr_i + d_{is}^a + \delta^{crew} \leq dep_j + d_{js}^d + \overline{d_i^a} y_{ijs} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d :\ R_{ij} = 1 \tag{2.9}$$

$$w_{is}^a \leq \overline{d_i^a} z_i^a \qquad \forall m \in M, s \in S, i \in I_m^a \tag{2.10}$$

$$w_{is}^a \leq d_{is}^a \qquad \forall m \in M, s \in S, i \in I_m^a \tag{2.11}$$

$$w_{js}^d \leq \overline{d_j^d} z_j^d \qquad \forall m \in M, s \in S, j \in I_m^d \tag{2.12}$$

$$w_{js}^d \leq d_{js}^d \qquad \forall m \in M, s \in S, j \in I_m^d \tag{2.13}$$

$$z_i^a \leq y_{ijs},\ z_j^d \leq y_{ijs} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d : R_{ij} = 1 \tag{2.14}$$

$$z_i^a \leq z_j^d \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d : L1_{ij} = 1 \tag{2.15}$$

$$z_j^d = z_n^a \qquad \forall m \in M, s \in S,\ j \in I_m^d, n \in I^a \backslash I_m^a : L2_{jn} = 1 \tag{2.16}$$

$$0 \leq d_{is}^a \leq \overline{d_i^a},\ 0 \leq d_{js}^d \leq \overline{d_j^d} \qquad \forall m \in M, s \in S,\ i \in I_m^a, j \in I_m^d \tag{2.17}$$

$$x_i^k, y_{ijs},\ u_{ijs}, z_i^a,\ z_j^d \in \{0,1\} \qquad \forall m \in M, s \in S, i, j \in I \tag{2.18}$$

Chapter 4. Experiments

4.0 Settings

To prove this thesis, various experiments are conducted. The results of the experiment and its analysis are also discussed in this chapter. Experiments were performed with real data from three airports in South Korea—Gimpo(GMP), Gimhae/Busan(PUS) and Jeju(CJU)—which have had the highest traffic volume recently. The data were from Korea Airportal (https://www.airportal.go.kr). There are 234 flights in a day in this setup. Based on arrival data of each airport and departure data of each airport, we set the situation in which the GDP has been issued at the start point of the day. Since curfew time exists directly or indirectly at domestic airports, the schedule horizon is set from 7:00 (0 min.) to 23:00 (960 min.). The timeslot gets invalidated if the time of timeslot exceeds 23:00 due to decreased AAR. With the situation mentioned as base scenario, we create scenarios with two factors [28] —GDP reissuance time and GDP flow rate—in a situation where the GDP occurs first and rescheduling is required. Scenarios include the case in which traffic conditions get worse (and therefore AAR decreases more), the case in which traffic conditions get better (and AAR recovers to their original capacity), and the case in which no change occurs. We had four experiments. First, we compared the single airport model considering delay propagation once (arrival delay to departure delay) with our thesis. The single airport MILP was proposed by Woo and Moon [28]. Second, we checked solutions of the MSOR and the MSSR to see how much the stochastic version can replace the optimal version. Next, the MSOR was then contrasted with Ration-By-Schedule (RBS) method, which is simple and used by many airlines for convenience. The RBS follows 'first-scheduled, first-served' rule, as illustrated in Figure 4.1.

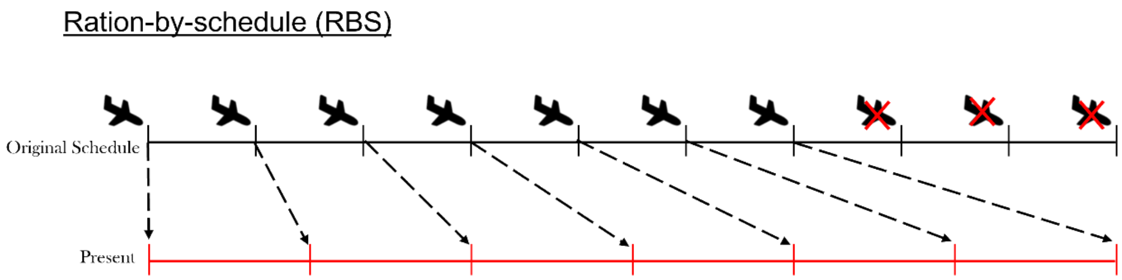

Figure 4.1: Rescheduling using the RBS method

Last, we analyzed sensitivity of costs. The decision to delay or cancel is bound to be sensitive to each cost. We checked solutions of various delay cost and cancellation cost. Also, experiments were conducted on how to set the standard of buffer time. The larger the buffer time that should be guaranteed, the smaller the urgent cost that occurs when it is violated, and vice versa.

The parameters used are illustrated in Table 4.1 below. All computations were carried out with CPLEX version 20.8 licensed by IBM ILOG [12]. We used default setting in CPLEX and problems were coded in Python language.

$\delta^{aircraft}$	δ^{crew}	Δ	c^{delay}	c^{cancel}	c^{crew}	c^{urgent}
40 min.	30 min.	30 min.	$6/min.	$350	$50	$50

Table 4.1: Parameters

4.1 Experiment 1

The scenario-based rescheduling of an airline in a single airport model was formulated by Woo et al. [28]. [28] considered one delay propagation and assumed only one airport under the GDP. The multi-airport model in this experiment means only MSOR of two presented models in this thesis. For comparison, the single airport model was slightly modified, including the urgent operation cost, and termed Single airport Scenario-based Optimal Rescheduling (SSOR). The details were presented in Appendix A. The experiment used 32 scenarios: base scenario and scenario that AAR reverting back to original. Other scenarios include severe disruptions of airports where AAR changes to 0.9, 0.75, 0.6, 0.45, 0.3, and 0.15 percent of original rate at 840 minutes; where AAR changes to 0.9, 0.75, 0.6, 0.45, 0.3, and 0.15 percent of original rate at 600 minutes; and where AAR changes to the above rate at 480 minutes, 360 minutes, and 120 minutes respectively. The timeslots for each scenario are attached to Appendix B. SSOR was performed for each of the three airports independently. Therefore, to compare with the MSOR, three values were added. SSOR does not include delays caused by other airports, so the total delay time and cost are lower than they are with the MSOR. However, infeasibility was confirmed when solution of a single airport was substituted into MSOR. We checked solutions of two models to see the reason why the infeasibility occurred. One of the actual assignments of experiment that caused the infeasibility is shown in Figure 4.2. Among the cases expressed in Figure 3.1, the SSOR often assigned an infeasible timeslot for the case (8). With this point, we charged a penalty fee if a sum of actual departure time that was modified due to delay propagation from predecessor and flying time exceeded the time of allocated timeslot at the destination when both departure and arrival airports were in an airport set. We set this penalty fee $500 arbitrarily. Results are expressed in Table 4.2. Table 4.2 shows that then TRC of SSOR with penalty fee got bigger than the TRC of MSOR in most of the scenarios. However, in severely delayed scenarios, the cost of MSOR was still higher. We could state that when comparing two models, we solved SSOR contemplating that if the origin airport decided to cancel without a timeslot allocation, the destination airport reflected this decision immediately, as with the MSOR. In fact, if disruption were serious like scenario 30, a flight could be cancelled instantaneously. In that case, there may be additional penalties because the arrival airport does not know to reflect this cancellation in planning step.

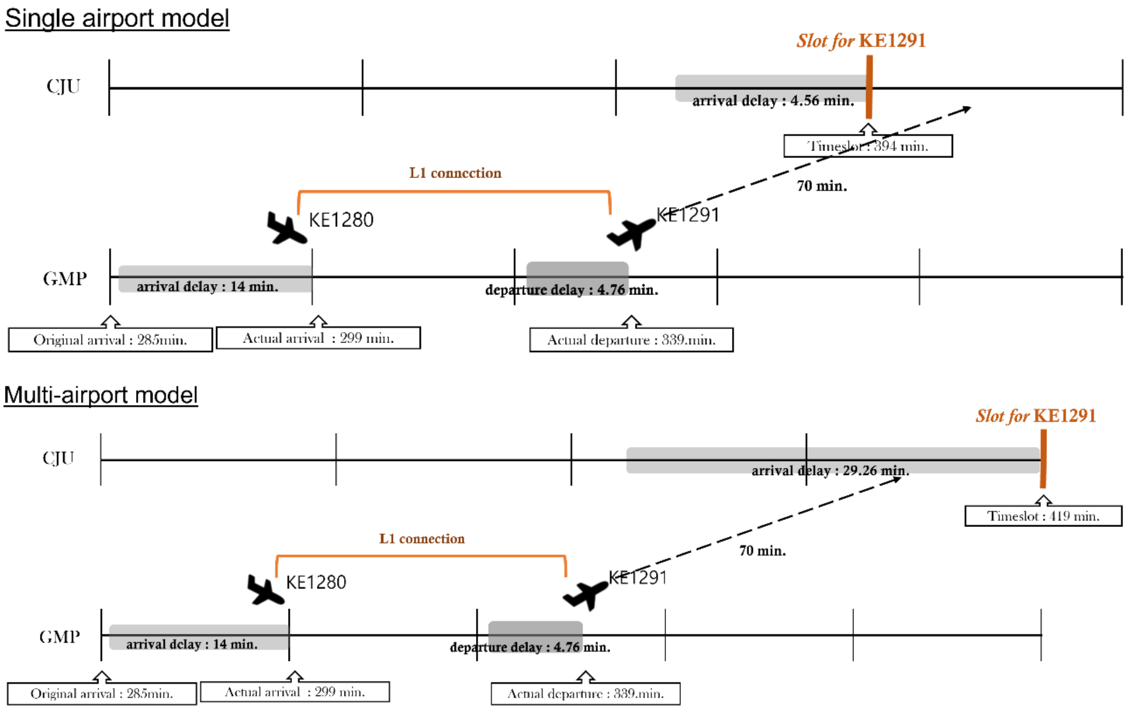

Figure 4.2: Example of different timeslot assignments between SSOR and MSOR

scenario	MSOR($)	SSOR($)	SSOR+penalty($)	Gap of TRC(*100%)
s0(base)	470,375	470,375	481,775	2.42%
s1	479,372	479,372	491,772	2.59%
s2	482,371	482,371	494,771	2.57%
s3	494,368	494,368	506,768	2.51%
s4	514,362	514,362	526,762	2.41%
s5	554,350	554,350	565,150	1.95%
s6	703,611	703,611	715,411	1.68%
s7	512,954	512,954	524,354	2.22%
s8	528,585	528,585	539,985	2.16%
s9	591,111	591,111	601,911	1.83%
s10	695,320	695,320	706,120	1.55%
s11	896,953	896,953	904,753	0.87%
s12	1,418,088	1,418,088	1,427,688	0.68%
s13	529,669	529,669	541,069	2.15%
s14	551,015	551,015	561,815	1.96%
s15	636,401	636,401	647,201	1.70%
s16	778,710	778,710	789,510	1.39%
s17	1,056,541	1,056,541	1,063,141	0.62%
s18	1,751,428	1,751,428	1,759,228	0.45%
s19	545,247	545,247	556,647	2.09%
s20	571,786	571,786	583,186	1.99%
s21	677,941	677,941	688,741	1.59%
s22	854,868	854,868	865,668	1.26%
s23	1,201,934	1,201,934	1,208,534	0.55%
s24	2,165,531	2,121,593	2,129,393	-1.67%
s25	578,458	578,458	589,858	1.97%
s26	616,192	616,192	626,992	1.75%
s27	767,181	767,181	777,981	1.41%
s28	1,018,745	1,018,745	1,029,545	1.06%
s29	1,525,012	1,525,012	1,528,612	0.24%
s30	2,744,890	2,700,952	2,710,552	-1.25%
s31	223,464	223,464	239,664	7.25%

Table 4.2: TRC($) of MSOR, SSOR, TRC+penalty fee($) of SSOR and its gap with MSOR

4.2 Experiment 2

The solutions of MSOR and MSSR were compared. In comparison, as the MSOR obtained total relevant cost of each scenario, we calculated the expected value with each value. On the contrary, since the objective function is defined as the expected value of all scenarios in MSSR, we calculated the cost for each scenario with a solution. First, we experimented by increasing the number of scenarios to check the difference between MSOR and MSSR. Since the cost itself depends on generated scenarios, gaps of TRC and computation times are calculated between the two models. As Table 4.3 displays, TRC always had a smaller value in the MSOR than the MSSR. This is natural, because MSOR is a solution of optimization for each scenario. The gaps of TRC and computation times do not increase or decrease monotonically because AAR in added scenarios does not consistently decrease or increase gradually. In computation times, the MSSR was mostly smaller, but there were cases where it was not.

Number of scenarios	MSOR TRC($)	MSSR TRC($)	Gap of TRC(*100%)	MSOR times(sec.)	MSSR Times(sec.)	Gap of times(*100%)
3	375,308	376,074	0.204	55.5	55.97	0.847
6	401,922	402,361	0.109	151.3	111.52	-26.292
11	445,325	446,117	0.178	211.75	217.72	2.819
18	496,628	497,633	0.202	357.46	347.6	-2.758
22	441,989	442,654	0.150	425.15	408.98	-3.803
27	495,551	496,655	0.223	543.07	518.69	-4.489
32	457,173	457,904	0.160	600.67	598.46	-0.368
38	510,249	511,274	0.201	742.35	736.67	-0.765
44	496,864	497,835	0.195	835.65	869.5	4.051
51	511,137	512,183	0.205	1019.05	1004.894125	-1.389
58	497,770	498,693	0.186	1091.91	1094.16	0.206
65	515,236	516,324	0.211	1265.27	1251.76	-1.068

Table 4.3: TRC($) and computation times(sec.) by the number of scenarios for MSOR and MSSR

4.3 Experiment 3

Next, the performance of proposed models was verified by comparing them with RBS. The RBS method maintains the same sequence as previously planned when the GDP occurs at each airport, so if the time interval between inbound flights increases and the overall number of timeslots decreases, the planned flights at the end could be cancelled. It is known that the RBS is the optimal method minimizing total arrival delay time for all flights, regardless of airlines in an airport [4]. However, it may not be the best method in terms of cost. Scenarios used in the experiment is the same as in Experiment 1.

Table 4.4 shows TRC, the number of cancelled flights, the number of buffer time violations which evoked urgent operation, and the number of crew misconnections for each scenario in the MSOR and the RBS. The TRC expectation for all scenarios was calculated as well.

In the case of scenarios where the timeslot is not much delayed, the cost difference did not occur, because the optimization assigned timeslots in the same way as the RBS that could minimize total delay time. However, the cost difference got larger in scenarios with severe delay as the MSOR tried to ensure the situation of connected flights and minimize urgent operations. The RBS did not cancel unless the timeslot was invalidated, but the MSOR arbitrarily cancelled if the cost of delay could be greater than the cost of cancellation.

scenario	MSOR TRC($)	RBS TRC($)	Gap of TRC(*100%)	MSOR cancel	RBS cancel	MSOR urgent	RBS urgent	MSOR crew	RBS crew
s0(base)	449,249	449,249	0.000%	0	0	1	1	0	0
s1	453,248	453,248	0.000%	0	0	1	1	0	0
s2	461,246	461,246	0.000%	0	0	1	1	0	0
s3	473,242	473,242	0.000%	0	0	1	1	0	0
s4	493,237	493,237	0.000%	0	0	1	1	0	0
s5	533,225	533,225	0.000%	0	0	1	1	0	0
s6	682,485	682,485	0.000%	2	2	1	1	0	0
s7	468,710	468,710	0.000%	0	0	1	1	0	0
s8	507,632	508,351	0.142%	0	0	1	2	0	0
s9	566,015	567,778	0.312%	0	0	1	2	0	0
s10	663,319	666,824	0.528%	0	0	1	2	0	0
s11	864,704	868,214	0.406%	0	0	3	3	0	0
s12	1,379,819	1,447,220	4.885%	5	2	3	6	1	1
s13	475,988	475,988	0.000%	0	0	1	1	0	0
s14	529,465	530,183	0.136%	0	0	1	2	0	0
s15	609,680	611,443	0.289%	0	0	1	2	0	0
s16	743,373	746,877	0.471%	0	0	1	2	0	0
s17	1,017,533	1,021,043	0.345%	0	0	3	3	0	0
s18	1,706,139	1,831,949	7.374%	7	2	4	8	2	1
s19	482,911	482,911	0.000%	0	0	1	1	0	0
s20	550,235	550,954	0.131%	0	0	1	2	0	0
s21	651,221	652,984	0.271%	0	0	1	2	0	0
s22	819,531	823,035	0.428%	0	0	1	2	0	0
s23	1,162,925	1,166,435	0.302%	0	0	3	3	0	0
s24	2,059,235	2,185,045	6.110%	7	2	4	8	2	1
s25	496,614	496,614	0.000%	0	0	1	1	0	0
s26	591,343	592,062	0.122%	0	0	1	2	0	0
s27	736,108	737,871	0.240%	0	0	2	3	0	0
s28	977,315	980,819	0.359%	0	0	2	3	0	0
s29	1,466,504	1,470,014	0.239%	0	0	4	4	0	0
s30	2,681,995	2,976,875	10.995%	13	2	6	17	2	3
s31	212,063	212,063	0.000%	0	0	0	0	0	0
expected TRC	811447.13	829259.19	2.195%						

Table 4.4: TRC($), the number of cancelled flights, buffer time violations, and crew misconnections for each scenario

4.4 Experiment 4

The decision to delay or cancel flight is cost sensitive. We compared the costs when choosing to assign timeslot (pure delay cost, urgent operation cost, and crew misconnection cost) and the costs when choosing to cancel (cancellation cost, crew misconnection cost) to check how the solution differs. For scenario 30, where the GDP occurs once more and the AAR decreases the most, the total delay time of the MSOR and the number of cancelled flights with various c^{delay} and c^{cancel} are shown in Figure 4.3 and Figure 4.4. Cancellation does not occur when c^{delay} is 3, but when c^{delay} becomes 5, delay cost increases rapidly, so cancellation of flights starts to occur, and instead the total delay time decreases.

To examine the cancellation of flights in detail, the solutions of the MSOR and the MSSR when scenario 30 occurred in '$c^{delay} = 7$' are shown in Table 4.5. The first three columns of Table 4.5 refer to the flight name and succeeding flight name of L1 connection and crew connection, if they exist. Next, TS means the timeslot number assigned for the flight and DT means delay time in minutes for each model. 1,2,3,4 means when c^{cancel} is 120, 160, 200, and 400 in order. The solution of MSSR should be used in all scenarios, so it was very defensive about canceling flights. This is because in the current scenario, the cancellation cost may be cheaper due to the large delay time, but in other scenarios, it may be unnecessarily cancelled. Therefore, regardless of how much c^{cancel} is, timeslots are allocated in the order originally planned, and delays appear continuously for more than 35 minutes. On the other hand, in the MSOR, when c^{cancel} is the lowest, flights that would have had a delay time more than 30 minutes were cancelled if there is no L1 or crew-connected flight. Especially, it tends to cancel flights that do not have connecting flights themselves but that instead following flight has connections. As c^{cancel} increased, flights that had cancelled in low cost were reassigned to timeslots so that the delay time among flights was distributed evenly without being biased.

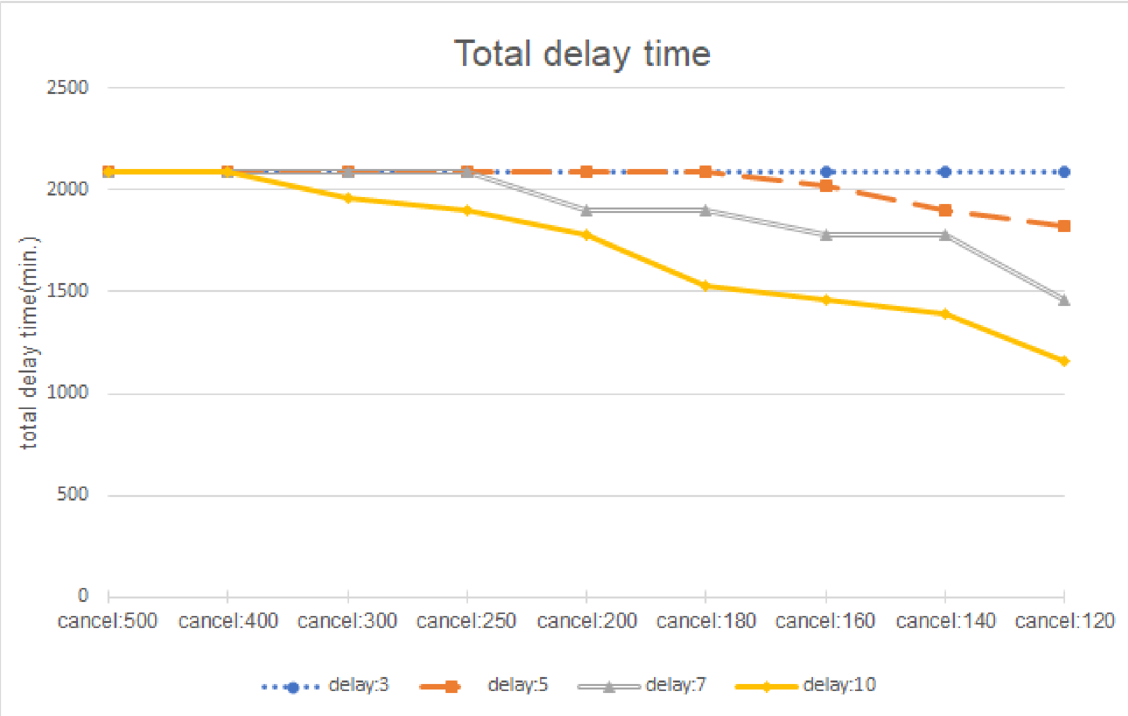

Figure 4.3: Total delay time(min.) by delay cost per cancel cost

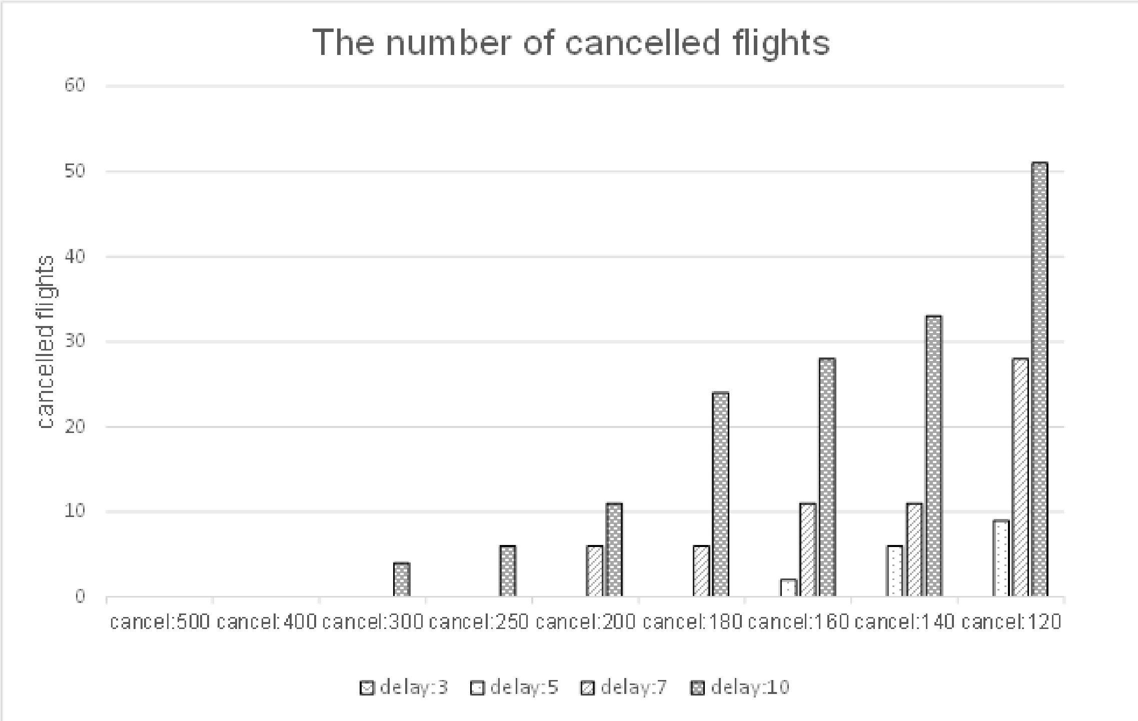

Figure 4.4: The number of cancelled flights by delay cost per cancel cost

This time, we experimented on how to set the standard of buffer time. The fact that the buffer time, which should be guaranteed, is large means that safety takes priority, so even if the buffer time is not guaranteed, the additional operation may not be huge. Accordingly, c^{urgent} is relatively small. On the contrary, if the buffer time is small, the c^{urgent} to be spent when it is not guaranteed will increase. Thus, we created pairs of (buffer time, c^{urgent}) that have inverse relationships. Also, to check if the costs affect the corresponding buffer time, computations were performed with a total of 16 pairs: (0,80), (0,160), (20,70), (20,140) (25,60), (25,120), (30,50), (30,100), (35,40), (35,80). (35,35), (35,70), (40,20), (40,40), (40,25), (40,55). Including Base scenario, in scenario 8, where the GDP changes to 80 percent of the AAR after 600 minutes from the start point, scenario 16, where the GDP changes to 80 percent of AAR after 360 minutes from the start point, scenario 24, where the GDP changes to 45 percent of AAR after 120 minutes from the start point, and scenario 26, where AAR is restored to original as the GDP is withdrawn, the number of buffer time violations occurring is shown in Figure 4.6. The TRC of each scenario is expressed in Figure 4.5.

The more the AAR decreased, the higher the number of buffer time violations and the higher the TRC. However, given that the number of violations remained constant even if c^{urgent} increased at the same buffer time, it could be explained that the decision is made by reflecting other connections more closely rather than by making a decision to change timeslots in order to keep the buffer time.

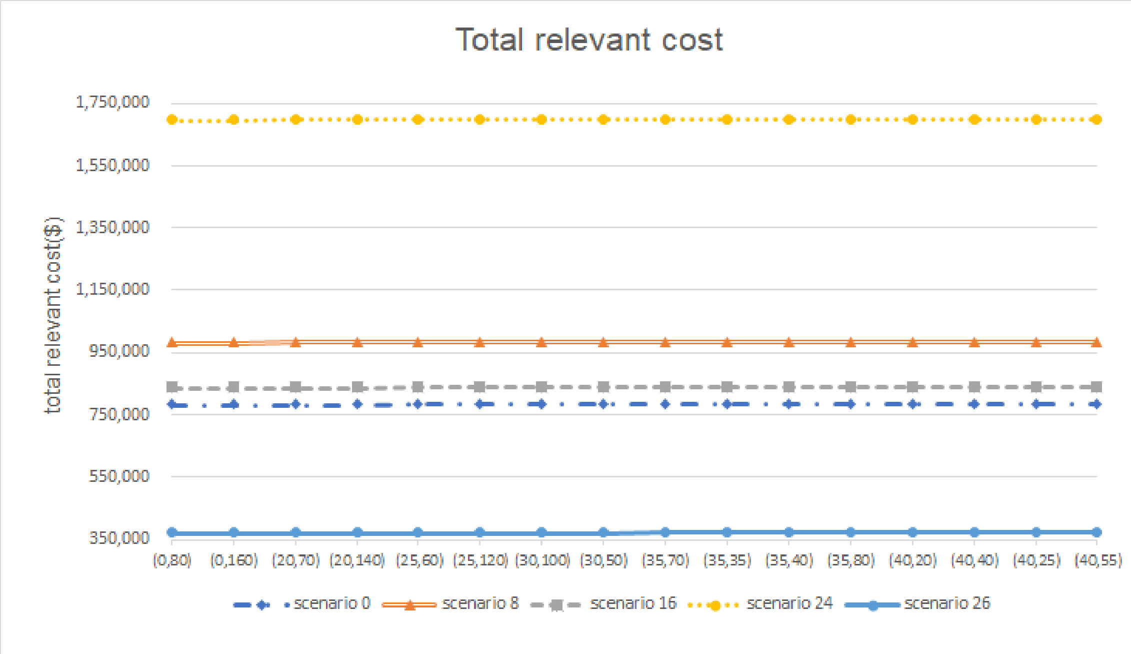

Figure 4.5: TRC($) by scenario per (buffer time, urgent cost)

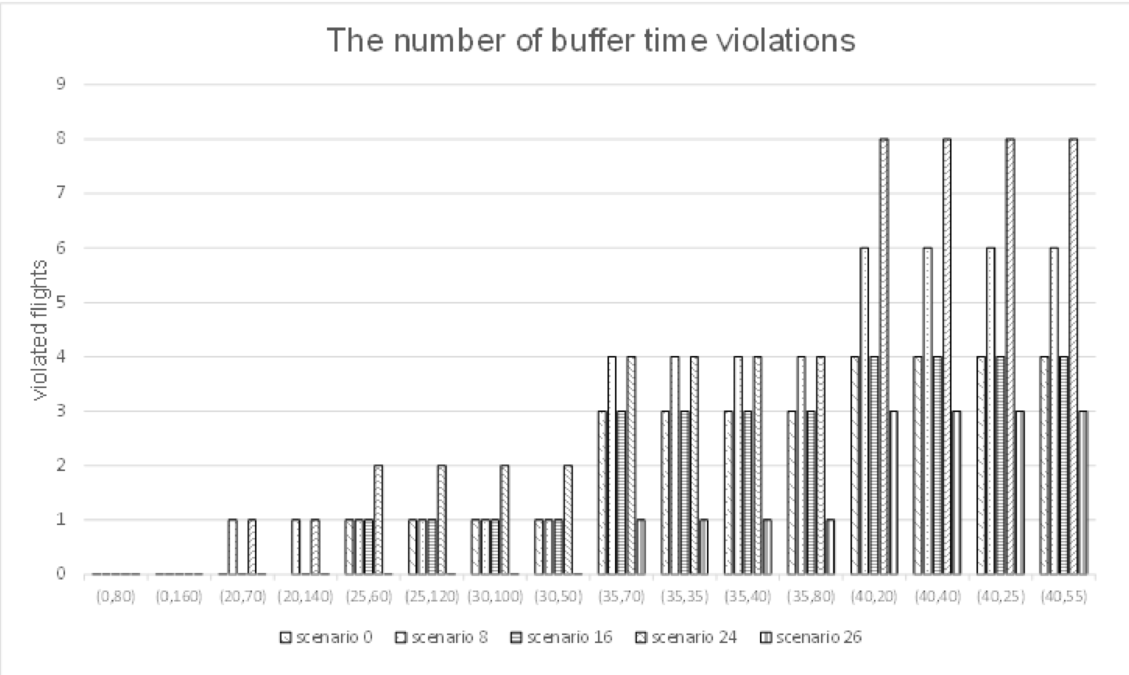

Figure 4.6:The number of buffer time violations by scenario per(buffer time, urgent cost)

Flight	L1 connection	Crew connection	MSOR TS	MSSR TS	MSOR DT	MSSR DT	MSOR TS2	MSSR TS2	MSOR DT2	MSSR DT2	MSOR TS3	MSSR TS3	MSOR DT3	MSSR DT3	MSOR TS4	MSSR TS4	MSOR DT4	MSSR DT4
KE1106			x	9	0	14.88	x	9	0	14.88	9	9	14.88	14.88	9	9	14.88	14.88
KE1220			11	10	19.88	14.88	11	10	19.88	14.88	11	10	19.88	14.88	11	10	19.88	14.88
KE1224	KE1235		10	11	9.88	14.88	10	11	9.88	14.88	10	11	9.88	14.88	10	11	9.88	14.88
KE1226			12	12	14.88	14.88	12	12	14.88	14.88	12	12	14.88	14.88	12	12	14.88	14.88
KE1228			13	13	14.88	14.88	13	13	14.88	14.88	13	13	14.88	14.88	13	13	14.88	14.88
KE1108	KE1115	KE1115	14	14	14.88	14.88	14	14	14.88	14.88	14	14	14.88	14.88	14	14	14.88	14.88
KE1230			15	15	14.88	14.88	15	15	14.88	14.88	15	15	14.88	14.88	16	15	24.88	14.88
...			...				...				...				...			
KE1101			49	49	11.24	11.24	49	49	11.24	11.24	49	49	11.24	11.24	49	49	11.24	11.24
KE1103	KE1106	KE1106	x	50	0	37.47	x	50	0	37.47	50	50	37.47	37.47	50	50	37.47	37.47
KE1002			50	51	2.47	37.47	50	51	2.47	37.47	x	51	0	37.47	51	51	37.47	37.47
KE1105			51	52	17.47	37.47	51	52	17.47	37.47	51	52	17.47	37.47	52	52	37.47	37.47
KE1107			x	53	0	37.47	53	53	37.47	37.47	53	53	37.47	37.47	53	53	37.47	37.47
KE1012	KE1015	KE1015	54	54	37.47	37.47	54	54	37.47	37.47	54	54	37.47	37.47	54	54	37.47	37.47
KE1014			x	55	0	37.47	x	55	0	37.47	x	55	0	37.47	55	55	37.47	37.47
KE1111		KE1116	55	56	12.47	37.47	55	56	12.47	37.47	55	56	12.47	37.47	56	56	37.47	37.47
KE1115			x	57	0	37.47	57	57	37.47	37.47	57	57	37.47	37.47	57	57	37.47	37.47
KE1020	KE1120	KE1120	58	58	37.47	37.47	58	58	37.47	37.47	58	58	37.47	37.47	58	58	37.47	37.47
KE1119			x	59	0	37.47	59	59	37.47	37.47	59	59	37.47	37.47	59	59	37.47	37.47
KE1121			x	60	0	37.47	x	60	0	37.47	60	60	37.47	37.47	60	60	37.47	37.47
KE1026			60	61	27.47	37.47	60	61	27.47	37.47	61	61	37.47	37.47	61	61	37.47	37.47
KE1028			x	62	0	37.47	62	62	37.47	37.47	62	62	37.47	37.47	62	62	37.47	37.47
KE1032	KE1031	KE1031	63	63	37.47	37.47	63	63	37.47	37.47	63	63	37.47	37.47	63	63	37.47	37.47
KE1125			x	64	0	37.47	64	64	37.47	37.47	64	64	37.47	37.47	64	64	37.47	37.47
KE1036			x	65	0	37.47	65	65	37.47	37.47	65	65	37.47	37.47	65	65	37.47	37.47
KE1201	KE1208	KE1208	66	66	4.39	4.39	66	66	4.39	4.39	66	66	4.39	4.39	66	66	4.39	4.39
KE1001	KE1002	KE1002	67	67	4.39	4.39	67	67	4.39	4.39	67	67	4.39	4.39	67	67	4.39	4.39
...			...				...				...				...			
KE1255			107	105	29.63	14.63	107	105	29.63	14.63	107	105	29.63	14.63	107	105	29.63	14.63
KE1297			105	106	4.63	14.63	105	106	4.63	14.63	105	106	4.63	14.63	105	106	4.63	14.63
KE1907			106	107	9.63	14.63	106	107	9.63	14.63	106	107	9.63	14.63	106	107	9.63	14.63
KE1957			x	108	0	14.63	x	108	0	14.63	109	108	24.63	14.63	109	108	24.63	14.63
KE1259	KE1272	KE1272	108	109	4.63	14.63	108	109	4.63	14.63	108	109	4.63	14.63	108	109	4.63	14.63
KE1263			110	110	14.63	14.63	110	110	14.63	14.63	110	110	14.63	14.63	110	110	14.63	14.63

Table 4.5 :Solutions and delay time(min.) of MSOR and MSSR for cancel cost=120$, 160$, 200$, 400$ when delay cost=7$

Chapter 5. Conclusions

So far, we have presented MILP models on how airlines can minimize losses, complying with the decreased AAR given when the GDP, one of the airport disruption control methods, has already been implemented by central authority. The delay propagation that can be considered by changing from a single airport to a multi-airport setup was reflected and shown through experiments. It is expected that this effect will increase as more airports are included in the airport set including international flights as well as domestic flights.

Moreover, the model was compared with the RBS method that follows the "first-scheduled, first-served rules," not with optimization. The RBS is a simple but powerful method for minimizing total delay time. For that reason, it is a good to use if someone is trying to increase the efficiency of the entire airport. In spite of that, since it is a thesis to help airlines operate, we set the cost considering the airline's resources and plan and show how the concept of buffer time can be used. The TRC of the presented model was lower than the TRC of the RBS, which was aim of experiment.

In the cost analysis, as mentioned in chapter 4.4, buffer time and the urgent cost seem to disaffect decision making. The result may be different if the cost of violation is very high, but the buffer time itself was not an essential time but rather a means to give stability to the operation. Thereby, we did not proceed further with different costs because it was different from the intention of the concept of buffer time.

A mathematical formulation using stochastic programming for robustness was also suggested. Considering that computation times of the MSOR is not that long, it may be sufficient to have scenario-based optimal MILP model. However, when airlines actually use it, they can have only one chance to reschedule, because it is difficult to change decisions again as airports are shared by not only one airline but many airlines, and are very crowded. Given the specificity of aviation, the scenarios that can actually occur will not be endless, so to minimize costs within a reasonable computing time, it would be better to use the MSOR and get all the solutions in advance to change the plan to those scenarios when the situation changes. However, if it is not possible, the cost gap does not exceed 1 percent, which makes using the MSSR enough of an alternative.

In conclusion, there are three expected effects of this thesis. The first is as follows. Thesedays, the aviation industry has more short-distance and round-trip operations within a day. Although there have been studies showing that delays in arriving flights will propagate as delays in departing flights when the same aircrafts are used, no studies have considered that when the flight which departed late because of delay propagated from predecessor flight arrives at its destination again, timeslot should be assigned with reflection of a late departure. If each decision is made independently without knowing the delay of other airports, there may be situations in which inappropriate timeslots are assigned and therefore flights can be inevitably delayed in the air, or rescheduled because of infeasibility. The multi-airport model allowed timeslots to be allocated to minimize costs while guaranteeing feasibility by solving a problem in several airports at once. Secondly, we further considered the realistic costs associated with the resources used by airlines for rescheduling. The transfer of aircraft and crews was addressed, and other operational losses that may occur in the event of delays were reflected in the concept of buffer time and urgent operation. Finally, in a situation in which the GDP occurs and rescheduling is required, possible scenarios are created, and decisions for each scenario can be derived within a reasonable time. Given that it took about 20 minutes for more than 60 scenarios to be calculated, we expect airlines to be able to use the model in the tactical stage. What is more, the stochastic version will be available in situations where it will be practically difficult to change the timeslot order again later in the situation where it is not yet known which scenario will be realized.

Some studies focused on how much and when the GDP should be issued to reduce AAR, but they are excluded because they are not within the scope of this thesis, and it is assumed that the probability of scenario occurrence follows uniform distribution. The probability may change depending on the information that is realized over time, so decisions could be made more dynamically. We hope that thesis can be expanded further.

Appendix. A

$$min. \quad E_{s\in S}\{c^{delay}\Big(\Sigma_{i\in I^a}(d_{is}^a - w_{is}^a) + \Sigma_{j\in I^d}(d_{js}^d - w_{js}^d)\big) + \Sigma_{i\in I^a, j\in I^d}(c^{crew}R_{ij}y_{ijs} + c^{urgent}L1_{ij}u_{ijs}\Big) + c^{cancel}(\Sigma_{i\in I^a}z_{is}^a + \Sigma_{j\in I^d}z_{js}^d)\} \quad \text{(A.1)}$$

s.t.

$$x_{is}^k = 0 \quad \forall s \in S, k \in K : \ t_s^k \leq arr_i \quad \text{(A.2)}$$

$$\sum_{i\in I^a} x_{is}^k \leq 1 \quad \forall s \in S, k \in K \quad \text{(A.3)}$$

$$\left(\sum_{k\in K} x_{is}^k\right) + z_{is}^a = 1 \quad \forall s \in S, i \in I^a \quad \text{(A.4)}$$

$$d_{is}^a = \sum_{k\in K: arr_i \leq t_s^k} (t_s^k - arr_i) x_{is}^k \quad \forall s \in S, i \in I^a \quad \text{(A.5)}$$

$$d_{js}^d \geq arr_i + d_{is}^a + \delta^{plane} - dep_j \quad \forall s \in S, i \in I^a, j \in I^d : L1_{ij} = 1 \quad \text{(A.6)}$$

$$-\overline{d_i^a}\, u_{ijs} \leq \{(dep_j - arr_i) - d_{is}^a\} - \Delta \leq \overline{d_i^a}\,(1 - u_{ijs}) \quad \forall s \in S, i \in I^a, j \in I^d : L1_{ij} = 1 \quad \text{(A.7)}$$

$$arr_i + d_{is}^a + \delta^{crew} \leq dep_j + d_{js}^d + \overline{d_i^a} y_{ijs} \quad \forall s \in S, \ i \in I^a, j \in I^d : \ R_{ij} = 1 \quad \text{(A.8)}$$

$$w_{is}^a \leq \overline{d_i^a} z_{is}^a \quad \forall s \in S, i \in I^a \quad \text{(A.9)}$$

$$w_{is}^a \leq d_{is}^a \quad \forall s \in S, i \in I^a \quad \text{(A.10)}$$

$$w_{js}^d \leq \overline{d_j^d} z_{js}^d \quad \forall s \in S, j \in I^d \quad \text{(A.11)}$$

$$w_{js}^d \leq d_{js}^d \quad \forall s \in S, j \in I^d \quad \text{(A.12)}$$

$$z_{is}^a \leq y_{ijs}, \ z_{js}^d \leq y_{ijs} \quad \forall s \in S, \ i \in I^a, j \in I^d : R_{ij} = 1 \quad \text{(A.13)}$$

$$z_{is}^a \leq z_{js}^d \quad \forall s \in S, \ i \in I^a, j \in I^d : L1_{ij} = 1 \quad \text{(A.14)}$$

$$z_{ns}^a = z_{js}^d \quad \forall s \in S, \ n \in I^a, j \in I^d : L2_{jn} = 1 \quad \text{(A.15)}$$

$$0 \leq d_{is}^a \leq \overline{d_i^a}, \ 0 \leq d_{js}^d \leq \overline{d_j^d} \quad \forall, s \in S, \ i \in I^a, j \in I^d \quad \text{(A.16)}$$

$$x_{is}^k, y_{ijs}, \ u_{ijs}, z_{is}^a, \ z_{js}^d \in \{0,1\} \quad \forall s \in S, i, j \in I \quad \text{(A.17)}$$

Appendix. B

-	Flight	Origin	Destination	Original schedule	base	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13	s14	s15
1	KE1204	CJU	GMP	70	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46
2	KE1102	PUS	GMP	165	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46
3	KE1208	CJU	GMP	170	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46
4	KE1602	USN	GMP	185	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46
5	KE1210	CJU	GMP	200	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46
6	KE1212	CJU	GMP	210	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46
7	KE1216	CJU	GMP	255	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46
8	KE1280	CJU	GMP	270	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46
9	KE1282	CJU	GMP	275	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46
10	KE1106	PUS	GMP	285	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46
11	KE1220	CJU	GMP	305	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46
12	KE1224	CJU	GMP	310	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46
13	KE1226	CJU	GMP	325	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46
14	KE1228	CJU	GMP	340	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46
15	KE1108	PUS	GMP	360	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46	364.46
16	KE1230	CJU	GMP	395	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46	399.46
17	KE1232	CJU	GMP	405	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46	409.46
18	KE1234	CJU	GMP	430	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46	434.46
19	KE1236	CJU	GMP	450	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46	454.46
20	KE1238	CJU	GMP	475	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46	479.46
21	KE1112	PUS	GMP	480	484.46	484.46	484.46	484.46	484.46	484.46	484.46	484.46	484.46	484.46	484.46	484.46	484.46	485.58	485.95	487.44
22	KE1284	CJU	GMP	515	519.46	519.46	519.46	519.46	519.46	519.46	519.46	519.46	519.46	519.46	519.46	519.46	519.46	520.58	520.95	522.44
23	KE1286	CJU	GMP	520	524.46	524.46	524.46	524.46	524.46	524.46	524.46	524.46	524.46	524.46	524.46	524.46	524.46	525.58	525.95	527.44
24	KE1288	CJU	GMP	525	529.46	529.46	529.46	529.46	529.46	529.46	529.46	529.46	529.46	529.46	529.46	529.46	529.46	530.58	530.95	532.44
25	KE1242	CJU	GMP	530	534.46	534.46	534.46	534.46	534.46	534.46	534.46	534.46	534.46	534.46	534.46	534.46	534.46	535.58	535.95	537.44
26	KE1246	CJU	GMP	550	554.46	554.46	554.46	554.46	554.46	554.46	554.46	554.46	554.46	554.46	554.46	554.46	554.46	555.58	555.95	557.44
27	KE1116	PUS	GMP	580	584.46	584.46	584.46	584.46	584.46	584.46	584.46	584.46	584.46	584.46	584.46	584.46	584.46	585.58	585.95	587.44
28	KE1248	CJU	GMP	590	594.46	594.46	594.46	594.46	594.46	594.46	594.46	594.46	594.46	594.46	594.46	594.46	594.46	595.58	595.95	597.44
29	KE1250	CJU	GMP	620	624.46	624.46	624.46	624.46	624.46	624.46	624.46	625.58	625.95	627.44	629.92	634.88	649.76	625.58	625.95	627.44
30	KE1252	CJU	GMP	625	629.46	629.46	629.46	629.46	629.46	629.46	629.46	630.58	630.95	632.44	634.92	639.88	654.76	630.58	630.95	632.44
31	KE1254	CJU	GMP	655	659.46	659.46	659.46	659.46	659.46	659.46	659.46	660.58	660.95	662.44	664.92	669.88	684.76	660.58	660.95	662.44
32	KE1256	CJU	GMP	665	669.46	669.46	669.46	669.46	669.46	669.46	669.46	670.58	670.95	672.44	674.92	679.88	694.76	670.58	670.95	672.44
33	KE1292	CJU	GMP	675	679.46	679.46	679.46	679.46	679.46	679.46	679.46	680.58	680.95	682.44	684.92	689.88	704.76	680.58	680.95	682.44
34	KE1120	PUS	GMP	705	709.46	709.46	709.46	709.46	709.46	709.46	709.46	710.58	710.95	712.44	714.92	719.88	734.76	710.58	710.95	712.44
35	KE1258	CJU	GMP	705	709.46	709.46	709.46	709.46	709.46	709.46	709.46	710.58	710.95	712.44	714.92	719.88	734.76	710.58	710.95	712.44
36	KE1294	CJU	GMP	730	734.46	734.46	734.46	734.46	734.46	734.46	734.46	735.58	735.95	737.44	739.92	744.88	759.76	735.58	735.95	737.44
37	KE1262	CJU	GMP	745	749.46	749.46	749.46	749.46	749.46	749.46	749.46	750.58	750.95	752.44	754.92	759.88	774.76	750.58	750.95	752.44
38	KE1122	PUS	GMP	780	784.46	784.46	784.46	784.46	784.46	784.46	784.46	785.58	785.95	787.44	789.92	794.88	809.76	785.58	785.95	787.44
39	KE1266	CJU	GMP	795	799.46	799.46	799.46	799.46	799.46	799.46	799.46	800.58	800.95	802.44	804.92	809.88	824.76	800.58	800.95	802.44
40	KE1296	CJU	GMP	805	809.46	809.46	809.46	809.46	809.46	809.46	809.46	810.58	810.95	812.44	814.92	819.88	834.76	810.58	810.95	812.44
41	KE1608	USN	GMP	820	824.46	824.46	824.46	824.46	824.46	824.46	824.46	825.58	825.95	827.44	829.92	834.88	849.76	825.58	825.95	827.44
42	KE1268	CJU	GMP	825	829.46	829.46	829.46	829.46	829.46	829.46	829.46	830.58	830.95	832.44	834.92	839.88	854.76	830.58	830.95	832.44
43	KE1124	PUS	GMP	840	844.46	845.58	845.95	847.44	849.92	854.88	869.76	845.58	845.95	847.44	849.92	854.88	869.76	845.58	845.95	847.44
44	KE1272	CJU	GMP	840	844.46	845.58	845.95	847.44	849.92	854.88	869.76	845.58	845.95	847.44	849.92	854.88	869.76	845.58	845.95	847.44
45	KE1274	CJU	GMP	870	874.46	875.58	875.95	877.44	879.92	884.88	899.76	875.58	875.95	877.44	879.92	884.88	899.76	875.58	875.95	877.44
46	KE1270	CJU	GMP	880	884.46	885.58	885.95	887.44	889.92	894.88	909.76	885.58	885.95	887.44	889.92	894.88	909.76	885.58	885.95	887.44
47	KE1276	CJU	GMP	900	904.46	905.58	905.95	907.44	909.92	914.88	929.76	905.58	905.95	907.44	909.92	914.88	929.76	905.58	905.95	907.44
48	KE1126	PUS	GMP	910	914.46	915.58	915.95	917.44	919.92	924.88	939.76	915.58	915.95	917.44	919.92	924.88	939.76	915.58	915.95	917.44
49	KE1278	CJU	GMP	925	929.46	930.58	930.95	932.44	934.92	939.88	954.76	930.58	930.95	932.44	934.92	939.88	954.76	930.58	930.95	932.44
50	KE1101	GMP	PUS	65	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24
51	KE1103	GMP	PUS	130	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24
52	KE1002	CJU	PUS	165	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24
53	KE1105	GMP	PUS	185	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24
54	KE1107	GMP	PUS	265	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24
55	KE1012	CJU	PUS	335	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24
56	KE1014	CJU	PUS	360	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24	371.24
57	KE1111	GMP	PUS	385	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24	396.24
58	KE1115	GMP	PUS	485	496.24	496.24	496.24	496.24	496.24	496.24	496.24	496.24	496.24	496.24	496.24	496.24	496.24	499.05	499.99	503.73
59	KE1020	CJU	PUS	545	556.24	556.24	556.24	556.24	556.24	556.24	556.24	556.24	556.24	556.24	556.24	556.24	556.24	559.05	559.99	563.73
60	KE1119	GMP	PUS	605	616.24	616.24	616.24	616.24	616.24	616.24	616.24	619.05	619.99	623.73	629.98	642.47	679.94	619.05	619.99	623.73
61	KE1121	GMP	PUS	685	696.24	696.24	696.24	696.24	696.24	696.24	696.24	699.05	699.99	703.73	709.98	722.47	759.94	699.05	699.99	703.73
62	KE1026	CJU	PUS	695	706.24	706.24	706.24	706.24	706.24	706.24	706.24	709.05	709.99	713.73	719.98	732.47	769.94	709.05	709.99	713.73
63	KE1028	CJU	PUS	740	751.24	751.24	751.24	751.24	751.24	751.24	751.24	754.05	754.99	758.73	764.98	777.47	814.94	754.05	754.99	758.73
64	KE1032	CJU	PUS	805	816.24	816.24	816.24	816.24	816.24	816.24	816.24	819.05	819.99	823.73	829.98	842.47	879.94	819.05	819.99	823.73
65	KE1125	GMP	PUS	815	826.24	826.24	826.24	826.24	826.24	826.24	826.24	829.05	829.99	833.73	839.98	852.47	889.94	829.05	829.99	833.73
66	KE1036	CJU	PUS	905	916.24	919.05	919.99	923.73	929.98	942.47	-100	919.05	919.99	923.73	929.98	942.47	-100	919.05	919.99	923.73
67	KE1201	GMP	CJU	50	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39
68	KE1001	PUS	CJU	60	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39
69	KE1203	GMP	CJU	70	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39
70	KE1209	GMP	CJU	85	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39
71	KE1205	GMP	CJU	100	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39
72	KE1207	GMP	CJU	140	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39
73	KE1283	GMP	CJU	160	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39
74	KE1285	GMP	CJU	165	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39
75	KE1211	GMP	CJU	185	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39
76	KE1213	GMP	CJU	190	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39
77	KE1953	CJJ	CJU	195	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39
78	KE1215	GMP	CJU	220	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39
79	KE1005	PUS	CJU	230	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39
80	KE1007	PUS	CJU	260	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39
81	KE1903	KWJ	CJU	275	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39
82	KE1219	GMP	CJU	285	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39
83	KE1221	GMP	CJU	295	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39
84	KE1223	GMP	CJU	310	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39
85	KE1225	GMP	CJU	330	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39
86	KE1287	GMP	CJU	360	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39	364.39
87	KE1227	GMP	CJU	365	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39	369.39
88	KE1291	GMP	CJU	390	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39	394.39
89	KE1289	GMP	CJU	410	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39	414.39
90	KE1231	GMP	CJU	415	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39	419.39
91	KE1235	GMP	CJU	430	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39	434.39
92	KE1015	PUS	CJU	440	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39	444.39
93	KE1237	GMP	CJU	450	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39	454.39
94	KE1239	GMP	CJU	465	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39	469.39
95	KE1017	PUS	CJU	480	484.39	484.39	484.39	484.39	484.39	484.39	484.39	484.39	484.39	484.39	484.39	484.39	484.39	485.49	485.85	487.31
96	KE1955	CJJ	CJU	490	494.39	494.39	494.39	494.39	494.39	494.39	494.39	494.39	494.39	494.39	494.39	494.39	494.39	495.49	495.85	497.31
97	KE1241	GMP	CJU	500	504.39	504.39	504.39	504.39	504.39	504.39	504.39	504.39	504.39	504.39	504.39	504.39	504.39	505.49	505.85	507.31
98	KE1243	GMP	CJU	510	514.39	514.39	514.39	514.39	514.39	514.39	514.39	514.39	514.39	514.39	514.39	514.39	514.39	515.49	515.85	517.31
99	KE1245	GMP	CJU	540	544.39	544.39	544.39	544.39	544.39	544.39	544.39	544.39	544.39	544.39	544.39	544.39	544.39	545.49	545.85	547.31
100	KE1293	GMP	CJU	550	554.39	554.39	554.39	554.39	554.39	554.39	554.39	554.39	554.39	554.39	554.39	554.39	554.39	555.49	555.85	557.31
101	KE1247	GMP	CJU	560	564.39	564.39	564.39	564.39	564.39	564.39	564.39	564.39	564.39	564.39	564.39	564.39	564.39	565.49	565.85	567.31
102	KE1249	GMP	CJU	585	589.39	589.39	589.39	589.39	589.39	589.39	589.39	589.39	589.39	589.39	589.39	589.39	589.39	590.49	590.85	592.31
103	KE1295	GMP	CJU	620	624.39	624.39	624.39	624.39	624.39	624.39	624.39	625.49	625.85	627.31	629.75	634.63	649.26	625.49	625.85	627.31
104	KE1251	GMP	CJU	635	639.39	639.39	639.39	639.39	639.39	639.39	639.39	640.49	640.85	642.31	644.75	649.63	664.26	640.49	640.85	642.31
105	KE1023	PUS	CJU	640	644.39	644.39	644.39	644.39	644.39	644.39	644.39	645.49	645.85	647.31	649.75	654.63	669.26	645.49	645.85	647.31
106	KE1255	GMP	CJU	675	679.39	679.39	679.39	679.39	679.39	679.39	679.39	680.49	680.85	682.31	684.75	689.63	704.26	680.49	680.85	682.31
107	KE1297	GMP	CJU	685	689.39	689.39	689.39	689.39	689.39	689.39	689.39	690.49	690.85	692.31	694.75	699.63	714.26	690.49	690.85	692.31
108	KE1907	KWJ	CJU	690	694.39	694.39	694.39	694.39	694.39	694.39	694.39	695.49	695.85	697.31	699.75	704.63	719.26	695.49	695.85	697.31
109	KE1957	CJJ	CJU	710	714.39	714.39	714.39	714.39	714.39	714.39	714.39	715.49	715.85	717.31	719.75	724.63	739.26	715.49	715.85	717.31
110	KE1259	GMP	CJU	720	724.39	724.39	724.39	724.39	724.39	724.39	724.39	725.49	725.85	727.31	729.75	734.63	749.26	725.49	725.85	727.31
111	KE1263	GMP	CJU	750	754.39	754.39	754.39	754.39	754.39	754.39	754.39	755.49	755.85	757.31	759.75	764.63	779.26	755.49	755.85	757.31
112	KE1265	GMP	CJU	765	769.39	769.39	769.39	769.39	769.39	769.39	769.39	770.49	770.85	772.31	774.75	779.63	794.26	770.49	770.85	772.31
113	KE1267	GMP	CJU	790	794.39	794.39	794.39	794.39	794.39	794.39	794.39	795.49	795.85	797.31	799.75	804.63	819.26	795.49	795.85	797.31
114	KE1027	PUS	CJU	795	799.39	799.39	799.39	799.39	799.39	799.39	799.39	800.49	800.85	802.31	804.75	809.63	824.26	800.49	800.85	802.31
115	KE1269	GMP	CJU	810	814.39	814.39	814.39	814.39	814.39	814.39	814.39	815.49	815.85	817.31	819.75	824.63	839.26	815.49	815.85	817.31
116	KE1273	GMP	CJU	880	884.39	885.49	885.85	887.31	889.75	894.63	909.26	885.49	885.85	887.31	889.75	894.63	909.26	885.49	885.85	887.31
117	KE1031	PUS	CJU	905	909.39	910.49	910.85	912.31	914.75	919.63	934.26	910.49	910.85	912.31	914.75	919.63	934.26	910.49	910.85	912.31

-	Flight	Origin	Destination	Original schedule	s16	s17	s18	s19	s20	s21	s22	s23	s24	s25	s26	s27	s28	s29	s30	s31
1	KE1204	CJU	GMP	70	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46	74.46
2	KE1102	PUS	GMP	165	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	169.46	170.58	170.95	172.44	174.92	179.88	194.76	169.46
3	KE1208	CJU	GMP	170	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	174.46	175.58	175.95	177.44	179.92	184.88	199.76	174.46
4	KE1602	USN	GMP	185	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	189.46	190.58	190.95	192.44	194.92	199.88	214.76	189.46
5	KE1210	CJU	GMP	200	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	204.46	205.58	205.95	207.44	209.92	214.88	229.76	204.46
6	KE1212	CJU	GMP	210	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	214.46	215.58	215.95	217.44	219.92	224.88	239.76	214.46
7	KE1216	CJU	GMP	255	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	259.46	260.58	260.95	262.44	264.92	269.88	284.76	259.46
8	KE1280	CJU	GMP	270	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	274.46	275.58	275.95	277.44	279.92	284.88	299.76	274.46
9	KE1282	CJU	GMP	275	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	279.46	280.58	280.95	282.44	284.92	289.88	304.76	279.46
10	KE1106	PUS	GMP	285	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	289.46	290.58	290.95	292.44	294.92	299.88	314.76	289.46
11	KE1220	CJU	GMP	305	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	309.46	310.58	310.95	312.44	314.92	319.88	334.76	309.46
12	KE1224	CJU	GMP	310	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	314.46	315.58	315.95	317.44	319.92	324.88	339.76	314.46
13	KE1226	CJU	GMP	325	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	329.46	330.58	330.95	332.44	334.92	339.88	354.76	329.46
14	KE1228	CJU	GMP	340	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	344.46	345.58	345.95	347.44	349.92	354.88	369.76	344.46
15	KE1108	PUS	GMP	360	364.46	364.46	364.46	365.58	365.95	367.44	369.92	374.88	389.76	365.58	365.95	367.44	369.92	374.88	389.76	364.46
16	KE1230	CJU	GMP	395	399.46	399.46	399.46	400.58	400.95	402.44	404.92	409.88	424.76	400.58	400.95	402.44	404.92	409.88	424.76	399.46
17	KE1232	CJU	GMP	405	409.46	409.46	409.46	410.58	410.95	412.44	414.92	419.88	434.76	410.58	410.95	412.44	414.92	419.88	434.76	409.46
18	KE1234	CJU	GMP	430	434.46	434.46	434.46	435.58	435.95	437.44	439.92	444.88	459.76	435.58	435.95	437.44	439.92	444.88	459.76	434.46
19	KE1236	CJU	GMP	450	454.46	454.46	454.46	455.58	455.95	457.44	459.92	464.88	479.76	455.58	455.95	457.44	459.92	464.88	479.76	454.46
20	KE1238	CJU	GMP	475	479.46	479.46	479.46	480.58	480.95	482.44	484.92	489.88	504.76	480.58	480.95	482.44	484.92	489.88	504.76	479.46
21	KE1112	PUS	GMP	480	489.92	494.88	509.76	485.58	485.95	487.44	489.92	494.88	509.76	485.58	485.95	487.44	489.92	494.88	509.76	480
22	KE1284	CJU	GMP	515	524.92	529.88	544.76	520.58	520.95	522.44	524.92	529.88	544.76	520.58	520.95	522.44	524.92	529.88	544.76	515
23	KE1286	CJU	GMP	520	529.92	534.88	549.76	525.58	525.95	527.44	529.92	534.88	549.76	525.58	525.95	527.44	529.92	534.88	549.76	520
24	KE1288	CJU	GMP	525	534.92	539.88	554.76	530.58	530.95	532.44	534.92	539.88	554.76	530.58	530.95	532.44	534.92	539.88	554.76	525
25	KE1242	CJU	GMP	530	539.92	544.88	559.76	535.58	535.95	537.44	539.92	544.88	559.76	535.58	535.95	537.44	539.92	544.88	559.76	530
26	KE1246	CJU	GMP	550	559.92	564.88	579.76	555.58	555.95	557.44	559.92	564.88	579.76	555.58	555.95	557.44	559.92	564.88	579.76	550
27	KE1116	PUS	GMP	580	589.92	594.88	609.76	585.58	585.95	587.44	589.92	594.88	609.76	585.58	585.95	587.44	589.92	594.88	609.76	580
28	KE1248	CJU	GMP	590	599.92	604.88	619.76	595.58	595.95	597.44	599.92	604.88	619.76	595.58	595.95	597.44	599.92	604.88	619.76	590
29	KE1250	CJU	GMP	620	629.92	634.88	649.76	625.58	625.95	627.44	629.92	634.88	649.76	625.58	625.95	627.44	629.92	634.88	649.76	620
30	KE1252	CJU	GMP	625	634.92	639.88	654.76	630.58	630.95	632.44	634.92	639.88	654.76	630.58	630.95	632.44	634.92	639.88	654.76	625
31	KE1254	CJU	GMP	655	664.92	669.88	684.76	660.58	660.95	662.44	664.92	669.88	684.76	660.58	660.95	662.44	664.92	669.88	684.76	655
32	KE1256	CJU	GMP	665	674.92	679.88	694.76	670.58	670.95	672.44	674.92	679.88	694.76	670.58	670.95	672.44	674.92	679.88	694.76	665
33	KE1292	CJU	GMP	675	684.92	689.88	704.76	680.58	680.95	682.44	684.92	689.88	704.76	680.58	680.95	682.44	684.92	689.88	704.76	675
34	KE1120	PUS	GMP	705	714.92	719.88	734.76	710.58	710.95	712.44	714.92	719.88	734.76	710.58	710.95	712.44	714.92	719.88	734.76	705
35	KE1258	CJU	GMP	705	714.92	719.88	734.76	710.58	710.95	712.44	714.92	719.88	734.76	710.58	710.95	712.44	714.92	719.88	734.76	705
36	KE1294	CJU	GMP	730	739.92	744.88	759.76	735.58	735.95	737.44	739.92	744.88	759.76	735.58	735.95	737.44	739.92	744.88	759.76	730
37	KE1262	CJU	GMP	745	754.92	759.88	774.76	750.58	750.95	752.44	754.92	759.88	774.76	750.58	750.95	752.44	754.92	759.88	774.76	745
38	KE1122	PUS	GMP	780	789.92	794.88	809.76	785.58	785.95	787.44	789.92	794.88	809.76	785.58	785.95	787.44	789.92	794.88	809.76	780
39	KE1266	CJU	GMP	795	804.92	809.88	824.76	800.58	800.95	802.44	804.92	809.88	824.76	800.58	800.95	802.44	804.92	809.88	824.76	795
40	KE1296	CJU	GMP	805	814.92	819.88	834.76	810.58	810.95	812.44	814.92	819.88	834.76	810.58	810.95	812.44	814.92	819.88	834.76	805
41	KE1608	USN	GMP	820	829.92	834.88	849.76	825.58	825.95	827.44	829.92	834.88	849.76	825.58	825.95	827.44	829.92	834.88	849.76	820
42	KE1268	CJU	GMP	825	834.92	839.88	854.76	830.58	830.95	832.44	834.92	839.88	854.76	830.58	830.95	832.44	834.92	839.88	854.76	825
43	KE1124	PUS	GMP	840	849.92	854.88	869.76	845.58	845.95	847.44	849.92	854.88	869.76	845.58	845.95	847.44	849.92	854.88	869.76	840
44	KE1272	CJU	GMP	840	849.92	854.88	869.76	845.58	845.95	847.44	849.92	854.88	869.76	845.58	845.95	847.44	849.92	854.88	869.76	840
45	KE1274	CJU	GMP	870	879.92	884.88	899.76	875.58	875.95	877.44	879.92	884.88	899.76	875.58	875.95	877.44	879.92	884.88	899.76	870
46	KE1270	CJU	GMP	880	889.92	894.88	909.76	885.58	885.95	887.44	889.92	894.88	909.76	885.58	885.95	887.44	889.92	894.88	909.76	880
47	KE1276	CJU	GMP	900	909.92	914.88	929.76	905.58	905.95	907.44	909.92	914.88	929.76	905.58	905.95	907.44	909.92	914.88	929.76	900
48	KE1126	PUS	GMP	910	919.92	924.88	939.76	915.58	915.95	917.44	919.92	924.88	939.76	915.58	915.95	917.44	919.92	924.88	939.76	910
49	KE1278	CJU	GMP	925	934.92	939.88	954.76	930.58	930.95	932.44	934.92	939.88	954.76	930.58	930.95	932.44	934.92	939.88	954.76	925
50	KE1101	GMP	PUS	65	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24	76.24
51	KE1103	GMP	PUS	130	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	141.24	144.05	144.99	148.73	154.98	167.47	204.94	141.24
52	KE1002	CJU	PUS	165	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	176.24	179.05	179.99	183.73	189.98	202.47	239.94	176.24
53	KE1105	GMP	PUS	185	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	196.24	199.05	199.99	203.73	209.98	222.47	259.94	196.24
54	KE1107	GMP	PUS	265	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	276.24	279.05	279.99	283.73	289.98	302.47	339.94	276.24
55	KE1012	CJU	PUS	335	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	346.24	349.05	349.99	353.73	359.98	372.47	409.94	346.24
56	KE1014	CJU	PUS	360	371.24	371.24	371.24	374.05	374.99	378.73	384.98	397.47	434.94	374.05	374.99	378.73	384.98	397.47	434.94	371.24
57	KE1111	GMP	PUS	385	396.24	396.24	396.24	399.05	399.99	403.73	409.98	422.47	459.94	399.05	399.99	403.73	409.98	422.47	459.94	396.24
58	KE1115	GMP	PUS	485	509.98	522.47	559.94	499.05	499.99	503.73	509.98	522.47	559.94	499.05	499.99	503.73	509.98	522.47	559.94	485
59	KE1020	CJU	PUS	545	569.98	582.47	619.94	559.05	559.99	563.73	569.98	582.47	619.94	559.05	559.99	563.73	569.98	582.47	619.94	545
60	KE1119	GMP	PUS	605	629.98	642.47	679.94	619.05	619.99	623.73	629.98	642.47	679.94	619.05	619.99	623.73	629.98	642.47	679.94	605
61	KE1121	GMP	PUS	685	709.98	722.47	759.94	699.05	699.99	703.73	709.98	722.47	759.94	699.05	699.99	703.73	709.98	722.47	759.94	685
62	KE1026	CJU	PUS	695	719.98	732.47	769.94	709.05	709.99	713.73	719.98	732.47	769.94	709.05	709.99	713.73	719.98	732.47	769.94	695
63	KE1028	CJU	PUS	740	764.98	777.47	814.94	754.05	754.99	758.73	764.98	777.47	814.94	754.05	754.99	758.73	764.98	777.47	814.94	740
64	KE1032	CJU	PUS	805	829.98	842.47	879.94	819.05	819.99	823.73	829.98	842.47	879.94	819.05	819.99	823.73	829.98	842.47	879.94	805
65	KE1125	GMP	PUS	815	839.98	852.47	889.94	829.05	829.99	833.73	839.98	852.47	889.94	829.05	829.99	833.73	839.98	852.47	889.94	815
66	KE1036	CJU	PUS	905	929.98	942.47	-100	919.05	919.99	923.73	929.98	942.47	-100	919.05	919.99	923.73	929.98	942.47	-100	905
67	KE1201	GMP	CJU	50	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39	54.39
68	KE1001	PUS	CJU	60	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39	64.39
69	KE1203	GMP	CJU	70	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39	74.39
70	KE1209	GMP	CJU	85	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39	89.39
71	KE1205	GMP	CJU	100	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39	104.39
72	KE1207	GMP	CJU	140	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	144.39	145.49	145.85	147.31	149.75	154.63	169.26	144.39
73	KE1283	GMP	CJU	160	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	164.39	165.49	165.85	167.31	169.75	174.63	189.26	164.39
74	KE1285	GMP	CJU	165	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	169.39	170.49	170.85	172.31	174.75	179.63	194.26	169.39
75	KE1211	GMP	CJU	185	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	189.39	190.49	190.85	192.31	194.75	199.63	214.26	189.39
76	KE1213	GMP	CJU	190	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	194.39	195.49	195.85	197.31	199.75	204.63	219.26	194.39
77	KE1953	CJJ	CJU	195	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	199.39	200.49	200.85	202.31	204.75	209.63	224.26	199.39
78	KE1215	GMP	CJU	220	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	224.39	225.49	225.85	227.31	229.75	234.63	249.26	224.39
79	KE1005	PUS	CJU	230	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	234.39	235.49	235.85	237.31	239.75	244.63	259.26	234.39
80	KE1007	PUS	CJU	260	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	264.39	265.49	265.85	267.31	269.75	274.63	289.26	264.39
81	KE1903	KWJ	CJU	275	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	279.39	280.49	280.85	282.31	284.75	289.63	304.26	279.39
82	KE1219	GMP	CJU	285	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	289.39	290.49	290.85	292.31	294.75	299.63	314.26	289.39
83	KE1221	GMP	CJU	295	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	299.39	300.49	300.85	302.31	304.75	309.63	324.26	299.39
84	KE1223	GMP	CJU	310	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	314.39	315.49	315.85	317.31	319.75	324.63	339.26	314.39
85	KE1225	GMP	CJU	330	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	334.39	335.49	335.85	337.31	339.75	344.63	359.26	334.39
86	KE1287	GMP	CJU	360	364.39	364.39	364.39	365.49	365.85	367.31	369.75	374.63	389.26	365.49	365.85	367.31	369.75	374.63	389.26	364.39
87	KE1227	GMP	CJU	365	369.39	369.39	369.39	370.49	370.85	372.31	374.75	379.63	394.26	370.49	370.85	372.31	374.75	379.63	394.26	369.39
88	KE1291	GMP	CJU	390	394.39	394.39	394.39	395.49	395.85	397.31	399.75	404.63	419.26	395.49	395.85	397.31	399.75	404.63	419.26	394.39
89	KE1289	GMP	CJU	410	414.39	414.39	414.39	415.49	415.85	417.31	419.75	424.63	439.26	415.49	415.85	417.31	419.75	424.63	439.26	414.39
90	KE1231	GMP	CJU	415	419.39	419.39	419.39	420.49	420.85	422.31	424.75	429.63	444.26	420.49	420.85	422.31	424.75	429.63	444.26	419.39
91	KE1235	GMP	CJU	430	434.39	434.39	434.39	435.49	435.85	437.31	439.75	444.63	459.26	435.49	435.85	437.31	439.75	444.63	459.26	434.39
92	KE1015	PUS	CJU	440	444.39	444.39	444.39	445.49	445.85	447.31	449.75	454.63	469.26	445.49	445.85	447.31	449.75	454.63	469.26	444.39
93	KE1237	GMP	CJU	450	454.39	454.39	454.39	455.49	455.85	457.31	459.75	464.63	479.26	455.49	455.85	457.31	459.75	464.63	479.26	454.39
94	KE1239	GMP	CJU	465	469.39	469.39	469.39	470.49	470.85	472.31	474.75	479.63	494.26	470.49	470.85	472.31	474.75	479.63	494.26	469.39
95	KE1017	PUS	CJU	480	489.75	494.63	509.26	485.49	485.85	487.31	489.75	494.63	509.26	485.49	485.85	487.31	489.75	494.63	509.26	480
96	KE1955	CJJ	CJU	490	499.75	504.63	519.26	495.49	495.85	497.31	499.75	504.63	519.26	495.49	495.85	497.31	499.75	504.63	519.26	490
97	KE1241	GMP	CJU	500	509.75	514.63	529.26	505.49	505.85	507.31	509.75	514.63	529.26	505.49	505.85	507.31	509.75	514.63	529.26	500
98	KE1243	GMP	CJU	510	519.75	524.63	539.26	515.49	515.85	517.31	519.75	524.63	539.26	515.49	515.85	517.31	519.75	524.63	539.26	510
99	KE1245	GMP	CJU	540	549.75	554.63	569.26	545.49	545.85	547.31	549.75	554.63	569.26	545.49	545.85	547.31	549.75	554.63	569.26	540
100	KE1293	GMP	CJU	550	559.75	564.63	579.26	555.49	555.85	557.31	559.75	564.63	579.26	555.49	555.85	557.31	559.75	564.63	579.26	550
101	KE1247	GMP	CJU	560	569.75	574.63	589.26	565.49	565.85	567.31	569.75	574.63	589.26	565.49	565.85	567.31	569.75	574.63	589.26	560
102	KE1249	GMP	CJU	585	594.75	599.63	614.26	590.49	590.85	592.31	594.75	599.63	614.26	590.49	590.85	592.31	594.75	599.63	614.26	585
103	KE1295	GMP	CJU	620	629.75	634.63	649.26	625.49	625.85	627.31	629.75	634.63	649.26	625.49	625.85	627.31	629.75	634.63	649.26	620
104	KE1251	GMP	CJU	635	644.75	649.63	664.26	640.49	640.85	642.31	644.75	649.63	664.26	640.49	640.85	642.31	644.75	649.63	664.26	635
105	KE1023	PUS	CJU	640	649.75	654.63	669.26	645.49	645.85	647.31	649.75	654.63	669.26	645.49	645.85	647.31	649.75	654.63	669.26	640
106	KE1255	GMP	CJU	675	684.75	689.63	704.26	680.49	680.85	682.31	684.75	689.63	704.26	680.49	680.85	682.31	684.75	689.63	704.26	675
107	KE1297	GMP	CJU	685	694.75	699.63	714.26	690.49	690.85	692.31	694.75	699.63	714.26	690.49	690.85	692.31	694.75	699.63	714.26	685
108	KE1907	KWJ	CJU	690	699.75	704.63	719.26	695.49	695.85	697.31	699.75	704.63	719.26	695.49	695.85	697.31	699.75	704.63	719.26	690
109	KE1957	CJJ	CJU	710	719.75	724.63	739.26	715.49	715.85	717.31	719.75	724.63	739.26	715.49	715.85	717.31	719.75	724.63	739.26	710
110	KE1259	GMP	CJU	720	729.75	734.63	749.26	725.49	725.85	727.31	729.75	734.63	749.26	725.49	725.85	727.31	729.75	734.63	749.26	720
111	KE1263	GMP	CJU	750	759.75	764.63	779.26	755.49	755.85	757.31	759.75	764.63	779.26	755.49	755.85	757.31	759.75	764.63	779.26	750
112	KE1265	GMP	CJU	765	774.75	779.63	794.26	770.49	770.85	772.31	774.75	779.63	794.26	770.49	770.85	772.31	774.75	779.63	794.26	765
113	KE1267	GMP	CJU	790	799.75	804.63	819.26	795.49	795.85	797.31	799.75	804.63	819.26	795.49	795.85	797.31	799.75	804.63	819.26	790
114	KE1027	PUS	CJU	795	804.75	809.63	824.26	800.49	800.85	802.31	804.75	809.63	824.26	800.49	800.85	802.31	804.75	809.63	824.26	795
115	KE1269	GMP	CJU	810	819.75	824.63	839.26	815.49	815.85	817.31	819.75	824.63	839.26	815.49	815.85	817.31	819.75	824.63	839.26	810
116	KE1273	GMP	CJU	880	889.75	894.63	909.26	885.49	885.85	887.31	889.75	894.63	909.26	885.49	885.85	887.31	889.75	894.63	909.26	880
117	KE1031	PUS	CJU	905	914.75	919.63	934.26	910.49	910.85	912.31	914.75	919.63	934.26	910.49	910.85	912.31	914.75	919.63	934.26	905

The start point (00:00) of the schedule horizon was fixed at 7 a.m. The time of the slot was expressed in minutes from the start point. For making scenarios, the time of the slot was calculated with two factors (AAR and the AAR change point) from the original time slot. The number -100 in the time slot table means that the slot itself disappeared because it exceeded the curfew time.

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국문초록

본 연구의 목적은 항공 교통을 제어하는 중요한 수단 중 하나인 지상 지연 프로그램(GDP)이 발생할 경우 공항의 변경된 수용력에 대응하도록 항공사의 관점에서 항공편을 재조정하는데 도움을 주는 것이다. 단일 공항이 아닌 다중 공항으로 확장하여 동일한 공항뿐 아니라 다른 공항으로부터의 지연 전파를 고려했으며, 항공기 및 승무원의 계획된 일정에서 발생하는 현실적인 비용을 포함했다.

GDP가 발행되면 항공사들은 변경된 시간대에 맞춰 항공편을 재조정할 수 있는 짧은 시간이 주어진다. 각 공항에는 수용력이 있으며, 특히 들어오는 항공기를 수용할 수 있는 용량인 공항 수용률(AAR)이 있다. 이 연구에서 비행 스케줄을 재조정하기 위해 혼합 정수 선형 프로그래밍 모델을 세웠다. 또한, 미래의 불확실성을 다루기 위해, MILP의 두 가지 버전을 사용하였다. AAR이 어느 시점에 다시 바뀌는 시나리오를 만든 후, 각 시나리오 별로 총 관련 비용을 최소화하는 솔루션을 도출하는 최적 모델과 모든 시나리오 솔루션의 총 관련 비용의 기댓값을 최소화하는 솔루션을 도출하는 추계 모델을 제시하고 서로 비교하였다.

주요어: 혼합 정수 선형 프로그래밍, 추계 계획법, 일정 변경, 지상 지연 프로그램, 항공 교통 제어;

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