OPTIMIZING FLIGHT GATE SCHEDULING AT AIRPORT TERMINALS

by

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APPROVAL PAGE

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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M. S. Thesis - Industrial Engineering
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ABSTRACT

It is getting compulsory to develop efficient systems at the airports because of traffic intensity of air transporting. Physical development; could be realized only in the restricted area so it is meaningful to concentrate operational managements at airport terminals.

One of the most important operations at the airport terminals is flight gate scheduling. These scheduling are concerned with efficient usage airport gates. Severe weather, unusual flight delay, equipment failure cause of constantly changing of assignment plans.These changing could disrupt the plannings of assignment.It is very important to arrange the idle time between two aircraft so that these disruption can be abserbed. This work evaluates three previous models from literature and proposes a new one under which the optimal solutions can be obtained in polynomial time.All model objectives are to minimize the variance of idle time. We use Xpress Mp and Lingo programs to solve these models in test problems. Finally real data set is used to evaluate the efficiency of the model proposed here.

Keywords: assignments, homogenous gates, heterogeneous gates, flight gate scheduling

HAVAALANI TERMİNALLERİNDE UÇUŞ KAPI ÇİZELGELEME OPTİMİZASYONU

Ahmet Gürcan ÇAPRAZ

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ÖZ

Havayolu taşımacılığındaki trafik yoğunluğun artması havaalanlarının verimli sistemlerin gelişimini zorunlu hale getiriyor. Fiziksel şartların iyileştirilmesi sınırlı bir alanda olacağından havaalanı terminallerindeki operasyonel işletmelerin iyileştirilmesi daha anlamlı hale gelmiştir.

Havaalanı terminallerindeki en önemli operasyonlardan biri uçuş kapı çizelgelemesidir. Bu çizelgelemeler havaalanlarındaki kapıların verimli kullanımı ile ilgilidir. Kötü hava koşulları, beklenmeyen gecikmeler ve hatalı parçalar yapılmış olan atama planlarının sürekli değişmesine neden olmaktadır. Bu değişiklikler yapılan atama planlarının bozulmasına neden olmaktadır. İki uçağın kapıyı kullanmaları arasında kalan boş zamanların iyi ayarlanması, bu bozulmaların absorbe edilebilmesi için çok önemlidir. Bu çalışmada literatürdeki üç eski ve tavsiye edilen yeni bir modelin polinomial zamanda hangi koşullar altında optimum çözümü verdiğini göstereceğiz. Bütün modellerin amaç fonksiyonu boşluk zamanlarının varyanslarının minimize edilmesi ile ilgilidir. Xpress Mp ve Lingo programları kullanılarak modellerin çözümleri denenmiştir. Sonuç olarak bu çalışmada tavsiye edilen modelin verimliğini değerlendirmek için gerçek veri kümeleri kullanılmıştır.

Anahtar Kelimeler: atamalar, homojen kapılar, heterojen kapılar ,uçuş kapı çizelgelemesi.

DEDICATION

To my wife Derya , my daughters Handan Hülya and Zeynep Azra.

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INTRODUCTION

1.1 INTRODUCTION

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports.

Airport economics survey, ACI World Annual Report (2010), contains strong response from 646 airports that together handled 3.23 billion passengers or about 67.5 percent of worldwide traffic in 2009, and provides unique and comprehensive insights into economics and finances of airports around the world.Top line figures of the 2010 Airport Economics Survey covering the financial year 2009 / 2010 were:

- Total airport industry revenue: USD 95 billion
- Proportion of non-aeronautical revenue: 46.5%
- Income from aircraft related user charges: USD 17.3 billion
- Total operating expenses: USD 57 billion (60% revenue)
- Capital expenditure 2009: USD 34.6 billion
- Interest and depreciation: USD 29.5 billion
- Global airport industry long term debt: USD 280 billion - 3 times higher than annual revenue

Strong competition between airlines and the demand of passengers for more comfort have lead to complex planning problems that require new models and methods. The scheduling problems nowadays faced by airport and airline managers are even more complicated than most other traditional scheduling problems. This fact can be easily explained. First of all, a wide range of resource modules apparently have to be considered: flights, terminals, crews, baggage etc. Moreover, decisions about the usage of these resources influence each other, that is, the resources are highly interdependent.

As a consequence, these modules set up the basis of a complex resource management system for airports and airlines of any size.

The term ``gate'' is used to designate not only the facility through which passengers pass to board or leave an aircraft but also the parking positions used for servicing a single aircraft (Bolat, 2000).

A 'gate' is synonymous with the space within a terminal building from where the boarding process starts. Boarding can either start into an aircraft (contact gate) or into a bus taking the passengers to an aircraft parked on a remote stand (bus gate) This includes a setup where passengers leave the terminal building via stairs and walk across the apron area towards the parking aircraft they depart with. Research undertaken assumes that in case a gate could be allocated, there would be a contact stand associated with this gate, or a remote stand would have to be allocated for that flight.

These station operations usually account for a smaller part of the overall cost of an airline's operations than the flight operations themselves.However, they can have a major impact on the efficiency with which the flight schedules are maintained and on the level of passenger satisfaction with the service.

The facilities and staffing levels of gates are planned to ensure that the traffic expected can be handled in the most cost-effective way. The estimations are often based on the average targeted number of operations per hour given the requirements of expected flights. Obviously, there is a tradeoff between the level of traffic (the level of service provided to passenger) and the overall costs of gates.

1.2 GATE WAITING DELAY

In 2007, flight delays cost passengers and airlines $12 to $14 billion in lost time and fuel (Robyn, 2008). In 2010, nationwide air traffic congestion is predicted to cost $46 billion to the nation's economy (Federal Aviation Administration, 2009).

This phenomenon is closely related to gate assignment, gate arrival process, turnaround process.

Gate assignment is usually handled in three phases (Bazargan, 2004).

Phase 1. Feasibility Check

The first phase is a long term planning effort which occurs several months before the day of operation. Ground controllers check that a feasible gate assignment can be made with the proposed flight schedule, without making an actual gate assignment. A gate assignment planning tool can be used to give an overall sense of the gate assignment plan. The schedule must be changed or reduced if there are not enough gates (except for over-scheduling).

Phase 2. Development of Daily Gate Assignment Plan

The second phase involves development of a single-day plan prior to the start of the actual day of operation. A gate assignment tool, similar to the planning tool, can be used to get the initial gate assignment plan at the start of the day.

Phase 3: Change of Gate Assignment During Operation

The third phase revises these daily plans throughout the day of operation due to irregular operations such as delays, bad weather, mechanical failures and maintenance requirements (Bolat, 2000). The same gate assignment tool can be used to create the initial gate board at the beginning of the day (phase 2) and to update the gate assignment throughout the day (phase 3). These updates affect gate waiting, and hence flight on-time performance, as well as airport staffing and passenger relocations. The updates are made based on gate controllers' experience sometimes with the assistance from computer algorithms.

If gate delay is a result of an airline's reluctance to change gate assignment at the last moment, one strategy to reduce gate delay is to use more efficient gate assignment algorithms to effectively increase the number of usable gates. Algorithms were developed to improve gate assignment robustness in planning and reduce gate idle time in operation.

1.3 FLIGHT-GATE SCHEDULING

There are several major classes of decisions for which airline and airport management is responsible: crew scheduling, disruption management, airline fleet assignment, aircraft scheduling and rotation, ground operations scheduling and some others that can be modeled as traditional machine scheduling problems. Nevertheless, one of the most important and most complicated airport management topics is flight gate scheduling.

The main purpose of gate scheduling is to find an assignment of flights, or rather the aircraft serving a flight, to aircraft stands, as well as start and completion times for processing an aircraft at the position it has been assigned to. Aircraft stands at the terminal and off-pier stands on the apron are often simply referred to as “gates’’.

Of course, a gate assignment must be suitable for airport services and convenient for passengers.

A well-constructed schedule must satisfy a set of strict rules and constraints:

1. One gate can process only one aircraft at the same time,
2. Service requirements and space restrictions with respect to adjacent gates must be fulfilled,
3. Minimum ground time and minimum time between subsequent aircraft have to be assured.

Typical objectives are:

1. The total walking distance for passengers has to be minimized,
2. Preferences of certain aircraft for particular gates have to be maximized,
3. The number of un-gated (open) aircraft activities has to be minimized,

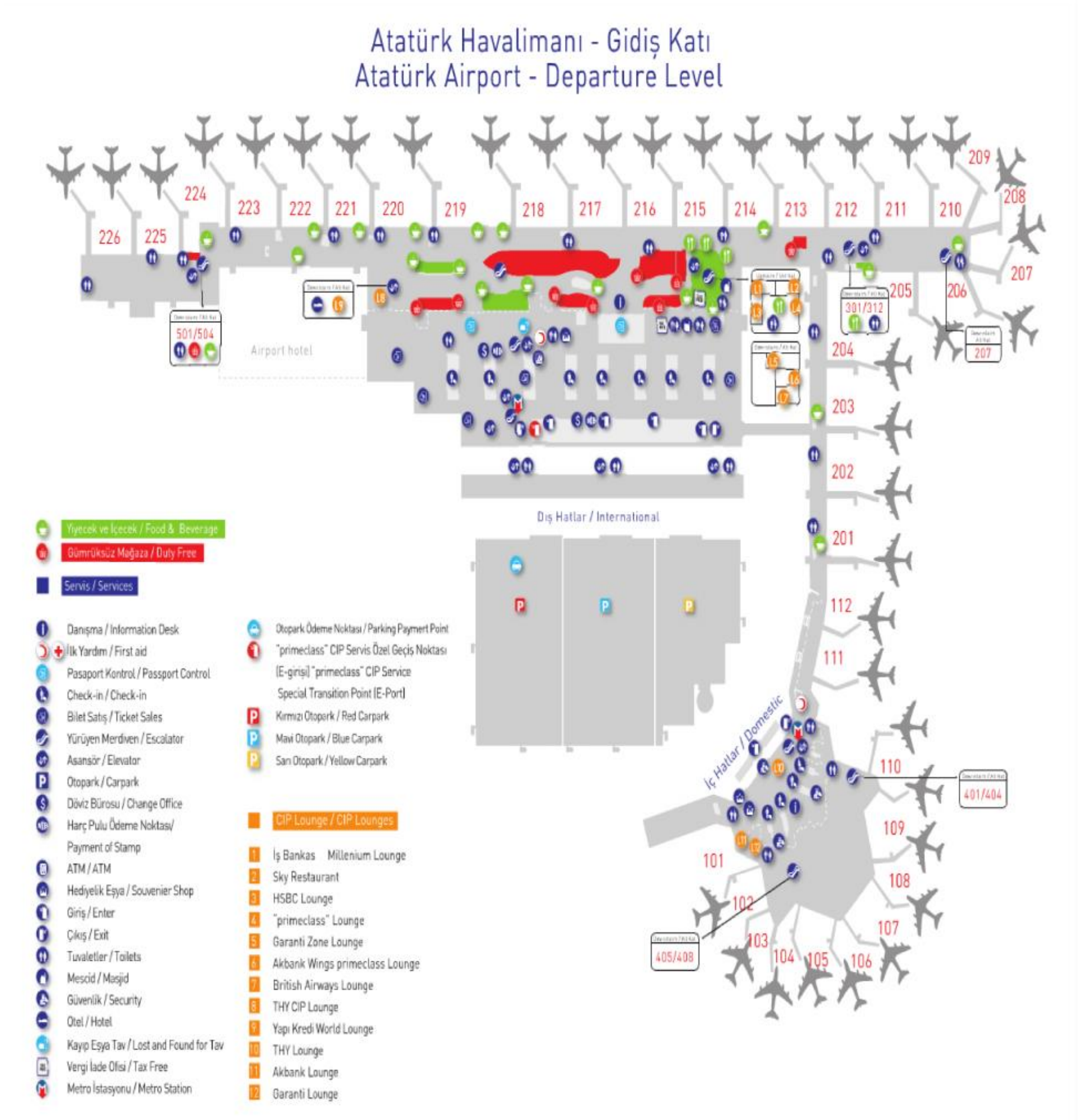

Figure1.1 Atatürk Airport Terminal

4. The deviation of the current schedule from a reference schedule has to be minimized in order to increase schedule robustness and passenger comfort,

5. The number of expensive aircraft towing procedures (that otherwise decrease the available time for some ground service operations on the ramp as well as in the terminal) has to be minimized,

6. To maximize the robustness of the schedule by distributing the idle times as uniform as possible.

Some special soft or strict constraints may also be introduced . For example, the assignment of a large aircraft to a particular gate may imply that neighboring gates can only accept aircraft of a certain size or are even completely blocked.

All these requirements make a gate scheduling problem very complicated both from a theoretical and a practical point of view. In fact, the multiple criteria and multiple constraints nature of the problem make it very unlikely that an optimal solution can be found and verified. Therefore, one has to determine a solution that provides an appropriate compromise between all the different objectives while assuring a set of hard constraints. Moreover, any practical gate scheduling instance of a big international airport usually has to deal with a large number of daily aircraft activities (around 1000) which have to be assigned to a pretty large number (around 100) of different flight gates.

The basic input data for gate scheduling is a flight timetable with arrival and departure times and additional specifications of flights: the origin and destination of a flight, the type of aircraft, the number of passengers, the cargo volume, the type of flight (domestic or international) as well as gate preferences, required airport services and inspection facilities.

It is worth pointing to—from a practical point of view—one of the most important issues of gate scheduling: A gate schedule should be insensitive to small changes of input data; in other words schedule flexibility is required. Obviously, the input data of any flight gate scheduling problem are subject to uncertainty and may change over time.Input data uncertainty in gate scheduling may have a couple of reasons:

1. Flight or gate breakdown,
2. Flight earliness or tardiness,
3. Emergency flights,
4. Severe weather conditions,
5. Errors made by staff and many others,
6. Equipment failure.

For example, a tardy arrival of one aircraft may generate a chain of delayed arrivals for other aircraft which have been assigned to the same gate. In the worst case, this may lead to a “domino effect’’ and finally require a complete rescheduling, a fact which is absolutely undesirable. (Dorndorf et al., 2007).

In this thesis, while we are solving the flight gate scheduling problem, our initial objective is to maximize the customer satisfaction through minizing variance of idle times between flights . The objectives are to consider all managerial and physical considerations to provide the required service level, and to make the assignments insensitive to the stochastic changes on flight schedules. A mixed-binary quadratic model (initial model), Homogeneous Gate Model, Heterogeneous Gate Model and New Homogeneous Gate Model are formulated to minimize the variance of idle times at gates.

We apply four-phase solution approach in order to solve flight gate scheduling. We worked with randomly generated data and real data obtained from Atatürk Airport for a week. The former researches considered 25 flight small size gate assignment problems, 50 flight medium size gate assignment problems and 100 flight big size gate assignment problems.We succeded to assign 400 flights to 25 gates for Homogenous Gates model. Similarly, we were able to assign 80 flights to 10 heterogeneous gates.

We apply two case study for the new homogeneous model with real data . First case study includes 118 flight to 10 gate and second case study includes 338 flights to 7 gate in the Atatürk Airport International terminal.

The remainder of this work is organized as follows: In Chapter 2, we review the related literature for the Flight Gate Scheduling. In Chapter 3, we report our observation about the models and then we explain the details of our solution method. Finally, Chapter 4 summarizes our findings and conclusions.

CHAPTER 2

LITERATURE REVIEW

"Flight Gate Scheduling" is also known as the "Gate Assignment Problem" (GAP). It is "an easilyunderstood but difficult to solve problem" (Haghani and Chen, 1998). Depending on the management of the airports it is the problem of the airport authorities or it is the problem of the airline. In either case, the constraints and policies of the airport also play an important role in this subject.

In some cases, both the management of the airport and the airline cooperate well to define their domain for operations. Murty (2008), mentions the "dynamic operational environment in modern busy airports, increasing numbers of flights and volumes of traffic, uncertainty (random deviations in data elements like arrival, departure times from flight time tables and schedules), its multi-objective nature, and its combinatorial complexity make the flight-gate assignment a very complicated decision problem both from a theoretical and a practical point of view."

We can try to solve the problem in several ways, like IP (integer problem) or MILP (mixed integer linear programming). "The basic constraints of the IP are that one aircraft is to be assigned to only one gate and two aircraft cannot be assigned to the same gate when their apron times overlap" Haghani and Chen (1998).

If GAP problem is concerned with only one target, such as passenger walking distance, then it is called as “Quadratic Assignment Problem” (QAP). It is also explained in Haghani and Chen (1998) and Dorndorf et al. (2007). That the gate assignment problem is an NP-hard (NP, non-deterministic polynomial time, is a complexity class in computational) problem. For Quadratic Assignment Problems that are NP- hard, there is no polynomial time bound algorithm for their solution and only implicit enumeration methods are known for solving them optimally. Also Lam et al. (2002) confirm that in technical terms, the gate assignment problem is combinatorial in nature, NP-hard, and cannot be optimized easily within a practical time frame.

This is one of the reasons which have been made about GAP. A variety of solutions can be applied through computers using different techniques. Hamzawi (1986) discussion the way to change from mainframe to microcomputers. Cheng (1997) classifies the work as assignment methods, problem solving methods and objective functions used. Assignment methods may be sequential (following a strict order), parallel (consider all flights and all gates concurrently) or grouped in a problem-oriented way (i.e. combination of the previous two methods). One of the first usages of the sequential assignment method is that of Hamzawi (1986). His basic framework is still valid for most approaches that aim to implement solutions of the GAP. He used his model as a planning tool in some airports in Canada. Also Mangoubi and Mathaisel (1985) considered a sequential approach, and implemented in a heuristic problem solving method.

It is usually observed that a better quality is achieved. When the paralell assignment method is applied. Because of the combinatorial nature of the problem, Babic et al. (1984) as well as Mangoubi and Mathaisel (1985) discovered that if one uses a plain paralell assignment method, it is clearly possible to compute a solution. Thus, the problem-oriented group assignment method promised to work better for many researchers.

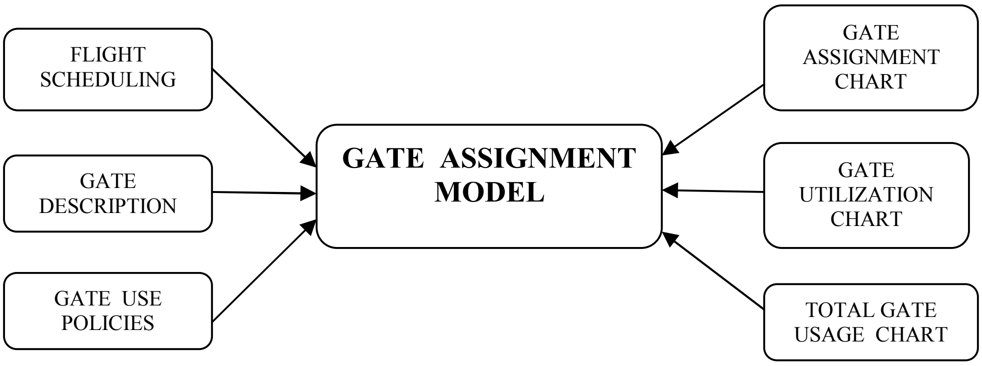

Figure 2.1 Model framework according to Hamzawi (1986,p193)

There are three ways about the problem solving method: mathematical programming approaches, heuristics and knowledge-based approaches. Although the first one gives exact solutions applying various mathematical programming methods like branch-and-bound, linear programming (with relaxation) or pure integer programming, it's main disadvantage is the huge amount of computing time. This is because of the combinatorial growth of the solution space. Researchers in this area also claim that it is very complex or impractical to change the objective function. In fact, practitioners often regard solutions as too simple, because the objective functions do not reflect the real world. Tosic (1992) also emphasizes the challenges with a large number of flights and gates.

Many heuristics have been tried to overcome the timing problem as problem solving method for all assignment methods. Early approaches have been conducted by

Mangoubi and Mathaisel (1985), or by Hamzawi (1986) for sequential assignment, and then later for problem-oriented group assignments. In Figure 2.1 Hamzawi (1986) describes the framework for such approach. According to Cheng (1997), six heuristics have been tested by Zhang et al. (1994) producing favourable results. Gu and Chung (1999) applied a genetic algorithm heuristic to the GAP, and most recently Hu and Di Paolo (2007). Ding et al. (2004) used a greedy algorithm with tabu search. A year later Ding et al. (2005) applied a pure simulated annealing approach to improve timing and then a hybrid simulated annealing with tabu search approach to delivere good results. Also Yan and Tang (2007) implemented a model with a heuristic method. But the problem with this is heuristic that it is specialized for certain situations. So, for a different setting of the problem it might become necessary to implement another heuristic.

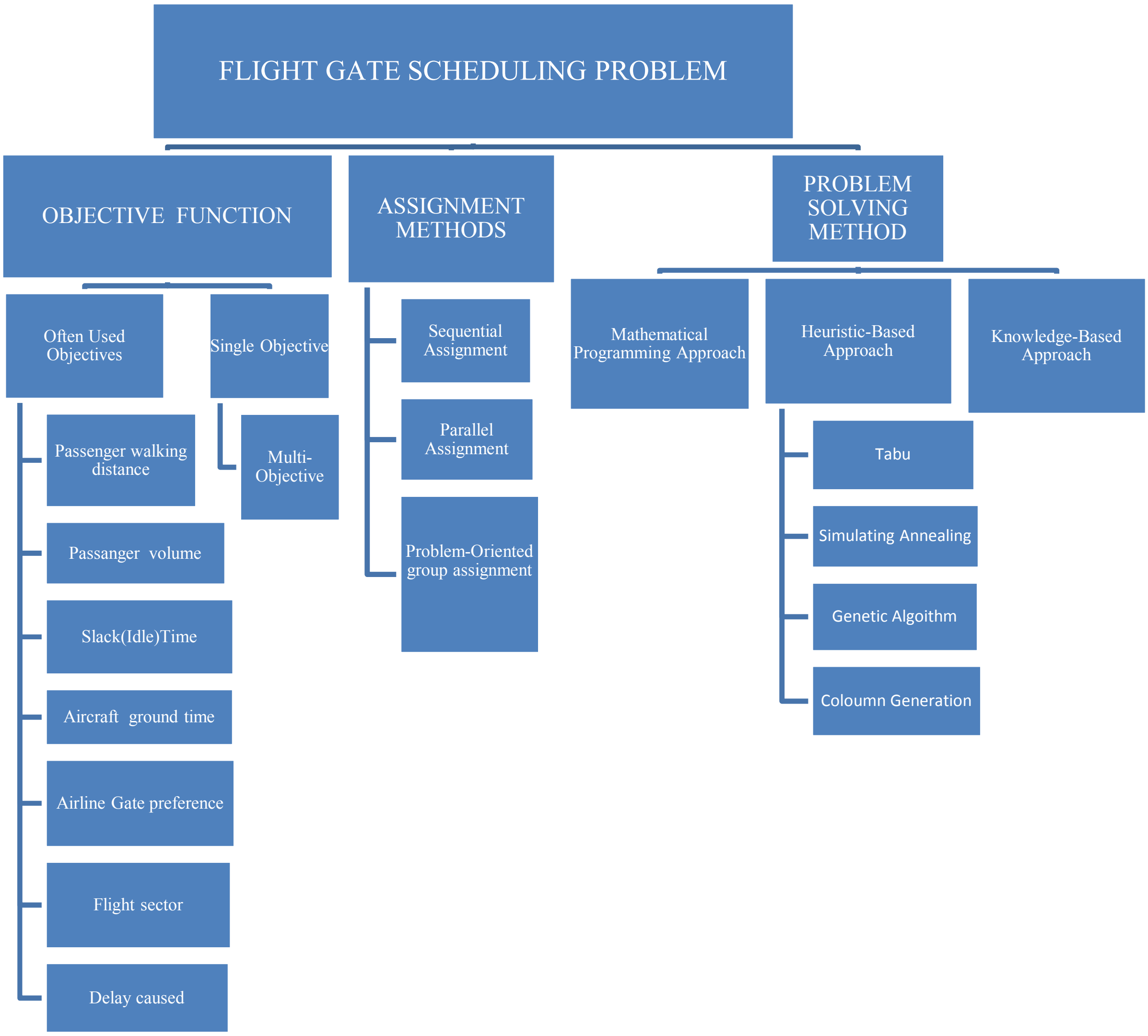

Figure 2.2 Flight Gate Scheduling Problem Diagram

Knowledge-based approaches are usually implemented in form of expert systems (Brazile and Swigger, 1988; Su and Srihari, 1993; Cheng, 1997; Cheng, 1998). In this context, an expert system is usually understood as a system that comprises the knowledge of personnel, which usually performs the gate assignment task. This is the implementation of an assignment method (sequential, parallel, problem-oriented) following the knowledge-based approach as the problem solving method. This type of knowledge is captured in form of rules. There may be different types of rules: hard rules (conflicts); soft rules: dependency rules (e.g. between resources), preference rules (e.g. airline wishes) and complex rules (e.g. passenger way combinations). Furthermore, rules may have specific situations or time windows when they are applied or when explicitly not. Moreover, it may be decided whether a system is used purely for planning purpose or also for real-time assignments. In terms of interaction, it may further be distinguished between user-interference during flight operations being permitted, or an autonomously running system. Expert systems are good solutions to cope with uncertainty, and to extend the knowledge-base. Unfortunately, in order to consider a large number of rules, similar to the mathematical programming approach, computing time becomes very long.

The early approaches have not addressed the dynamic nature of gate assignments, says Yan and Tang (2007). So they developed a heuristic approach and tested it successfully at Taiwan Taoyuan International Airport. The main components of their model include a stochastic flight delay gate assignment model for the planned gate assignments, a reassignment rule to be applied in real-time operations and two penalty adjustment methods. Their work is partly based on previous work of Yan, Shieh and Chen (2002) who addressed stochastic flight delays, and flexible buffer times in the context of gate assignments. Earlier works of Hassounah and Steuart (1993), Yan and Chang (1998), and Yan and Huo (2001) already used buffer times to address the delay aspect. However, those buffer times were fixed.

There is a summary and the structure of the main aspects and solution methods in Figure 2.2. It is observed that previous approaches purely focus on operations, and that they do not show any application in commercial airport processes.

The following are the summaries of the recent researches about the flight gate scheduling.

Maharjan and Matis (2011), consider an optimization model for gate reassignment in response to flight delays. They propose a binary integer program in this paper which is formulated for the best assignment of planes to the gates in case of day-of flight delays. This programme reduces the walking distance of the passengers to minimum, those having connecting flights or coming from the original airports who had taken boarding tickets before the reassignments for the affected flights. There is also a numerical illustration that demonstrates the speed and efficiency of this program in both the real world and the real time setting. A binary integer program formulation minimizes the walking distance of passengers between disrupted flights if these reassignments are not made within sufficient lead time for gate information to be correctly printed on a passengers boarding ticket. At some experiences it proved to give very good solutions in a matter of seconds.

Wen and Yu (2009), proposes Graph Coloring Model and an algorithm for Airport Gate Assignment. The characteristics of time intervals are analyzed and a graph coloring model for airport gate assignment is set up. The vertex sequence coloring algorithm is presented according to the rule “First-In First-Out”. At the end, there is an example to demonstrate the application of this algorithm.

Yang and Hu (2009), propose a strategy in order to improve the efficiency of gate assignment. It predicts the arrival time and departure time of each flight, and then assigns flights to gates according to the forecasting results. To improve the low forecasting precision of traditional GM(1, 1) model, a moving operator is presented to improve the traditional GM(1, 1) model, and the improved GM(1, 1) model predicts the arrival time and the gate occupation time of a flight. Then a 0-1 programming model is proposed to minimize the passenger walking distances within the airport terminal area. A heuristic algorithm is designed for the model. Test results show that the gate assignment on the basis of forecasting results is better than that of the flight schedule in both efficiency and passenger satisfaction.

Zheng et al. (2010), propose a model to appoint a gate for the arrival or leave flight and to ensure that the flight is on schedule. Assigning the airport gate with high efficiency is a key task among the airport ground busywork. As the center of airport operation, aircraft gate assignment is known as a kind of complicated optimization problem. This paper proposed a strong assignment model to minimize the overall contradiction of time. According to the characteristics of the target function, a Tabu Search (TS) algorithm and meta-heuristic method are given to solve the gate assignment problem. A number of numerical simulations are made to show that the meta-heuristic TS and random algorithm TS have made an improvement of 60.63%. Thus the meta-heuristic method and TS in the airport gate assignment problem is feasible and efficient.

Nikulin and Drexl (2009), address the airport flight gate scheduling problem with multiple objectives to maximize the total flight gate preferences, to minimize the number of towing activities, and to minimize the absolute separation of the new gate assignment from a reference schedule.

Dong and Chang (2009), propose a fuzzy model to handle two main goals, minimizing the total walking distance for passengers and maximizing the strength and the efficiency of assignment. The free times of flight-to-gate are regarded as fuzzy variables, and membership degrees are used to express influence on strength of assignment. Adjustment function on membership degree is used to transfer two aims into one. An illustrative example is given to evaluate the performance of fuzzy model. Three distribution functions are tested and comparison with the method of fixed buffer time is given. The results of the simulation show the feasibility and effectiveness of proposed fuzzy method.

Yan et al. (2008), develop a reassignment model for the purpose of helping airport authorities with flight-to-gate reassignments at temporary airport closures. The aim of the model is to minimize the number of gate changes. An evaluation of how good the performance of the model is presented, using real operating data from the Chiang Kai-Shek International Airport in Taiwan. Several problem instances of different scales are generated to test the model's efficiency. The results show that the network model would be useful for actual operations.

İmga (2010), has discussed the gate assignment and used the data which is received from Ataturk International Airport. Aircrafts that use the airport with a given flight schedule and types are assigned to available gates considering the aircraft - gate size compatibility, domestic and international terminal priority and customer satisfaction which is directly related to the walking distance. It offers a way that combines a mathematical programming techniques and a greedy heuristic. In order to test the solution approach, one week data of Ataturk Airport including 2323 domestic and international flights, 68 aircraft types, 32 gates and 58 remote parking areas is used. The test results are compared with the results obtained by the approach which is currently used at the airport. The solution method assigns more flights to the related terminal gates and also provides higher customer satisfaction.

CHAPTER 3

MATHEMATICAL MODELS AND SOLUTIONS

3.1 INTRODUCTION

In this chapter, we introduce some mathematical models for flight gate scheduling. These are initial model, homogenous gate model and heteregoneous gate model and new homogeneous gate model. First three model from, the work of Bolat (2000) improved. We Explain and analysis of these models helping lingo and xpress mp programs.

3.2 INITIAL MODEL

Assume that there are N flights to be assigned to M gates over a certain period of time, and the expected arrival and ground time of flights are known in advance. Binary parameter $P_{j,k}$ is used for each possible assignment: It is set to 1 when the assignment of flight j to gate k is permissible, that is, it satisfies all physical and managerial considerations, and results in passenger service satisfaction above the target level. The following additional notation will be used to formulate the model:

A_j scheduled arrival time of flight j,

D_j scheduled departure time of flight j,

G_j ground time of flight j, i.e. ,($G_j = D_j - A_j$),

$L_{0,k}$ earliest available time of gate k in the beginning of planning period,

$L_{N+1,k}$ latest available time of gate k at the end of the planning period,

$$X_{j,k} = \begin{cases} 1 & \text{if flight j is assigned to gate k;} \\ 0 & \text{otherwise} \end{cases}$$

$E_{j,k}$ entering time of flight j to gate k,

$L_{j,k}$ leaving time of flight j from gate k,

$S_{j,k}$ the last idle time (slack time) at gate k until the arrival of the flight j,

$S_{N+1,k}$ idle time at gate k after the last departure from this gate.

Without loss of generality, it is assumed that the flights are sorted in ascending order of their arrival times so that $A_i \leq A_j$ if $i \leq j$. The following mixed-binary quadratic programming model is proposed to assign the flights to gates with the minimum variance of idle times:

$$\text{Min} \sum_{k=1}^{M} \sum_{j=1}^{N+1} S^2(j,k) \quad (1)$$

s.t.

$$\sum_{k=1}^{M} Y(j,k)\, X(j,k) = 1 \qquad j = 1,..,N \quad (2)$$

$$E_{j,k} \geq A_j X_{j,k}, \qquad j = 1, \ldots, N, \quad k = 1, \ldots, M, \quad (3)$$

$$E_{j,k} \geq L_{j-1,k}, \qquad j = 1, \ldots, N, \quad k = 1, \ldots, M, \quad (4)$$

$$L_{j,k} = E_{j,k} + G_j X_{j,k}, \qquad j = 1, \ldots, N, \quad k = 1, \ldots, M, \quad (5)$$

$$S_{j,k} = E_{j,k} - L_{j-1,k}, \qquad j = 1, \ldots, N, \quad k = 1, \ldots, M, \quad (6)$$

$$S_{N+1,k} = L_{N+1,k} - L_{N,k}, \qquad k = 1, \ldots, M, \quad (7)$$

$$X_{j,k} = 0 \text{ or } 1, \qquad j = 1, \ldots, N,\ k = 1, \ldots, M, \quad (8)$$

$$E_{j,k},\ L_{j,k},\ S_{j,k},\ S_{N+1,k} \geq 0, \qquad j = 1, \ldots, N,\ k = 1, \ldots, M, \quad (9)$$

(Bolat,2000)

First of all, let us discuss the constraints:

Eq. (2) guarantees the assignment of each flight to one of the available and permissible gates. Constraint (3) and (4) are used to implement the fact that $E_{j,k} = \max \{A_j X_{j,k}, L_{j-1,k}\}$. If there is an assignment ($X_{j,k} = 1$) , then constraints (3), (5) and (6) will be binding ($E_{j,k} = A_j$, $L_{j,k} = D_j$, and $S_{j,k} = E_{j,k} - L_{j-1,k}$) Otherwise ($X_{j,k} = 0$), constraint (4) will be binding and a dummy idle time will result in (Ej,k = Lj-1,k , Lj,k = L j-1,k , and Sj,k = 0). For a N-Flight and M-gate problem, the number of assignments is N, and the number of non-dummy idle times is N+M. The idle times at the beginning of horizon are determined by Eq. (6) when j=1, and the ones at the end by Eq. (7). Note that the dummy slacks do not have any effect on the objective function.

Now we present the idea behind using surrogate objective equation 1. Note that the total idle times is equal to the difference between the total available time of gates and the total ground time of flights, i.e.,

T.A.G =Total Available time of gates;

$$\sum_{k=1}^{M} \left(L(N+1,k) - L(0,k) \right) \tag{10}$$

($L_{0,k}$,$L_{N+1,k}$) Earliest And latest available time of gate k.

T.G.F = Total duration of aircrafts at gates;

$$\sum_{k=1}^{M} G() \tag{11}$$

Total Slack (idle) Time of Gates

T.S.G = T.A.G - T.G.F

$$\text{Min} \sum_{k=1}^{M} \sum_{j=}^{N+1} S(,k) = \sum_{k=1}^{M} \left(L(N+1,k) - L(0,k) \right) - \sum_{j=1}^{N} G(j) \tag{12}$$

Thus, the mean value of slack times is constant, regardless of the way that the flights are assigned. Since minimizing variance is equivalent to minimizing the second moment centered at zero, equation (1) can be utilized instead of a more complicated formula to determine the variance of idle times. The minimum variance of the final solution can be calculated by a simple transformation with constant factors.

3.2.1 Initial Model Example

The following example is used to expose the details of the formulation. There are 4 flights and 2 gates available between 0 and 10 unit time.

Table3.1 Data for initial model example

Flight no	A_j	D_j
1	1	4
2	2	5
3	5	8
4	6	9

Table3.2 Solution table for initial model example

	E(i,j)		L(i,j)		S(i,j)	
flight	Gate1	Gate2	Gate1	Gate2	Gate1	Gate2
1	1	0	4	0	1	0
2	4	2	4	5	0	2
3	5	5	8	5	1	0
4	8	6	8	9	0	1
N+1	10	10	-	-	2	1

İf X1,2=X2,2=X3,2=X4,1= 1and otherwise=0 ; $\sum S^2=14$
If X1,2=X2,2=X3,1=X4,2= 1and otherwise=0 ; $\sum S^2=12$

Lingo solution assigns flights 2 and 3 to gate 1 and flights 1 and 4 to gate 2

Local optimal solution found.

Objective value: 12.000000

Extended solver steps: 105

Total solver iterations: 1436

Model Title: Quadratic Gate Assignment

Variable	Value
X(1, 1)	1.000000
X(2, 2)	1.000000
X(3, 1)	1.000000
X(4, 2)	1.000000

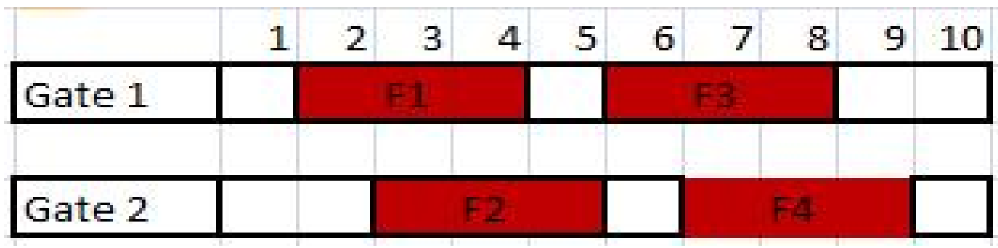

Figure3. 1 Solution graph of initial model example

3.3 HOMOGENOUS GATE MODEL

Let Yi,j be equal to 1 if flights i and j are consecutively assigned to the same gate, where i=1,…,N-1 and j=i+1,…,N. Since the gates identical, the gate to which the previous flight i was assigned is no longer important to determine whether to assign flight j immediately after flight i. For the beginning and ending effect of the horizon, we define some additional variables. Specifically, let $Y_{0,j}$ be equal to 1 if flight j is the first flight assigned to a gate where j=1,2,…,N, and $Y_{i,N+1}$ be equal to 1 if flight i the last flight assigned to a gate where i=1,2,…,N.

Since the gates are homogenous, all gates are available between 0 and H time units, That is, B_k =0 for each k and F_k =H for each k. We let $I_{i,j}$ be the idle period between flights i and j if they are successively assigned to the same gate. Notice that

$$I_{i,j} = \begin{cases} A_j - D_i & \text{if } A_j \geq D_i \\ Z & \text{Otherwise} \end{cases} \qquad (13)$$

Here Z is used to indicate that assigning successively flights i and j to the same gate infeasible. Similarly, we define $I_{0,j}$ and $I_{i,N+1}$ for the idle times of the first and last assignments, that is,

$$I_{0,j} = A_j \qquad j=1,\ldots,N \qquad (14)$$

$$I_{i,N+1} = H - D_i \qquad i=1,\ldots,N \qquad (15)$$

Pure binary linear mathematical model that minimizes the variance of idle times can be formulated as follows Bolat (2000):

M number of Flight;

N number of Gate ;

$$Min \sum_{i=0}^{N} \sum_{j=i+1}^{N+1} I^2(i,j) * Y(i,j) \tag{16}$$

$$\sum_{i=0}^{N} \sum_{j=i+1}^{N+1} Y(i,j) = N + M \tag{17}$$

$$\sum_{j=1}^{N+1} Y(0,j) \leq M \tag{18}$$

$$\sum_{i=0}^{N} Y(i, N+1) \leq M \tag{19}$$

$$\sum_{i=0}^{j-1} Y(i,j) = 1 \qquad j = 1, \dots, N \tag{20}$$

$$\sum_{j=i+1}^{N+1} Y(i,j) = 1 \qquad i = 1, \dots, N \tag{21}$$

$$Y_{i,j} = 0 \text{ or } 1 \qquad i=0,1,\dots,N, \qquad j=i+1,\dots,N+1 \tag{22}$$

Equation (17) states that there will be exactly N+M idle periods, if there is feasible solution (all flights can be served by the available gates). Keeping in mind that there are at most M gates to be utilizied, constrains (18) and (19) guarantee that in each gate at most one flight can be the first one arriving and most one can be the last departing flight, respectively. Equation (20) and (21), on the other hand, indicate that only one aircraft can be assigned immediately before j and only one immediately after i, respectively. Finally objective function (17) is used to choose N+M idle times to minimize the sum of square. The most important contribution of mathematical model for homogoneous gates, which has (N+1)(N+2)/2 binary variables and 2N+3 constraints,is that it has a linear objective function so that it can optimally be solved by LPR.

3.3.1 Example

The following example presents the details of mathematical model. There are 10 flight and 3 gates available between 0 and 50 time units.

Table 3.3 Data for homogenous gate model example

	Arrival	Departure
F1	5	12
F2	5	14
F3	5	16
F4	17	22
F5	19	30
F6	21	28
F7	27	33
F8	33	45
F9	35	45
F10	38	45

We construct the diagonal matrix according to formulas of (13), (14) and (15) for each example .
Thus,
$I_{0,1}=5$, $I_{0,2}=5$, $I_{0,3}=5$, $I_{0,4}=17$, … , $I_{10,11} = 5$

Table 3.4 Diagonal Matrix for Idle Time

I \ j	1	2	3	4	5	6	7	8	9	10	11
0	5	5	5	17	19	21	27	33	35	38	50
1		50	50	5	7	9	15	21	23	26	38
2			50	3	5	7	13	19	21	24	36
3				1	3	5	11	17	19	22	34
4					50	50	5	11	13	16	28
5						50	50	3	5	8	20
6							50	5	7	10	22
7								0	2	5	17
8									50	50	5
9										50	5
10											5

Lingo solution provides that flights 1, 4, 7 and 10 are groupped together in one gate, 2, 5, 9 in one gate and 3, 6, 8 in one gate.

Global optimal solution found.

Number of variables = 66

Number of constraints = 22

Number of nonzeros = 255

Objective value: 325.0000

Extended solver steps: 0

Total solver iterations: 28

Variable	Value	Reduced Cost
N	12.00000	0.000000
M	3.000000	0.000000
Y(1, 2)	1.000000	0.000000
Y(1, 3)	1.000000	25.00000
Y(1, 4)	1.000000	25.00000
Y(2, 5)	1.000000	25.00000
Y(3, 6)	1.000000	25.00000
Y(4, 7)	1.000000	25.00000
Y(5, 8)	1.000000	25.00000
Y(6, 10)	1.000000	25.00000
Y(7, 9)	1.000000	25.00000
Y(8, 11)	1.000000	25.00000
Y(9, 12)	1.000000	25.00000
Y(10, 12)	1.000000	25.00000

Y(11, 12)   1.000000   0.000000

Lingo solution is above and according the properties of our lingo code the assignment $Y_{k,t}$ mean Actually $Y_{k-1,t-1}$. So;

$Y_{0,1} = Y_{1,4} = Y_{4,7} = Y_{7,10} = Y_{10,12} = 1$; F1, F4, F7, F10 assign first gate ,

$Y_{0,2} = Y_{2,5} = Y_{5,9} = Y_{9,12} = 1$; F2, F5 and F10 assign the second gate,

$Y_{0,3} = Y_{3,6} = Y_{6,8} = Y_{8,12} = 1$; F3, F6 and F8 assign the third gate,

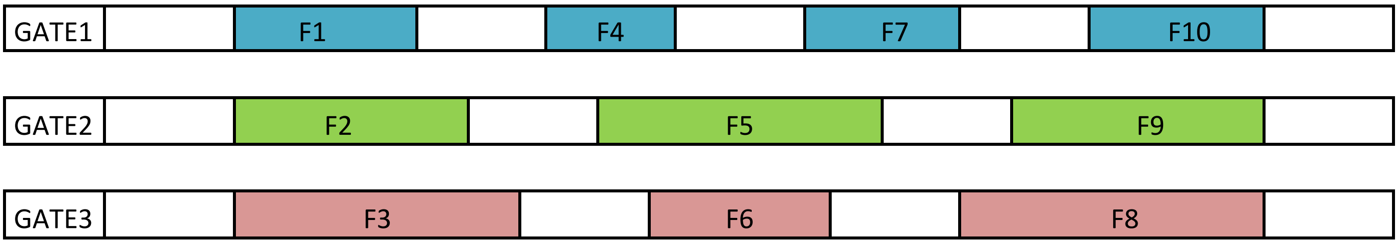

Figure 3.3 Solution Graph of Homogenous Gate Model

3.3.2 Some Experiments For Homogenous Gates Model

Some examples for this model were generated.These examples were tested with the help of Xpress Mp. Daily time capacity of a gate is 288 time units (60min/hour x 24 hour =1440 min,and 1440 min/ 5min=288 unit per day). Some examples for 2 day has horizon equals to 576 units. Each slack (idle) time is equal to 10 unit.

Results of examples were given very succesfull achivements. The former researches approximetely were excepted 25 flight small size gate assignment problems, 50 flight medium size gate assignment problems, 100 flight big size gate assignment problems. Previous work didn't try models with 100 flights. In this thesis, it was succeded to assign 400 flights to 25 gates in such a short time such as 4-5 seconds.

The details were given in the table below;

N=number of flights
M=number of gates

NXM	Objective value	total time(s)	progress graphs time(s)	writing output time(s)	presolved			matrix			number of simplex iterations
					constraints	variables	nonzero elements	constraints	variables	nonzero elements	
40X5	4500	0.2s	0.1s	0.1s	78	857	1714	81	861	2581	79
57x7	6400	0.1s	0.1s	0.1s	112	1707	3414	115	1711	5131	146
80x10	9000	0.1s	0.1s	0.3s	158	3317	6634	161	3321	9961	259
98x12	11000	0.2s	0.1s	0.4s	194	4946	9892	197	4950	14848	368
121x15	13600	0.3s	0.2s	0.6s	240	7499	14998	243	7503	22507	550
164x20	18200	0.7s	0.5s	1.3s	322	13362	26724	325	13366	40096	913
201x25	22600	1.1s	0.6s	2.2s	400	20499	40998	403	20503	61507	1348
239x30	26900	1.6s	0.9s	2.7s	476	28916	57832	479	28920	86758	1783
324x20	34400	2.6s	1.5s	5.6s	646	52971	105942	649	52975	158923	2149
402x25	42700	4.4s	2.4s	7.4s	802	81402	162804	805	81406	244216	2876

Table 3.5 Experimental Results For Homogenous Gates model

3.4 HETEROGENEOUS GATES MODEL

Some of the gates may not be permissible for certain flights, or may not provide the desired service level. Furthermore, in a rolling horizon basis or when the reassignments are required to match up the disrupted schedules, the earliest available times of gates may differ. In any case, one should additionally determine the gates to which flights are assigned when the gates are not identical. Let $Y_{i,j,k}$ be equal to 1 if flight i and j are successively assigned to gate k where i=1,…,N-1, j=i+1,…,N, and k=1,…,M. Accordingly $Y_{i,j,k}$ and $Y_{i,N+1,k}$ are defined for the first and last assigned flights to gate k. The idle periods are also modified: $I_{i,j,k}$ is the idle time between flights i and j assigned to gate k, successively, that is,

$$I_{i,j,k} = \begin{cases} A_j - D_i, & \text{if } A_i > B_k,\ A_j \geq D_i \text{ and } P_{i,k} = P_{j,k} = 1 \\ Z & \text{otherwise} \end{cases} \tag{23}$$

Similarly, idle times for the first and last assigned flights to gate k are defined as follows:

$$I_{0,j,k} = \begin{cases} Aj - Bk & \text{if } Aj \geq Bk \\ Z & \text{otherwise} \end{cases} \tag{24}$$

$$I_{i,N+1,k} = \begin{cases} Fk - Di & \text{if } Di \leq Fk \\ Z & \text{otherwise} \end{cases} \tag{25}$$

Bolat (2000) developes below model to minimize the square of the idle times for heterogeneous gate problem.

$$\text{Min} \sum_{k=1}^{M} \sum_{i=0}^{N} \sum_{j=i+1}^{N+1} I^2(i,j,k) * Y(i,j,k) \tag{26}$$

S.T;

$$\sum_{k=1}^{M} \sum_{i=0}^{N} \sum_{j=i+1}^{N+1} Y(i,j,k) = N + M \tag{27}$$

$$\sum_{j=1}^{N+1} Y(0,j,k) \leq 1 \qquad k = 1, \dots, M \tag{28}$$

$$\sum_{k=1}^{M} \sum_{i=0}^{j-1} Y(i,j,k) = 1 \qquad j = 1, \dots, N \tag{29}$$

$$\sum_{k=1}^{M}\sum_{j=+1}^{N+1} Y(i,j,k) = 1 \qquad i = 1,..,N \qquad (30)$$

$$Y(i,j,k) + \sum_{\substack{t=1 \\ t\neq k}}^{M}\sum_{v=j-1}^{N+1} Y(j,v,t) \leq 1 \quad i = 1,\dots,N-1, j = i+1,\dots,N, k = 1,\dots,M \quad (31)$$

$Y_{i,j,k}$ =0 or 1 i = 1, ... ,N , j= i+1, … ,N+1 , k= 1, … ,M (32)

Objective function and equation (26) are simple extension of objective function (16) and equation(17) of homogenous gates model. Now each gate has to be considered individually to determine the first assigned flight i.e. , constraint (28). Equation (29) and (30), which are extensions of equations (20) and (21) guarantee that only one flight can be assigned immediately before and after a flight, respectively. Since each gate is evaluated separately, the extansion of (19) for the last flights will be redundant, and thus, it is ommitted. Notice Equations (27) - (28), which still possess the integrality property, are not enough to provide the continuity of assignments. Infeasible solutions such as Y0,1,3= Y1,5,1= Y5,8,2= Y8,11,1 (assign flight 1 to gates 3 and 1, flight 5 to gates 1 and 2, and flight 8 to gates 2 and1) may come out from the LPR. Meanwhile, constraint (31) forces the contnuities between successively assigned flights i and j, and j and v, allocating them to the same gate. If Yi,j,k=1, i and j are assigned to k, then j cannot be assigned to any other gate, i.e,

$$\sum_{\substack{t=1 \\ t\neq k}}^{M}\sum_{v=j-1}^{N+1} Y(j,v,t) = 0$$

Although the number of binary variables in heterogeneous gates model is M times more than in homogenous gates model, this increse is not really of concern. The main difficulty arises from the introduction of constraint (31) because it may destroy the integrality property. Furthermore, it increases the nonzero elements very rapidly because Y i,j,k appears in this inequality several times. More specifically, Y i,j,k appears at

$$Y(a,b,c) + \sum_{\substack{t=1 \\ t\neq k}}^{M} \sum_{v=j-1}^{N+1} Y(b,v,t) \leq 1 \qquad (33)$$

when $Y_{b,v,t} = Y_{i,j,k}$. This happens for a=0,1,...,i-1, c=1,...,M but c≠k and i=b.Thus, variable $Y_{i,j,k}$ appears i(M-1) times in constraint (31). Bolat,2000 provide more details on the number of nonzero elements in heterogeneous gates model.

Total number of 1s in the constraint sets of heterogeneous gates model is bounded by

$M(N+1)[12(N+1)+(M-1)(N^2+2N)]/6$

If we apply the same example of homogenous gates model to the heterogeneous gates model;

Lingo program will assign the some solution but several times more variables and nonzero elements:

number of variables=198

number of constraint =223

number of nonzero elements= 2274

Global optimal solution found.

Objective value: 325.0000

Extended solver steps: 0

Total solver iterations: 94

Variable	Value	Reduced Cost
N	12.00000	0.000000
M	3.000000	0.000000
Y(1, 2, 1)	1.000000	25.00000
Y(1, 3, 3)	1.000000	25.00000
Y(1, 4, 2)	1.000000	25.00000
Y(2, 5, 1)	1.000000	25.00000

Y(3, 6, 3)	1.000000	25.00000
Y(4, 7, 2)	1.000000	25.00000
Y(5, 8, 1)	1.000000	25.00000
Y(6, 10, 3)	1.000000	25.00000
Y(7, 9, 2)	1.000000	25.00000
Y(8, 11, 1)	1.000000	25.00000
Y(9, 12, 2)	1.000000	25.00000
Y(10, 12, 3)	1.000000	25.00000
Y(11, 12, 1)	1.000000	25.00000

Gate1=Y(1, 2, 1), Y(2, 5, 1), Y(5, 8, 1), Y(8, 11, 1), Y(11, 12, 1) = 1,

Gate2= Y(1, 4, 2),Y(4, 7, 2),Y(7, 9, 2),Y(9, 12, 2)=1,

Gate3=Y(1, 3, 3), Y(3, 6, 3), Y(6, 10, 3),Y(10, 12, 3), =1,

Mean;

$Y_{0,1,1} = Y_{1,4,1} = Y_{4,7,1} = Y_{7,10,1} = Y_{10,12,1} = 1$, F1, F4, F7, F10 are assigned the first gate,

$Y_{0,3,2} = Y_{3,6,2} = Y_{6,8,2} = Y_{8,11,2} = 1$, F3, F6 and F8 are assigned the second gate,

$Y_{0,2,3} = Y_{2,5,3} = Y_{5,9,3} = Y_{9,12,3} = 1$,F3, F6 and F8 are assigned the third gate,

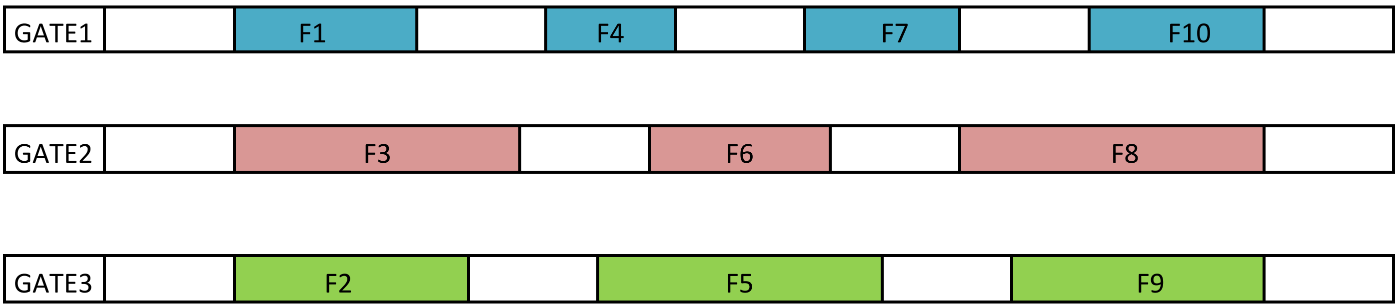

Figure 3.3 Gate Assignment Graph of Heterogeneous Model Example

3.4.1 Some Experiments For Heterogeneous Gates Model

Some examples for this model were generated.This examples were tested with the help of Xpress Mp. Daily time capacity of a gate is 288 time units (60min/hour x 24 hour =1440 min,and 1440 min/ 5min=288 unit per day). Some example for 2 days, is equal to 576 units. Each slack (idle) time is equal to 10 unit as before.

Results of examples were given very succesfull achivements. Now up to 80 flights can be assigned to 10 gates very effectively i.e., in 232.6 seconds.

The details were given in the table below;

Table 3.6 Experimental Results For Heterogeneous Gates model

					presolved			matrix			lp relaxation simplex iterations
NXM	Objective value	total cpu time(sec)	progress graphs	writing output	constraints	variables	nonzero elements	constraints	variables	nonzero elements	
25x3	2800	0.3s	0.1s	0.1s	168	1027	6318	704	1056	15434	66
34x4	3800	0.8s	0.2s	0.1s	286	2486	12250	1858	2524	73469	172
40X5	4500	1.5 s	0.4s	0.2s	481	4265	27254	3366	4310	199675	304
49x6	5500	4.6s	0.9s	0.4s	932	7601	70113	6230	7656	549406	452
57x7	6400	12.3s	1.6s	0.5s	1739	11920	168823	10040	11984	1215774	751
64x8	7200	29.3s	3.1s	1.1s	3444	17096	380346	14697	17168	2307768	1010
72x9	8100	83.5	5.3s	0.9s	11341	24237	1389846	21178	24318	4242039	1483
80x10	9000	232.6 s	17s	1.3s	22245	33130	4520766	29331	33220	7301350	1900

3.4.2 Conflicted Gates Assignment For Heterogeneous Gate Model

We assume that some gates are conflicted in certain time interval. The following example presents the details of mathematical model for that case. There are 25 flights, 5 conflicted time interval and normally 5 gates available between 0 and 100 time units but the first gate is not available between 0 - 10 units, second gate is not available 0 - 16 units and 28 - 66 units, third gate is not available 91- 100 units, fifth gate is not available 61- 100 units. Fourth gate is not conflicted. Each idle time is equal to 3 time unit. X1 , … , X5 the name of conflicted interval time of gates.

Table 3.7 Conflicted Gate Problem Data

	Arrival time	Departure time
X1	0	10
X4	0	16
F1	3	17
F2	3	16
F3	3	14
F4	13	24
F5	17	31
F6	19	34
F7	19	28
F8	20	35
F9	27	44
X3	28	66
F10	34	45
F11	37	51
F12	38	48
F13	47	57
F14	48	58
F15	51	62
F16	54	69
F17	60	72
X5	61	100
F18	65	76
F19	66	81
F20	72	84
F21	75	85
F22	79	88
F23	84	97
F24	87	97
F25	88	97
X2	91	100

We construct the diagonal matrix for idle time.

Table3.8 Diagonal Matrix For Idle Time of Conflicted Gate Problem

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	10	16	17	16	14	24	31	34	28	35	44	66	45	51	48	57	58	62	69	72	100	76	81	84	85	88	97	97	97	100	
1	0	0	3	3	3	13	17	19	19	20	27	28	34	37	38	47	48	51	54	60	61	65	66	72	75	79	84	87	88	91	100
2		100	100	100	100	3	7	9	9	10	17	18	24	27	28	37	38	41	44	50	51	55	56	62	65	69	74	77	78	81	90
3			100	100	100	100	1	3	3	4	11	12	18	21	22	31	32	35	38	44	45	49	50	56	59	63	68	71	72	75	84
4				100	100	100	0	2	2	3	10	11	17	20	21	30	31	34	37	43	44	48	49	55	58	62	67	70	71	74	83
5					100	100	1	3	3	4	11	12	18	21	22	31	32	35	38	44	45	49	50	56	59	63	68	71	72	75	84
6						100	3	5	5	6	13	14	20	23	24	33	34	37	40	46	47	51	52	58	61	65	70	73	74	77	86
7							100	100	100	100	3	4	10	13	14	23	24	27	30	36	37	41	42	48	51	55	60	63	64	67	76
8								100	100	100	100	100	3	6	7	16	17	20	23	29	30	34	35	41	44	48	53	56	57	60	69
9									100	100	100	100	0	3	4	13	14	17	20	26	27	31	32	38	41	45	50	53	54	57	66
10										100	100	0	6	9	10	19	20	23	26	32	33	37	38	44	47	51	56	59	60	63	72
11											100	100	100	2	3	12	13	16	19	25	26	30	31	37	40	44	49	52	53	56	65
12												100	100	100	100	3	4	7	10	16	17	21	22	28	31	35	40	43	44	47	56
13													100	100	100	100	100	100	100	100	100	100	0	6	9	13	18	21	22	25	34
14														100	100	2	3	6	9	15	16	20	21	27	30	34	39	42	43	46	55
15															100	100	100	0	3	9	10	14	15	21	24	28	33	36	37	40	49
16																100	0	3	6	12	13	17	18	24	27	31	36	39	40	43	52
17																	100	100	100	3	4	8	9	15	18	22	27	30	31	34	43
18																		100	100	2	3	7	8	14	17	21	26	29	30	33	42
19																			100	100	100	3	4	10	13	17	22	25	26	29	38
20																				100	100	100	100	3	6	10	15	18	19	22	31
21																					100	100	100	0	3	7	12	15	16	19	28
22																						100	100	100	100	100	100	100	100	100	0
23																							100	100	100	3	8	11	12	15	24
24																								100	100	100	3	6	7	10	19
25																									100	100	0	3	4	7	16
26																										100	100	2	3	6	15
27																											100	100	0	3	12
28																												100	100	100	3
29																													100	100	3
30																														100	3
																															0

We assume that conflicted time intervals are accepted as flights and first of all we apply homogenous gate model for example and assign all flights to the gates so we have learned which flights are assigned to which gates.

So;

The problem is solved with lingo for heteregoneous gate model.

Conflict interval time is assigned and equal 1.

X1=Y(1,2,1)=1;

X2=Y(1,3,2)=1;

X3=Y(10,13,2)=1;

X4=Y(13,24,2)=1;

X5=Y(22,32,5)=1;

X6=Y(31,32,3)=1;

Lingo solution is as below.

Global optimal solution found.

Objective value:	261.0000
Extended solver steps:	0
Total solver iterations:	3447

Variable	Value
Y(1, 2, 1)	1.000000
Y(1, 3, 2)	1.000000
Y(1, 4, 3)	1.000000
Y(1, 5, 4)	1.000000
Y(1, 6, 5)	1.000000
Y(2, 7, 1)	1.000000
Y(3, 10, 2)	1.000000
Y(4, 11, 3)	1.000000
Y(5, 9, 4)	1.000000
Y(6, 8, 5)	1.000000

Y(7, 12, 1) 1.000000

Y(8, 14, 5) 1.000000

Y(9, 15, 4) 1.000000

Y(10, 13, 2) 1.000000

Y(11, 16, 3) 1.000000

Y(12, 17, 1) 1.000000

Y(13, 24, 2) 1.000000

Y(14, 18, 5) 1.000000

Y(15, 20, 4) 1.000000

Y(16, 19, 3) 1.000000

Y(17, 21, 1) 1.000000

Y(18, 22, 5) 1.000000

Y(19, 23, 3) 1.000000

Y(20, 25, 4) 1.000000

Y(21, 26, 1) 1.000000

Y(22, 32, 5) 1.000000

Y(23, 27, 3) 1.000000

Y(24, 28, 2) 1.000000

Y(25, 29, 4) 1.000000

Y(26, 30, 1) 1.000000

Y(27, 31, 3) 1.000000

Y(28, 32, 2) 1.000000

Y(29, 32, 4) 1.000000

Y(30, 32, 1) 1.000000

Y(31, 32, 3) 1.000000

So; the result of assignment ,

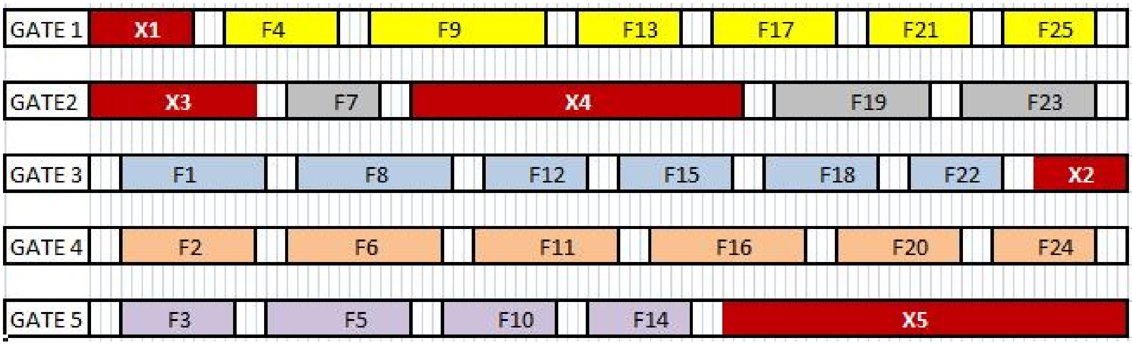

Figure 3.4 Solution Graph of Conflicted Gate Problem

3.5 NEW MODEL FOR HOMOGENOUS GATES

It is similar to previous homogenous gates model

$$I_{i,j} = \begin{cases} Aj-Di & \text{if } Aj \geq Di \\ Z & \text{Otherwise} \end{cases} \qquad (13)$$

Here Z is used to indicate that assigning successively flights i and j to the same gate infeasible.Similarly, we define I 0,j and I i,N+1 for the idle times of the first and last assignments, that is,

$I_{0,j} = A_j$ $\quad$ j=1,…,N $\quad$ (14)

$I_{i,N+1} = H-D_i$ $\quad$ i=1,…,N $\quad$ (15)

Pure binary linear mathematical model that minimizes the variance of idle times can be formulated as follows:

M $\quad$ number of flight;

N $\quad$ number of gate;

$$Mi \sum_{i=0}^{N} \sum_{j=+1}^{N+1} I^2(i,j) * Y(i,j) - \sum_{j=1}^{N-1} Y(i,j) * H^2 \qquad (34)$$

s.t;

$$\sum_{i=0}^{N}\sum_{j=i+1}^{N+1} Y(i,j) * A(i,j) = N + M \qquad (35)$$

$$\sum_{j=1}^{N+1} Y(0,j) \leq M \qquad (36)$$

$$\sum_{i=0}^{N} Y(i,N+1) \leq M \qquad (37)$$

$$\sum_{i=0}^{j-1} Y(i,j) \leq 1 \qquad j = 1, \ldots, N \qquad (38)$$

$$\sum_{j=i+1}^{N+1} Y(i,j) \leq 1 \qquad i = 1, \ldots, N \qquad (39)$$

$$\sum_{i=0}^{j-1} Y(i,j) - \sum_{j=1}^{N+1} Y(j,k) = 0 \qquad j = 1, \ldots, N \qquad (40)$$

$$\sum_{i=0}^{N}\sum_{j=i+1}^{N+1} Y(i,j) - \sum_{i=0}^{N}\sum_{j=i+1}^{N-1} Y(i,j) * A(i,j) \qquad (41)$$

$Y_{i,j}$= 0 or 1 i=0,1,...,N, j=i+1,…,N+1 (42)

3.5.1 Example For New Model

Table.3.9 Data for New Model Example

Flight Number	Arrival Time	Departure Time
F1	2	7
F2	2	5
F3	2	8
F4	8	13
F5	9	16
F6	10	22
F7	15	21
F8	18	28
F9	23	28
F10	24	28

The idle time matrix is prepared according to (13),(14),(15)

Table.3.10 Idle Time Matrix

i \ j	1	2	3	4	5	6	7	8	9	10	11
0	2	2	2	8	9	10	15	18	23	24	30
1	30	30	30	1	2	3	8	11	16	17	23
2	30	30	30	3	4	5	10	13	18	19	25
3	30	30	30	0	1	2	7	10	15	16	22
4	30	30	30	30	30	30	2	5	10	11	17
5	30	30	30	30	30	30	30	2	7	8	14
6	30	30	30	30	30	30	30	30	1	2	8
7	30	30	30	30	30	30	30	30	2	3	9
8	30	30	30	30	30	30	30	30	30	30	2
9	30	30	30	30	30	30	30	30	30	30	2
10	30	30	30	30	30	30	30	30	30	30	2

And also 0 or 1 matrix is prepared according to

$$A_{i,j} = \begin{cases} 0 & \text{if } A_j - D_i = H \\ 1 & \text{otherwise} \end{cases} \qquad (44)$$

Table 3.11 0 or 1 Matrix for New Model Example

i \ j	1	2	3	4	5	6	7	8	9	10	11
0	1	1	1	1	1	1	1	1	1	1	0
1	0	0	0	1	1	1	1	1	1	1	1
2	0	0	0	1	1	1	1	1	1	1	1
3	0	0	0	1	1	1	1	1	1	1	1
4	0	0	0	0	0	0	1	1	1	1	1
5	0	0	0	0	0	0	0	1	1	1	1
6	0	0	0	0	0	0	0	0	1	1	1
7	0	0	0	0	0	0	0	0	1	1	1
8	0	0	0	0	0	0	0	0	0	0	1
9	0	0	0	0	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0	0	1

So; Lingo assignment solution for nonzeros

Variable	Value	Reduced Cost
Y(0, 1)	1.000000	-96.00000
Y(0, 3)	1.000000	-96.00000
Y(1, 4)	1.000000	-100.0000
Y(3, 5)	1.000000	-99.00000
Y(4, 7)	1.000000	-96.00000
Y(5, 8)	1.000000	-96.00000
Y(7, 9)	1.000000	-96.00000
Y(8, 11)	1.000000	-96.00000
Y(9, 11)	1.000000	-96.00000

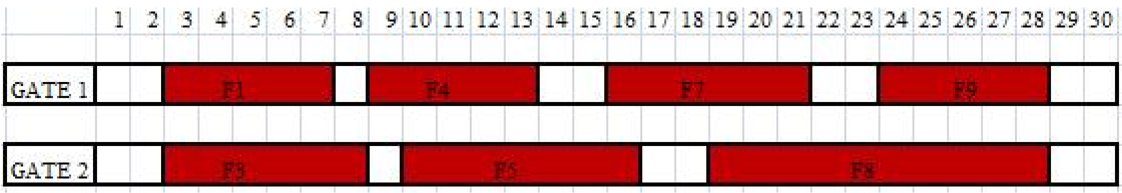

Figure 3.5 Solution Graph of New Model Example

F2, F6 and F10 were not assigned and directed to remote area.

3.5.2 Case Study 1:

The data is taken from Turkish Airlines, with one week flight scheduling for 21 route in different destinations. Airbus A330 aircraft used for these flights. We have noticed that there are similarity of the fleet assignment to the gate assignment. The departure time of flight scheduling is used as arrival time of the gate and arrival time of flight scheduling is used as departure time from the gate.

Table 3.12 Weekly Flight Schedule of Turkish Airlines for 10 Airbus 330-300

		Departure		Arrival	
Flight Code	Route	Days	Time	Days	Time
TK1979-1980	ISTLHRIST	1234567	08:25	1234567	17:30
TK651-652	ISTALGIST	1234567	10:25	1234567	18:50
TK617-618	ISTCMNIST	1234567	09:55	1234567	20:30
TK792-793	ISTTLVIST	1234567	23:55	1234567	08:35
TK661-662	ISTTUNIST	1234567	10:40	1234567	17:05
TK1821-1822	ISTCDGIST	1234567	07:45	1234567	16:00
TK1587-1588	ISTFRAIST	1234567	08:25	1234567	15:35
TK1951-1952	ISTAMSIST	1234567	07:55	1234567	16:10
TK760-761	ISTDXBIST	1234567	20:10	1234567	06:30
TK254-255	ISTDYUIST	. . 3. . . 7	19:55	1. . 4. . .	14:20
TK720-721	ISTBOMIST	1234567	18:35	1234567	09:15
TK874-875	ISTIKAIST	1234567	21:30	1234567	05:55
TK716-717	ISTDELIST	1234567	18:40	1234567	09:10
TK60-61	ISTBKKIST	1234567	23:40	1234567	05:30
TK350-351	ISTALAIST	. 2. 4. 67	23:05	1.3.5.7	12:25
TK352-353	ISTALAIST	1. 3. 5. .	17:25	. 2. 4. 6.	06:45
TK346-347	ISTFRUIST	. 2. 4. 67	17:50	1. 3. 5. 7	06:40
TK354-355	ISTTSEIST	. . 3. . 6.	18:40	. . . 4. . 7	06:40
TK627-628	ISTDKRIST	. 2. . 5. 7	07:30	. 2. . 5. 7	22:40
TK603-604	ISTDARIST	1.3..6.	18:00	.2.4..7	12:10
TK708-709	ISTDACIST	1.3.5.7	00:30	12.4.6.	05:50

This problem consists of 116 flights and 10 gates.

First of all; the problem is solved according to the rule of First Arrive –First Assign (FAFA) by hand. 18 flights were not assigned to the gates, and thus, F22, F24, F38, F40, F49, F50, F57, F69, F72, F74, F98, F99, F102, F106, F107, F111, F114, F115 were directed to remote area.

Secondly; the problem is solved according to the rule of First Departure –First Assign (FDFA) by hand. 17 flights were not assigned to the gates, and F1, F6, F15, F17, F31, F33, F49, F55, F64, F66, F67, F90, F96, F100, F105, F106, F115 were directed to remote area.

Finally, the problem is solved by new model for homogenous gate with Lingo. Only 7 flights were not assigned to the gates. F21, F48, F68, F71, F96, F99, F100 were directed to remote area. The solution assignment is below.

- GATE1= F1-F19-F30-F47-F53-F61-F70-F78-F84-F94-F104-F113
- GATE2= F2-F14-F17-F35-F42-F65-F73-F79-F86-F98-F106-F116
- GATE3= F3-F10-F27-F40-F48-F51-F58-F72-F80-F101-F108
- GATE4= F4-F18-F25-F36-F46-F60-F74-F76-F92-F107-F112
- GATE5= F5-F13-F20-F28-F37-F41-F54-F66-F83-F89-F103-F111
- GATE6= F6-F16-F23-F32-F39-F50-F56-F62-F67-F82-F93-F105-F114
- GATE7= F7-F15-F38-F49-F69-F81-F87-F95-F102-F109
- GATE8= F8-F11-F29-F34-F45-F55-F63-F77-F88-F97
- GATE9= F9-F22-F31-F52-F64-F91-F110
- GATE10= F12-F24-F26-F44-F57-F59-F75-F85-F90-F115

3.5.3. Case Study 2

The data is taken from the Atatürk Airport. 338 Turkish Airlines Flights (5 day flight schedule with similar type aircraft) were assigned to 7 gates at the International terminal by our method. This case was tested with the help of Lingo. 5 Day time capacity of a gate is 288 unit time per day x 5 day = 1440 unit time for 5 day. (60min/hour x 24 hour =1440 min,and 1440 min/ 5min=288 unit per day).

Solution set of flight gate Schedule as below;

Table 3.13 Flight Gate Schedule of Case Study 2

	GATE1	GATE2	GATE3	GATE4	GATE5	GATE6	GATE7
1	F1	F2	F3	F4	F5	F6	F7
2	F11	F16	F20	F19	F14	F18	F15
3	F17	F27	F31	F30	F29	F28	F26
4	F25	F32	F38	F36	F53	F34	F35
5	F33	F37	F42	F41	F60	F49	F39
6	F43	F40	F48	F46	F88	F57	F44
7	F51	F47	F56	F52	F98	F82	F50
8	F59	F54	F66	F58	F106	F94	F55
9	F67	F62	F89	F64	F114	F105	F61
10	F72	F71	F95	F69	F123	F115	F81
11	F77	F76	F108	F73	F143	F120	F93
12	F83	F84	F117	F75	F147	F127	F102
13	F90	F92	F125	F86	F154	F134	F109
14	F100	F103	F132	F97	F159	F151	F118
15	F101	F112	F138	F104	F168	F170	F124
16	F107	F121	F145	F113	F178	F177	F131
17	F116	F128	F149	F119	F185	F184	F140
18	F122	F133	F156	F126	F191	F190	F148
19	F129	F150	F158	F130	F201	F198	F155
20	F137	F172	F164	F139	F205	F209	F162
21	F141	F175	F181	F142	F220	F221	F173
22	F144	F180	F188	F169	F226	F228	F179
23	F160	F186	F194	F174	F236	F238	F187
24	F171	F192	F206	F182	F242	F250	F193
25	F176	F207	F214	F195	F251	F256	F203
26	F183	F218	F222	F204	F258	F268	F210
27	F189	F235	F232	F212	F270	F274	F224
28	F196	F240	F239	F216	F281	F286	F234
29	F208	F248	F247	F219	F291	F293	F241
30	F223	F255	F252	F229	F301	F305	F249
31	F243	F264	F261	F237	F310	F312	F257
32	F254	F284	F271	F246	F316	F317	F272
33	F269	F297	F279	F253	F324	F325	F275
34	F273	F302	F285	F262	F330	F334	F280
35	F282	F314	F295	F276	F338		F287
36	F298	F322	F299	F289			F292
37	F303	F328	F304	F296			F300
38	F313	F337	F315	F308			F306
39	F321		F323	F311			F318
40	F326		F329	F319			F327
41	F336		F335	F331			F333

271 flights were assigned to available gate, and 67 flights were directed the remote areas. Utilization of 7 gates is 80 %.

Table 3.14 Percentage Table For Gate Using Time

GATE NUMBER	TOTAL IDLE TIME	TOTAL USING TIME	PERCENTAGE OF USING
1	425	1015	70%
2	365	1075	74%
3	357	1083	75%
4	455	985	68%
5	345	1095	76%
6	432	1008	70%
7	416	1024	71%

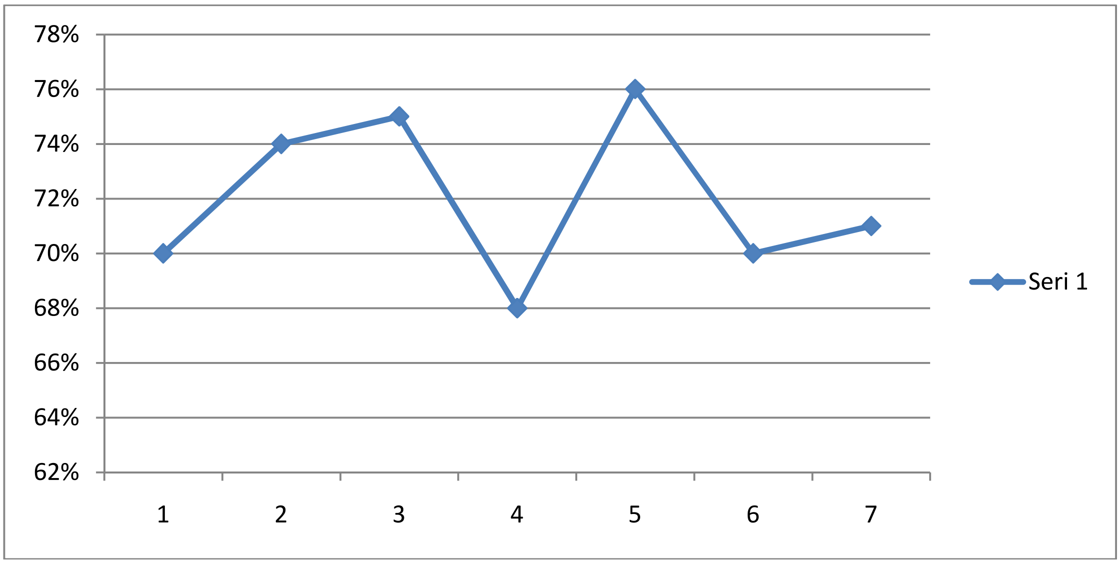

Figure:3.6 Percentage of using time of each gate

CHAPTER 4

CONCLUSIONS

The main objective in our study is to provide the robustness of the flight gate scheduling. Static flight gate scheduling may be distrupted in some cases, like severe air conditions, delayed flights and unexpected events. For the customer satisfaction, it is important to use the gates at the airport in the most efficient way. The main aim in the objective functions that we used is to provide the most possible uniform distribution of the idle times between gates by minimizing the variances of slack times.

The objectives are to consider all managerial and physical considerations to provide the required service level, and to make the assignments insensitive to the stochastic changes on flight schedules. A mixed-binary quadratic model (initial model), Homogeneous Gates Model, Heterogeneous Gate Model and New Homogeneous Model are formulated to minimize the variance of idle times at gates.

We applied four-phase solution approach in order to solve flight gate scheduling. We worked with example data and real data for a week. The former researches used 25 flight small size gate assignment problems, 50 flight medium size gate assignment problems and 100 flight big size gate assignment problems. However they did not succeed to solve big size problems. In this work, it was succeeded to assign 400 flights to 25 gates for Homogenous Gates model and it was succeeded to assign 80 flights to 10 heterogeneous gates.

We apply two case study for the new homogeneous model with real data. In the first case study, including 118 flights with 10 gates FAFA method assigned 18 flighs to remote, FDFA method assigned 17 flights to remote, our model sent only 7 flights to remote areas. only 7 flights have been diverted. Second case study includes 338 flights and 7 gate in the Atatürk Airport International terminal. We were able to assign 271 Flights to gates and 67 flights to the remote areas. Utilization of 7 gates is 80 %.

Since we have succeeded in assigning more flights to the gates, more people have a chance to use the gates and that has increased the customer satisfaction.

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APPENDICES

A.1 LINGO CODES OF MODELS

A.1.1 INITIAL MODEL LINGO CODE

```
MODEL:
TITLE Quadratic Gate Assignment;
SETS:
F1/1..5/:;
F2(F1)/1,2,3,4/:A,D;
G/1..2/:B,F;
F1G(F1,G):E,L,S;
F2G(F2,G):X,P;
ENDSETS
DATA:
A=1 2 5 6  ;
D=4 5 8 9  ;
P= 1 1 1 1
   1 1 1 1 ;
B=0 0 ;
F=10 10;
ENDDATA
MIN=@SUM(F1G:S*S);
@FOR(F2(J):@SUM(G(K):P(J,K)*X(J,K))=1);
@FOR(G(K):E(1,K)>=A(1)*X(1,K));
```

```
@FOR(G(K):E(1,K)>=B(K));
@FOR(F2(J)| J #NE# 1:@FOR(G(K):E(J,K)>=A(J)*X(J,K)));
@FOR(F2(J)| J #NE# 1:@FOR(G(K):E(J,K)>=L(J-1,K)));
@FOR(F2(J):@FOR(G(K):L(J,K)=E(J,K)+(D(J)-A(J))*X(J,K)));
@FOR(G(K):S(1,K)=E(1,K)-B(K));
@FOR(F1(J)| J #NE# 1:@FOR(G(K):S(J,K)=E(J,K)-L(J-1,K)));
@FOR(G(K):S(5,K)=F(K)-L(4,K));
@FOR(F1G:@GIN(E));
@FOR(F1G:@GIN(L));
@FOR(F1G:@GIN(S));
@FOR(F2G:@BIN(X));
END
```

A.1.2 HOMOGENOUS MODEL LINGO CODE

```
MODEL: ! Assignment model(ASSIGN);
SETS:
FLIGHT;
ASSIGN( FLIGHT, FLIGHT) | &2 #GT# &1:VAR, Y;
ENDSETS
DATA:
N=42;
M=5;
FLIGHT =1..N;
VAR = @OLE ( 'C:\Users\KARTAL\Desktop\ORNEK.xlsx') ;
  ENDDATA
MIN = @SUM(ASSIGN: VAR^2* Y);
```

```
@SUM(ASSIGN:Y) = M+N-2 ;
@SUM(FLIGHT(J) | J #GT# 1 :Y(1,J)) <= M ;
@SUM(FLIGHT(I) | I #LT# N :Y(I,N)) <= M ;
@FOR( FLIGHT( K)|K #LT# N  #AND#  K #GT# 1:
@SUM(FLIGHT(J) | J #GT# K:Y(K,J)) = 1 ;);
@FOR( FLIGHT( K)|K #LT# N  #AND#  K #GT# 1:
@SUM(FLIGHT(I) | I #LT# K :Y(I,K))= 1 ;
);
@FOR( ASSIGN ( I, J) : @BIN( Y( I, J)));
END
```

A.1.3 HETEROGENEOUS GATE MODEL LINGO CODE

```
MODEL: ! Assignment model(ASSIGN);
SETS:
FLIGHT;
ASSIGN( FLIGHT, FLIGHT)| &2 #GT# &1 :VAR;
GATE ;
GT(ASSIGN,GATE) :Y;
ENDSETS
DATA:
N=42;
M=5;
FLIGHT=1..N;
GATE=1..M;
VAR = @OLE ( 'C:\Users\KARTAL\Desktop\ORNEK.xlsx') ;
!@OLE ( 'C:\Users\KARTAL\Desktop\graphlingo5.xlsx') = Y;
```

```
ENDDATA
MIN = @SUM(GT(I,J,K):VAR(I,J)^2*Y(I,J,K)) ;
@SUM(GT(I,J,K):Y(I,J,K)) = M+N-2 ;
@FOR(GATE(K):
@SUM(FLIGHT(J) | J #GT# 1 :Y(1,J,K)) <= 1);
@FOR( FLIGHT( L)|L #LT# N  #AND#  L #GT# 1:
@SUM(GT(L,J,K) | J #GT# L:Y(L,J,K)) = 1);
@FOR( FLIGHT( L)|L #LT# N  #AND#  L #GT# 1:
@SUM(GT(I,L,K) | I #LT# L :Y(I,L,K))= 1 );
@FOR(FLIGHT(I)| I #LT# N:
@FOR(FLIGHT(J)| J #GT# I:
@FOR(GATE(K):
Y(I,J,K)+@SUM(GATE(L)| L #NE# K:
@SUM(FLIGHT(V)| V #GT# J:Y(J,V,L)))<=1
)
)
);
@FOR(GT(I,J,K) : @BIN(Y(I,J,K)));
END
```

A.1.4 NEW GATE MODEL LINGO CODE

MODEL:

TITLE Fleet Assignment Homogeneous;

SETS:

F/0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335,336,337,338,339/:;

F1(F)/0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,149,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,169,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,189,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,

209,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,
229,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,
249,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,
269,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,
289,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,
309,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,
329,330,331,332,333,334,335,336,337,338/:;

F2(F)/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,
29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,
57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,
85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,1
09,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,1
29,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144,145,146,147,148,1
49,150,151,152,153,154,155,156,157,158,159,160,161,162,163,164,165,166,167,168,1
69,170,171,172,173,174,175,176,177,178,179,180,181,182,183,184,185,186,187,188,1
89,190,191,192,193,194,195,196,197,198,199,200,201,202,203,204,205,206,207,208,2
09,210,211,212,213,214,215,216,217,218,219,220,221,222,223,224,225,226,227,228,2
29,230,231,232,233,234,235,236,237,238,239,240,241,242,243,244,245,246,247,248,2
49,250,251,252,253,254,255,256,257,258,259,260,261,262,263,264,265,266,267,268,2
69,270,271,272,273,274,275,276,277,278,279,280,281,282,283,284,285,286,287,288,2
89,290,291,292,293,294,295,296,297,298,299,300,301,302,303,304,305,306,307,308,3
09,310,311,312,313,314,315,316,317,318,319,320,321,322,323,324,325,326,327,328,3
29,330,331,332,333,334,335,336,337,338,339/:;

F1XF2(F1,F2):Y,Z,A;

ENDSETS

DATA:

Z= @OLE('OR1.xlsx','xxxx');

A= @OLE('OR1.xlsx','xxyy');

ENDDATA

MIN=@SUM(F1(I):@SUM(F2(J)|J#GE#I:Z(I,J)^2*Y(I,J)))-
@SUM(F1(I):@SUM(F2(J)| J #GE# I:Y(I,J)*1440));

```
@SUM(F1(I):@SUM(F2(J)| J #GE# I:Y(I,J)*A(I,J)))<=345;
@SUM(F2(J):Y(1,J))<=7;
@SUM(F1(I):Y(I,340))<=7;
@FOR(F2(J)| J #NE# 340:@SUM(F1(I):Y(I,J))<=1);
@FOR(F1(I)| I #NE# 1:@SUM(F2(J):Y(I,J))<=1);
@FOR(F1(J)| J #NE# 1:@SUM(F1(I):Y(I,J))-@SUM(F2(K):Y(J,K))=0);
@SUM(F1XF2:Y)-@SUM(F1XF2:Y*A)=0;
@FOR(F1XF2:@BIN(Y));
END
```

A.2 XPRESS MP CODES OF MODELS

A.2.1 HOMOGENOUS GATE MODEL XPESS MP CODE

```
model "Homogeneous Gate Assignment"
uses "mmxprs"
declarations
NFLIGHTS = 118
FLIGHTS = 1..NFLIGHTS ! flights
M = 12
GATE = 1..M
VAR: array(FLIGHTS,FLIGHTS) of integer ! VAR is SLACK between flights
Y: array(FLIGHTS,FLIGHTS) of mpvar ! 1 if flight from i to j
end-declarations
initializations from 'flight.dat'
VAR
end-initializations
```

```
forall(i,j in FLIGHTS|i<j)VAR(j,i):=VAR(i,j)

!Objective: Total

Total:= sum(i,j in FLIGHTS| i<j ) VAR(i,j)^2*Y(i,j)

sum(i,j in FLIGHTS | i<j)Y(i,j)=M+NFLIGHTS-2

sum(j in FLIGHTS| 1<j )Y(1,j)<=M

sum(i in FLIGHTS| i<NFLIGHTS)Y(i,NFLIGHTS)<=M

forall(j in 2..NFLIGHTS|j<>NFLIGHTS) sum(i in FLIGHTS| i<j) Y(i,j) = 1

forall(i in 2..NFLIGHTS|i<>NFLIGHTS) sum(j in FLIGHTS|j>i) Y(i,j) = 1

forall(i,j in FLIGHTS ) Y(i,j) is_binary

! Solve the problem

minimize(Total)

writeln("Solution:\ Objective: ", getobjval)

forall(i,j in FLIGHTS) writeln(" ASSIGN(", i,j, "): ", getsol(Y(i,j)))

end-model
```

A.2.2 HETEROGENEOUS GATE MODEL XPESS MP CODE

```
model "GATE1"

uses "mmxprs"

declarations

NFLIGHTS = 100

FLIGHTS = 1..NFLIGHTS ! flights

M = 12

GATE = 1..M

VAR: array(FLIGHTS,FLIGHTS) of integer ! VAR is SLACK between flights

Y: array(FLIGHTS,FLIGHTS,GATE) of mpvar ! 1 if flight from i to j
```

```
end-declarations
initializations from  'gate12.dat'
VAR
end-initializations
forall(i,j in FLIGHTS|i<j)VAR(j,i):=VAR(i,j)
!Objective: Total
Total:= sum(i,j in FLIGHTS| i<j ,k in GATE) VAR(i,j)^2*Y(i,j,k)
!assign every flight once
sum(i,j in FLIGHTS | i<j,k in GATE)Y(i,j,k)= M + NFLIGHTS - 2
forall(k in 1..M)sum(j in FLIGHTS)Y(1,j,k)<= 1
forall(j in 2..NFLIGHTS|j<>100) sum(i in FLIGHTS| i<j,k in GATE) Y(i,j,k) = 1
forall(i in 2..NFLIGHTS|i<>100) sum(j in FLIGHTS|j>i,k in GATE) Y(i,j,k) = 1
forall(i in FLIGHTS| i<100,j in FLIGHTS|i<j,k in GATE|k<>12)Y(i,j,k)+sum( l in GATE |l<>k,v in FLIGHTS| v>j)Y(j,v,l)<=1
forall(i,j in FLIGHTS|i<j , k in GATE) Y(i,j,k) is_binary
! Solve the problem
minimize(Total)
writeln("Solution:\ Objective: ", getobjval)
forall(i,j in FLIGHTS|i<j , k in GATE) writeln(" ASSIGN(", i,j,k, "): ", getsol(Y(i,j,k)))
end-model
```

A.3 CASE STUDIES

A.3.1 1st CASE STUDY

1.3.1.1 DATA FOR INTERNATIONAL TERMINAL FOR A WEEK (116 FLIGHT-10GATE)

No	Flight Code	Route Name	Departure Unit	Arrival Unit	Available Unit
1	TK708-709_1	ISTDACIST	6	358	376
2	TK1821-1822_1	ISTCDGIST	93	192	210
3	TK1951-1952_1	ISTAMSIST	95	194	212
4	TK1979-1980_1	ISTLHRIST	101	210	228
5	TK1587-1588_1	ISTFRAIST	101	187	205
6	TK617-618_1	ISTCMNIST	119	246	264
7	TK651-652_1	ISTALGIST	125	226	244
8	TK661-662_1	ISTTUNIST	128	205	223
9	TK352-353_1	ISTALAIST	209	369	387
10	TK603-604_1	ISTDARIST	216	434	452
11	TK720-721_1	ISTBOMIST	223	399	417
12	TK716-717_1	ISTDELIST	224	398	416
13	TK760-761_1	ISTDXBIST	242	366	384
14	TK874-875_1	ISTIKAIST	258	359	377
15	TK60-61_1	ISTBKKIST	284	642	660
16	TK792-793_1	ISTTLVIST	287	391	409
17	TK627-628_1	ISTDKRIST	378	560	578
18	TK1821-1822_2	ISTCDGIST	381	480	498
19	TK1951-1952_2	ISTAMSIST	383	482	500
20	TK1979-1980_2	ISTLHRIST	389	498	516
21	TK1587-1588_2	ISTFRAIST	389	475	493
22	TK617-618_2	ISTCMNIST	407	534	552
23	TK651-652_2	ISTALGIST	413	514	532
24	TK661-662_2	ISTTUNIST	416	493	511
25	TK346-347_1	ISTFRUIST	502	656	674
26	TK720-721_2	ISTBOMIST	511	687	705
27	TK716-717_2	ISTDELIST	512	686	704
28	TK760-761_2	ISTDXBIST	530	654	672
29	TK874-875_2	ISTIKAIST	546	647	665
30	TK350-351_1	ISTALAIST	565	725	743
31	TK60-61_2	ISTBKKIST	572	930	948
32	TK792-793_2	ISTTLVIST	575	679	697

33	TK708-709_2	ISTDACIST	582	934	952
34	TK1821-1822_3	ISTCDGIST	669	768	786
35	TK1951-1952_3	ISTAMSIST	671	770	788
36	TK1979-1980_3	ISTLHRIST	677	786	804
37	TK1587-1588_3	ISTFRAIST	677	763	781
38	TK617-618_3	ISTCMNIST	695	822	840
39	TK651-652_3	ISTALGIST	701	802	820
40	TK661-662_3	ISTTUNIST	704	781	799
41	TK352-353_2	ISTALAIST	785	945	963
42	TK603-604_2	ISTDARIST	792	1010	1028
43	TK720-721_3	ISTBOMIST	799	975	993
44	TK716-717_3	ISTDELIST	800	974	992
45	TK354-355_1	ISTTSEIST	800	944	962
46	TK254-255_1	ISTDYUIST	815	1036	1054
47	TK760-761_3	ISTDXBIST	818	942	960
48	TK874-875_3	ISTIKAIST	834	935	953
49	TK60-61_3	ISTBKKIST	860	1218	1236
50	TK792-793_3	ISTTLVIST	863	967	985
51	TK1821-1822_4	ISTCDGIST	957	1056	1074
52	TK1951-1952_4	ISTAMSIST	959	1058	1076
53	TK1979-1980_4	ISTLHRIST	965	1074	1092
54	TK1587-1588_4	ISTFRAIST	965	1051	1069
55	TK617-618_4	ISTCMNIST	983	1110	1128
56	TK651-652_4	ISTALGIST	989	1090	1108
57	TK661-662_4	ISTTUNIST	992	1069	1087
58	TK346-347_2	ISTFRUIST	1078	1232	1250
59	TK720-721_4	ISTBOMIST	1087	1263	1281
60	TK716-717_4	ISTDELIST	1088	1262	1280
61	TK760-761_4	ISTDXBIST	1106	1230	1248
62	TK874-875_4	ISTIKAIST	1122	1223	1241
63	TK350-351_2	ISTALAIST	1141	1301	1319
64	TK60-61_4	ISTBKKIST	1148	1506	1524
65	TK792-793_4	ISTTLVIST	1151	1255	1273
66	TK708-709_3	ISTDACIST	1158	1510	1528
67	TK627-628_2	ISTDKRIST	1242	1424	1442
68	TK1821-1822_5	ISTCDGIST	1245	1344	1362
69	TK1951-1952_5	ISTAMSIST	1247	1346	1364
70	TK1979-1980_5	ISTLHRIST	1253	1362	1380
71	TK1587-1588_5	ISTFRAIST	1253	1339	1357
72	TK617-618_5	ISTCMNIST	1271	1398	1416
73	TK651-652_5	ISTALGIST	1277	1378	1396
74	TK661-662_5	ISTTUNIST	1280	1357	1375
75	TK352-353_3	ISTALAIST	1361	1521	1539
76	TK720-721_5	ISTBOMIST	1375	1551	1569
77	TK716-717_5	ISTDELIST	1376	1550	1568

78	TK760-761_5	ISTDXBIST	1394	1518	1536
79	TK874-875_5	ISTIKAIST	1410	1511	1529
80	TK60-61_5	ISTBKKIST	1436	1794	1812
81	TK792-793_5	ISTTLVIST	1439	1543	1561
82	TK1821-1822_6	ISTCDGIST	1533	1632	1650
83	TK1951-1952_6	ISTAMSIST	1535	1634	1652
84	TK1979-1980_6	ISTLHRIST	1541	1650	1668
85	TK1587-1588_6	ISTFRAIST	1541	1627	1645
86	TK617-618_6	ISTCMNIST	1559	1686	1704
87	TK651-652_6	ISTALGIST	1565	1666	1684
88	TK661-662_6	ISTTUNIST	1568	1645	1663
89	TK346-347_3	ISTFRUIST	1654	1808	1826
90	TK603-604_3	ISTDARIST	1656	1874	1892
91	TK720-721_6	ISTBOMIST	1663	1839	1857
92	TK716-717_6	ISTDELIST	1664	1838	1856
93	TK354-355_2	ISTTSEIST	1664	1808	1826
94	TK760-761_6	ISTDXBIST	1682	1806	1824
95	TK874-875_6	ISTIKAIST	1698	1799	1817
96	TK350-351_3	ISTALAIST	1717	1877	1895
97	TK60-61_6	ISTBKKIST	1724	2082	2100
98	TK792-793_6	ISTTLVIST	1727	1831	1849
99	TK708-709_4	ISTDACIST	1734	2086	2104
100	TK627-628_3	ISTDKRIST	1818	2000	2018
101	TK1821-1822_7	ISTCDGIST	1821	1920	1938
102	TK1951-1952_7	ISTAMSIST	1823	1922	1940
103	TK1979-1980_7	ISTLHRIST	1829	1938	1956
104	TK1587-1588_7	ISTFRAIST	1829	1915	1933
105	TK617-618_7	ISTCMNIST	1847	1974	1992
106	TK651-652_7	ISTALGIST	1853	1954	1972
107	TK661-662_7	ISTTUNIST	1856	1933	1951
108	TK346-347_4	ISTFRUIST	1942	2096	2114
109	TK720-721_7	ISTBOMIST	1951	2127	2145
110	TK716-717_7	ISTDELIST	1952	2126	2144
111	TK254-255_2	ISTDYUIST	1967	2188	2206
112	TK760-761_7	ISTDXBIST	1970	2094	2112
113	TK874-875_7	ISTIKAIST	1986	2087	2105
114	TK350-351_4	ISTALAIST	2005	2165	2183
115	TK60-61_7	ISTBKKIST	2012	2370	2388
116	TK792-793_7	ISTTLVIST	2015	2119	2137

Table A1 Data for Case Study 1

A.3.2 CASE STUDY 2

A.3.2 DATA SET FOR INTERNATIONAL TERMINAL

Arr date(S)	Dep date(S)	Arrival Time(S)	Departure Time(S)	Arr Gate	Dep Gate	duta(s)	dutd(s)	GT(s)	Airline	LEG
1	1	00:00	05:30	13	13	0	66	66	TK	II
1	1	00:00	04:10	16	16	0	50	50	TK	II
1	1	00:00	07:00	137	137	0	84	84	TK	II
1	1	02:45	06:15	119	119	33	75	42	TK	II
1	1	03:00	05:30	210	210	36	66	30	TK	II
1	1	03:00	05:45	215	215	36	69	33	TK	II
1	1	03:15	05:30	10	10	39	66	27	TK	II
1	1	04:00	05:45	216	216	48	69	21	TK	II
1	1	04:30	12:00	20	20	54	144	90	TK	II
1	1	04:30	05:30	117	117	54	66	12	TK	II
1	1	04:45	06:00	101	101	57	72	15	TK	II
1	1	04:45	18:45	130	130	57	225	168	TK	II
1	1	05:25	07:10	201	201	65	86	21	TK	II
1	1	06:00	08:30	112	112	72	102	30	TK	II
1	1	06:49	08:00	101	101	82	96	14	TK	II
1	1	06:54	07:59	106	106	83	96	13	TK	II
1	1	07:02	08:02	102	102	84	96	12	TK	II
1	1	07:00	08:15	208	208	84	99	15	TK	II
1	1	07:00	09:00	211	211	84	108	24	TK	II
1	1	07:50	09:10	108	108	94	110	16	TK	II
1	1	08:00	09:30	205	205	96	114	18	TK	II
1	1	08:00	09:00	206	206	96	108	12	TK	II
1	1	08:00	09:30	207	207	96	114	18	TK	II
1	1	08:00	09:15	209	209	96	111	15	TK	II
1	1	08:15	09:45	202	202	99	117	18	TK	II
1	1	08:26	09:51	102	102	101	118	17	TK	II
1	1	08:30	09:30	106	106	102	114	12	TK	II
1	1	08:45	10:00	210	210	105	120	15	TK	II
1	1	09:00	15:30	12	12	108	186	78	TK	II
1	1	09:08	10:14	104	104	110	123	13	TK	II
1	1	09:30	11:00	209	209	114	132	18	TK	II
1	1	09:45	11:00	211	211	117	132	15	TK	II
1	1	10:00	13:02	101	101	120	156	36	TK	II
1	1	11:00	14:00	14	14	132	168	36	TK	II
1	1	11:00	12:00	104	104	132	144	12	TK	II
1	1	11:09	12:15	217	217	134	147	13	TK	II
1	1	11:30	12:15	211	211	138	147	9	TK	II

1	1	11:45	12:45	213	213	141	153	12	TK	II
1	1	12:00	13:15	203	203	144	159	15	TK	II
1	1	12:30	13:30	114	114	150	162	12	TK	II
1	1	12:30	13:30	215	215	150	162	12	TK	II
1	1	13:00	14:00	217	217	156	168	12	TK	II
1	1	13:15	14:26	104	104	159	173	14	TK	II
1	1	13:30	14:30	203	203	162	174	12	TK	II
1	1	14:01	15:05	107	107	168	181	13	TK	II
1	1	13:58	15:27	116	116	168	185	17	TK	II
1	1	14:00	15:52	215	215	168	190	22	TK	II
1	1	14:10	16:07	117	117	170	193	23	TK	II
1	1	14:45	16:15	106	106	177	195	18	TK	II
1	1	15:00	16:00	102	102	180	192	12	TK	II
1	1	15:00	16:45	111	111	180	201	21	TK	II
1	1	15:45	17:00	12	12	189	204	15	TK	II
1	1	16:00	17:45	216	216	192	213	21	TK	II
1	1	16:59	17:53	101	101	204	215	11	TK	II
1	1	17:15	18:00	213	213	207	216	9	TK	II
1	1	18:30	20:15	215	215	222	243	21	TK	II
1	2	18:54	04:50	106	106	227	346	119	TK	II
1	1	19:00	19:54	101	101	228	239	11	TK	II
1	1	19:00	20:45	207	207	228	249	21	TK	II
1	2	19:35	05:52	116	116	235	358	123	TK	II
1	2	20:00	03:45	111	111	240	333	93	TK	II
1	1	20:00	22:00	119	119	240	264	24	TK	II
1	2	20:15	03:45	101	101	243	333	90	TK	II
1	1	20:30	21:45	128	128	246	261	15	TK	II
1	2	20:30	03:45	130	130	246	333	87	TK	II
1	2	20:30	06:00	213	213	246	360	114	TK	II
1	1	21:00	22:15	210	210	252	267	15	TK	II
1	2	21:30	05:00	102	102	258	348	90	TK	II
1	1	22:15	23:30	121	121	267	282	15	TK	II
1	2	23:00	13:00	12	12	276	444	168	TK	II
1	2	23:00	03:00	216	216	276	324	48	TK	II
2	2	00:30	04:00	110	110	294	336	42	TK	II
2	2	01:00	02:07	217	217	300	313	13	TK	II
2	2	03:00	04:14	108	108	324	339	15	TK	II
2	2	03:30	05:45	1	1	330	357	27	TK	II
2	2	03:30	05:30	104	104	330	354	24	TK	II
2	2	03:30	05:00	127	127	330	348	18	TK	II
2	2	05:00	19:00	133	133	348	516	168	TK	II
2	3	05:15	09:30	123	123	351	690	339	TK	II
2	3	05:15	09:30	219	219	351	690	339	TK	II
2	2	05:30	07:45	105	105	354	381	27	TK	II
2	2	05:45	08:00	220	220	357	384	27	TK	II
2	2	06:00	07:05	201	201	360	373	13	TK	II
2	2	06:00	07:18	209	209	360	376	16	TK	II
2	2	06:15	07:05	206	206	363	373	10	TK	II
2	2	06:25	08:15	104	104	365	387	22	TK	II
2	2	06:30	08:51	125	125	366	394	28	TK	II

2	2	06:56	08:15	207	207	371	387	16	TK	II
2	2	06:53	08:15	208	208	371	387	16	TK	II
2	2	07:30	08:45	213	213	378	393	15	TK	II
2	2	07:52	09:37	202	202	382	403	21	TK	II
2	2	07:55	10:08	121	121	383	410	27	TK	II
2	2	08:00	10:00	105	105	384	408	24	TK	II
2	2	08:20	10:15	216	216	388	411	23	TK	II
2	2	08:25	11:18	127	127	389	424	35	TK	II
2	2	08:30	09:33	104	104	390	403	13	TK	II
2	2	08:31	10:15	120	120	390	411	21	TK	II
2	2	08:30	10:38	122	122	390	416	26	TK	II
2	2	08:36	10:03	102	102	391	409	18	TK	II
2	2	09:00	10:00	205	205	396	408	12	TK	II
2	2	10:00	11:08	217	217	408	422	14	TK	II
2	2	11:17	12:08	117	117	423	434	11	TK	II
2	2	11:36	12:57	201	201	427	443	16	TK	II
2	2	11:33	12:45	209	209	427	441	14	TK	II
2	2	11:41	13:00	102	102	428	444	16	TK	II
2	2	11:43	12:50	101	101	429	442	13	TK	II
2	2	11:51	13:30	204	204	430	450	20	TK	II
2	2	11:54	13:40	105	105	431	452	21	TK	II
2	2	12:15	13:45	215	215	435	453	18	TK	II
2	2	12:22	13:20	125	125	436	448	12	TK	II
2	2	12:30	15:15	120	120	438	471	33	TK	II
2	2	13:00	14:45	104	104	444	465	21	TK	II
2	2	13:00	14:30	110	110	444	462	18	TK	II
2	2	13:00	15:00	216	216	444	468	24	TK	II
2	2	13:30	14:45	209	209	450	465	15	TK	II
2	2	13:45	14:55	102	102	453	467	14	TK	II
2	2	14:00	15:49	215	215	456	478	22	TK	II
2	2	14:13	15:15	105	105	459	471	12	TK	II
2	2	14:30	16:00	210	210	462	480	18	TK	II
2	2	15:03	16:15	101	101	469	483	14	TK	II
2	2	15:05	16:45	104	104	469	489	20	TK	II
2	2	15:10	17:03	102	102	470	493	23	TK	II
2	3	16:50	01:00	120	120	490	588	98	TK	II
2	2	17:30	18:54	211	211	498	515	17	TK	II
2	2	17:36	19:00	105	105	499	516	17	TK	II
2	2	17:44	18:45	104	104	501	513	12	TK	II
2	2	17:45	19:30	125	125	501	522	21	TK	II
2	2	17:58	19:00	216	216	504	516	12	TK	II
2	2	18:20	19:48	101	101	508	526	18	TK	II
2	2	18:54	20:45	220	220	515	537	22	TK	II
2	2	19:06	20:45	104	104	517	537	20	TK	II
2	2	19:28	20:43	107	107	522	537	15	TK	II
2	3	19:45	05:30	203	203	525	642	117	TK	II
2	3	20:15	06:00	2	2	531	648	117	TK	II
2	3	20:30	02:00	133	133	534	600	66	TK	II
2	3	20:30	06:00	213	213	534	648	114	TK	II
2	2	20:30	22:17	216	216	534	555	21	TK	II

2	3	21:21	03:00	107	107	544	612	68	TK	II
2	2	21:50	23:36	115	115	550	571	21	TK	II
2	3	22:30	05:08	104	104	558	638	80	TK	II
2	3	23:00	02:45	105	105	564	609	45	TK	II
3	3	00:45	09:00	14	14	585	684	99	TK	II
3	3	03:00	04:00	130	130	612	624	12	TK	II
3	3	03:15	08:15	20	20	615	675	60	TK	II
3	3	03:30	05:18	210	210	618	640	22	TK	II
3	4	04:45	06:15	132	132	633	939	306	TK	II
3	3	05:30	06:30	101	101	642	654	12	TK	II
3	3	05:30	06:33	104	104	642	655	13	TK	II
3	3	05:37	06:45	212	212	643	657	14	TK	II
3	3	06:00	10:00	126	126	648	696	48	TK	II
3	3	06:30	09:15	2	2	654	687	33	TK	II
3	3	06:30	08:00	206	206	654	672	18	TK	II
3	3	06:30	08:00	210	210	654	672	18	TK	II
3	3	06:30	08:15	216	216	654	675	21	TK	II
3	3	07:00	08:15	101	101	660	675	15	TK	II
3	3	07:01	08:00	110	110	660	672	12	TK	II
3	3	07:15	08:15	104	104	663	675	12	TK	II
3	3	08:00	09:00	108	108	672	684	12	TK	II
3	3	08:15	09:02	107	107	675	684	9	TK	II
3	3	08:30	09:30	104	104	678	690	12	TK	II
3	3	08:30	10:30	216	216	678	702	24	TK	II
3	3	08:53	09:55	204	204	683	695	12	TK	II
3	3	08:56	10:32	217	217	683	702	19	TK	II
3	3	09:00	11:28	102	102	684	714	30	TK	II
3	3	09:00	21:00	123	123	684	828	144	TK	II
3	3	09:00	21:00	208	208	684	828	144	TK	II
3	3	09:00	21:00	218	218	684	828	144	TK	II
3	3	09:15	11:29	212	212	687	714	27	TK	II
3	3	09:20	10:30	220	220	688	702	14	TK	II
3	3	09:45	11:07	104	104	693	709	16	TK	II
3	3	09:45	11:00	209	209	693	708	15	TK	II
3	3	10:00	11:00	219	219	696	708	12	TK	II
3	3	10:10	11:40	207	207	698	716	18	TK	II
3	3	11:00	12:30	217	217	708	726	18	TK	II
3	3	11:15	12:15	116	116	711	723	12	TK	II
3	3	11:45	13:00	220	220	717	732	15	TK	II
3	3	12:15	13:15	204	204	723	735	12	TK	II
3	3	12:15	13:30	219	219	723	738	15	TK	II
3	3	12:30	14:00	104	104	726	744	18	TK	II
3	3	12:30	14:00	208	208	726	744	18	TK	II
3	3	12:30	14:00	214	214	726	744	18	TK	II
3	3	12:45	16:18	218	218	729	772	43	TK	II
3	3	13:00	14:30	105	105	732	750	18	TK	II
3	3	13:30	14:30	204	204	738	750	12	TK	II
3	3	13:45	15:30	202	202	741	762	21	TK	II
3	3	14:30	16:00	101	101	750	768	18	TK	II
3	3	14:30	16:00	201	201	750	768	18	TK	II

3	3	14:45	17:00	105	105	753	780	27	TK	II
3	3	15:30	17:00	7	7	762	780	18	TK	II
3	3	16:30	17:32	107	107	774	786	12	TK	II
3	3	17:00	18:00	201	201	780	792	12	TK	II
3	3	17:00	20:15	218	218	780	819	39	TK	II
3	3	17:15	18:30	105	105	783	798	15	TK	II
3	3	17:15	20:00	124	124	783	816	33	TK	II
3	3	17:15	18:00	126	126	783	792	9	TK	II
3	3	17:16	20:16	216	216	783	819	36	TK	II
3	3	17:30	19:30	102	102	786	810	24	TK	II
3	3	17:47	20:14	213	213	789	819	30	TK	II
3	4	18:30	05:15	122	122	798	927	129	TK	II
3	4	18:30	02:00	204	204	798	888	90	TK	II
3	3	18:45	19:30	222	222	801	810	9	TK	II
3	3	19:00	20:30	105	105	804	822	18	TK	II
3	3	19:00	20:53	127	127	804	827	23	TK	II
3	3	19:00	21:00	205	205	804	828	24	TK	II
3	4	19:45	05:33	13	13	813	931	118	TK	II
3	4	20:15	02:45	14	14	819	897	78	TK	II
3	4	20:15	03:30	104	104	819	906	87	TK	II
3	4	20:30	06:00	213	213	822	936	114	TK	II
3	4	20:45	05:30	125	125	825	930	105	TK	II
3	4	21:00	07:00	108	108	828	948	120	TK	II
3	4	21:15	04:30	202	202	831	918	87	TK	II
3	4	22:00	03:15	207	207	840	903	63	TK	II
4	4	00:00	05:00	110	110	864	924	60	TK	II
4	4	02:45	05:00	214	214	897	924	27	TK	II
4	4	03:00	05:00	218	218	900	924	24	TK	II
4	4	03:30	04:45	204	204	906	921	15	TK	II
4	4	03:45	09:30	219	219	909	978	69	TK	II
4	4	03:45	09:30	223	223	909	978	69	TK	II
4	4	06:00	07:45	217	217	936	957	21	TK	II
4	4	06:45	07:30	101	101	945	954	9	TK	II
4	4	06:45	07:45	102	102	945	957	12	TK	II
4	4	06:45	08:15	106	106	945	963	18	TK	II
4	4	07:30	12:15	131	131	954	1.011	57	TK	II
4	4	08:00	09:15	217	217	960	975	15	TK	II
4	4	08:15	09:15	5	5	963	975	12	TK	II
4	4	08:30	10:15	220	220	966	987	21	TK	II
4	4	08:42	10:00	106	106	968	984	16	TK	II
4	4	08:45	10:30	11	11	969	990	21	TK	II
4	4	08:45	10:15	14	14	969	987	18	TK	II
4	4	08:45	10:00	201	201	969	984	15	TK	II
4	4	08:45	10:00	209	209	969	984	15	TK	II
4	4	09:00	10:30	10	10	972	990	18	TK	II
4	4	09:00	10:00	205	205	972	984	12	TK	II
4	4	09:45	11:45	119	119	981	1.005	24	TK	II
4	4	10:00	10:45	116	116	984	993	9	TK	II
4	4	10:45	11:45	101	101	993	1.005	12	TK	II
4	4	11:45	12:45	117	117	1.005	1.017	12	TK	II

4	4	11:45	13:58	207	207	1.005	1.032	27	TK	II
4	4	12:00	13:30	216	216	1.008	1.026	18	TK	II
4	4	12:15	13:30	120	120	1.011	1.026	15	TK	II
4	4	12:30	13:45	205	205	1.014	1.029	15	TK	II
4	4	12:46	14:03	220	220	1.017	1.033	16	TK	II
4	4	13:00	14:30	108	108	1.020	1.038	18	TK	II
4	4	13:00	14:00	208	208	1.020	1.032	12	TK	II
4	4	13:11	14:15	101	101	1.022	1.035	13	TK	II
4	4	13:15	14:30	214	214	1.023	1.038	15	TK	II
4	4	13:30	14:15	105	105	1.026	1.035	9	TK	II
4	4	13:45	14:45	202	202	1.029	1.041	12	TK	II
4	4	13:55	15:06	106	106	1.031	1.045	14	TK	II
4	4	16:00	17:00	104	104	1.056	1.068	12	TK	II
4	4	16:07	17:30	201	201	1.057	1.074	17	TK	II
4	4	16:30	17:45	211	211	1.062	1.077	15	TK	II
4	4	17:00	18:10	102	102	1.068	1.082	14	TK	II
4	4	16:58	18:45	220	220	1.068	1.089	21	TK	II
4	4	17:15	18:30	217	217	1.071	1.086	15	TK	II
4	4	17:30	19:30	106	106	1.074	1.098	24	TK	II
4	4	17:30	21:00	121	121	1.074	1.116	42	TK	II
4	4	18:00	20:00	122	122	1.080	1.104	24	TK	II
4	4	18:00	20:30	201	201	1.080	1.110	30	TK	II
4	4	18:07	20:30	104	104	1.081	1.110	29	TK	II
4	4	18:15	20:39	120	120	1.083	1.112	29	TK	II
4	4	18:30	23:00	216	216	1.086	1.140	54	TK	II
4	4	18:45	20:30	209	209	1.089	1.110	21	TK	II
4	5	19:00	05:05	10	10	1.092	1.213	121	TK	II
4	4	19:00	20:48	204	204	1.092	1.114	22	TK	II
4	4	19:00	21:00	217	217	1.092	1.116	24	TK	II
4	5	19:45	04:28	118	118	1.101	1.206	105	TK	II
4	4	20:00	21:45	207	207	1.104	1.125	21	TK	II
4	4	20:00	21:30	221	221	1.104	1.122	18	TK	II
4	5	20:15	05:00	211	211	1.107	1.212	105	TK	II
4	5	21:30	03:45	102	102	1.122	1.197	75	TK	II
4	5	22:00	03:00	210	210	1.128	1.188	60	TK	II
5	5	02:00	05:00	222	222	1.176	1.212	36	TK	II
5	5	03:00	06:45	132	132	1.188	1.233	45	TK	II
5	5	03:00	04:15	216	216	1.188	1.203	15	TK	II
5	5	03:00	07:00	218	218	1.188	1.236	48	TK	II
5	5	05:00	23:55	219	219	1.212	1.439	227	TK	II
5	5	05:00	23:55			1.212	1.439	227	TK	II
5	5	05:15	06:15	101	101	1.215	1.227	12	TK	II
5	5	06:00	07:00	202	202	1.224	1.236	12	TK	II
5	5	06:00	08:15	215	215	1.224	1.251	27	TK	II
5	5	07:00	09:45	219	219	1.236	1.269	33	TK	II
5	5	07:15	08:45	118	118	1.239	1.257	18	TK	II
5	5	07:15	09:45	210	210	1.239	1.269	30	TK	II
5	5	07:30	08:57	222	222	1.242	1.259	17	TK	II
5	5	07:45	09:00	126	126	1.245	1.260	15	TK	II
5	5	07:55	09:00	217	217	1.247	1.260	13	TK	II

5	5	08:00	09:30	105	105	1.248	1.266	18	TK	II
5	5	08:00	09:45	108	108	1.248	1.269	21	TK	II
5	5	08:30	15:15	128	128	1.254	1.335	81	TK	II
5	5	08:30	10:30	216	216	1.254	1.278	24	TK	II
5	5	09:00	10:15	118	118	1.260	1.275	15	TK	II
5	5	09:00	11:30	211	211	1.260	1.290	30	TK	II
5	5	09:00	11:00	214	214	1.260	1.284	24	TK	II
5	5	09:15	10:10	104	104	1.263	1.274	11	TK	II
5	5	09:45	11:45	106	106	1.269	1.293	24	TK	II
5	5	10:00	11:00	205	205	1.272	1.284	12	TK	II
5	5	10:00	11:15	217	217	1.272	1.287	15	TK	II
5	5	10:20	11:30	101	101	1.276	1.290	14	TK	II
5	5	10:30	11:45	102	102	1.278	1.293	15	TK	II
5	5	10:51	12:15	104	104	1.282	1.299	17	TK	II
5	5	11:45	12:58	101	101	1.293	1.308	15	TK	II
5	5	12:00	13:00	106	106	1.296	1.308	12	TK	II
5	5	12:00	13:00	203	203	1.296	1.308	12	TK	II
5	5	12:00	13:00	207	207	1.296	1.308	12	TK	II
5	5	12:15	13:45	10	10	1.299	1.317	18	TK	II
5	5	12:15	13:15	120	120	1.299	1.311	12	TK	II
5	5	12:15	12:45	216	216	1.299	1.305	6	TK	II
5	5	12:30	14:30	104	104	1.302	1.326	24	TK	II
5	5	12:30	13:30	114	114	1.302	1.314	12	TK	II
5	5	12:45	14:00	116	116	1.305	1.320	15	TK	II
5	5	13:02	13:55	105	105	1.308	1.319	11	TK	II
5	5	13:15	14:30	13	13	1.311	1.326	15	TK	II
5	5	13:15	14:30	214	214	1.311	1.326	15	TK	II
5	5	13:27	14:45	101	101	1.313	1.329	16	TK	II
5	5	13:45	15:15	209	209	1.317	1.335	18	TK	II
5	5	14:00	15:15	120	120	1.320	1.335	15	TK	II
5	5	14:00	15:30	212	212	1.320	1.338	18	TK	II
5	5	14:15	16:30	201	201	1.323	1.350	27	TK	II
5	5	14:15	16:15	218	218	1.323	1.347	24	TK	II
5	5	14:45	15:45	104	104	1.329	1.341	12	TK	II
5	5	14:55	16:00	214	214	1.331	1.344	13	TK	II
5	5	15:15	16:24	102	102	1.335	1.349	14	TK	II
5	5	15:30	16:30	4	4	1.338	1.350	12	TK	II
5	5	15:30	17:00	120	120	1.338	1.356	18	TK	II
5	5	15:43	17:15	113	113	1.341	1.359	18	TK	II
5	5	15:45	16:45	205	205	1.341	1.353	12	TK	II
5	5	16:45	18:00	101	101	1.353	1.368	15	TK	II
5	5	16:51	17:58	102	102	1.354	1.368	14	TK	II
5	5	18:16	19:43	102	102	1.371	1.389	18	TK	II
5	5	18:29	20:45	104	104	1.374	1.401	27	TK	II
5	5	18:30	19:30	206	206	1.374	1.386	12	TK	II
5	5	18:30	20:04	217	217	1.374	1.393	19	TK	II
5	5	18:34	20:17	222	222	1.375	1.395	20	TK	II
5	5	18:47	20:45	126	126	1.377	1.401	24	TK	II
5	5	18:45	20:00	207	207	1.377	1.392	15	TK	II
5	5	19:15	20:30	124	124	1.383	1.398	15	TK	II

5	5	21:00	22:00	121	121	1.404	1.416	12	TK	II

Table A2 Data for Case Study 2

A.3.3 SOLUTION FOR INTERNATIONAL TERMINAL

Variable	Value	Reduced Cost
Y(0, 1)	1.000000	-2073600.
Y(0, 2)	1.000000	-2073600.
Y(0, 3)	1.000000	-2073600.
Y(0, 4)	1.000000	-2072511.
Y(0, 5)	1.000000	-2072304.
Y(0, 6)	1.000000	-2072304.
Y(0, 7)	1.000000	-2072079.
Y(1, 11)	1.000000	-2073551.
Y(2, 16)	1.000000	-2073311.
Y(3, 20)	1.000000	-2073500.
Y(4, 19)	1.000000	-2073519.
Y(5, 14)	1.000000	-2073564.
Y(6, 18)	1.000000	-2073375.
Y(7, 15)	1.000000	-2073344.
Y(11, 17)	1.000000	-2073456.
Y(14, 29)	1.000000	-2073564.
Y(15, 26)	1.000000	-2073575.
Y(16, 27)	1.000000	-2073564.
Y(17, 25)	1.000000	-2073591.
Y(18, 28)	1.000000	-2073564.
Y(19, 30)	1.000000	-2073596.
Y(20, 31)	1.000000	-2073584.
Y(25, 33)	1.000000	-2073591.
Y(26, 35)	1.000000	-2073404.
Y(27, 32)	1.000000	-2073591.
Y(28, 34)	1.000000	-2073456.
Y(29, 53)	1.000000	-2073564.
Y(30, 36)	1.000000	-2073479.
Y(31, 38)	1.000000	-2073519.
Y(32, 37)	1.000000	-2073564.
Y(33, 43)	1.000000	-2073591.
Y(34, 49)	1.000000	-2073519.
Y(35, 39)	1.000000	-2073600.
Y(36, 41)	1.000000	-2073591.
Y(37, 40)	1.000000	-2073591.
Y(38, 42)	1.000000	-2073591.

Y(39, 44)	1.000000	-2073591.
Y(40, 47)	1.000000	-2073564.
Y(41, 46)	1.000000	-2073564.
Y(42, 48)	1.000000	-2073596.
Y(43, 51)	1.000000	-2073551.
Y(44, 50)	1.000000	-2073564.
Y(46, 52)	1.000000	-2073584.
Y(47, 54)	1.000000	-2073404.
Y(48, 56)	1.000000	-2072759.
Y(49, 57)	1.000000	-2072576.
Y(50, 55)	1.000000	-2073375.
Y(51, 59)	1.000000	-2072871.
Y(52, 58)	1.000000	-2073024.
Y(53, 60)	1.000000	-2073116.
Y(54, 62)	1.000000	-2072975.
Y(55, 61)	1.000000	-2073024.
Y(56, 66)	1.000000	-2073591.
Y(57, 82)	1.000000	-2073479.
Y(58, 64)	1.000000	-2073551.
Y(59, 67)	1.000000	-2073591.
Y(60, 88)	1.000000	-2073431.
Y(61, 81)	1.000000	-2073159.
Y(62, 71)	1.000000	-2073456.
Y(64, 69)	1.000000	-2073564.
Y(66, 89)	1.000000	-2073479.
Y(67, 72)	1.000000	-2072871.
Y(69, 73)	1.000000	-2073276.
Y(71, 76)	1.000000	-2073564.
Y(72, 77)	1.000000	0.000000
Y(73, 75)	1.000000	-2073311.
Y(75, 86)	1.000000	-2073536.
Y(76, 84)	1.000000	-2073564.
Y(77, 83)	1.000000	-2073456.
Y(81, 93)	1.000000	-2073591.
Y(82, 94)	1.000000	-2073584.
Y(83, 90)	1.000000	-2073575.
Y(84, 92)	1.000000	-2073551.
Y(86, 97)	1.000000	-2073591.
Y(88, 98)	1.000000	-2073591.
Y(89, 95)	1.000000	-2073596.
Y(90, 100)	1.000000	-2073591.
Y(92, 103)	1.000000	-2073311.
Y(93, 102)	1.000000	-2073375.
Y(94, 105)	1.000000	-2073311.
Y(95, 108)	1.000000	-2073551.
Y(97, 104)	1.000000	-2073344.

Y(98, 106)	1.000000	-2073431.
Y(100, 101)	1.000000	-2073600.
Y(101, 107)	1.000000	-2073536.
Y(102, 109)	1.000000	-2073599.
Y(103, 112)	1.000000	-2073599.
Y(104, 113)	1.000000	-2073591.
Y(105, 115)	1.000000	-2073564.
Y(106, 114)	1.000000	-2073596.
Y(107, 116)	1.000000	-2073591.
Y(108, 117)	1.000000	-2073584.
Y(109, 118)	1.000000	-2073564.
Y(112, 121)	1.000000	-2073584.
Y(113, 119)	1.000000	-2073600.
Y(114, 123)	1.000000	-2073116.
Y(115, 120)	1.000000	-2073584.
Y(116, 122)	1.000000	-2073591.
Y(117, 125)	1.000000	-2073159.
Y(118, 124)	1.000000	-2072871.
Y(119, 126)	1.000000	-2073159.
Y(120, 127)	1.000000	-2073276.
Y(121, 128)	1.000000	-2073375.
Y(122, 129)	1.000000	-2073375.
Y(123, 143)	1.000000	-2073024.
Y(124, 131)	1.000000	-2073596.
Y(125, 132)	1.000000	-2073564.
Y(126, 130)	1.000000	-2073596.
Y(127, 134)	1.000000	-2073519.
Y(128, 133)	1.000000	-2073519.
Y(129, 137)	1.000000	-2073536.
Y(130, 139)	1.000000	-2073431.
Y(131, 140)	1.000000	-2073159.
Y(132, 138)	1.000000	-2073551.
Y(133, 150)	1.000000	-2073564.
Y(134, 151)	1.000000	-2073564.
Y(137, 141)	1.000000	-2073519.
Y(138, 145)	1.000000	-2073564.
Y(139, 142)	1.000000	-2073404.
Y(140, 148)	1.000000	-2073584.
Y(141, 144)	1.000000	-2073564.
Y(142, 169)	1.000000	-2073584.
Y(143, 147)	1.000000	-2073276.
Y(144, 160)	1.000000	-2073591.
Y(145, 149)	1.000000	-2073591.
Y(147, 154)	1.000000	-2073600.
Y(148, 155)	1.000000	-2073575.
Y(149, 156)	1.000000	-2073591.

Y(150, 172)	1.000000	-2073600.
Y(151, 170)	1.000000	-2073564.
Y(154, 159)	1.000000	-2073600.
Y(155, 162)	1.000000	-2073536.
Y(156, 158)	1.000000	-2073600.
Y(158, 164)	1.000000	-2073600.
Y(159, 168)	1.000000	-2073591.
Y(160, 171)	1.000000	-2073591.
Y(162, 173)	1.000000	-2073591.
Y(164, 181)	1.000000	-2073456.
Y(168, 178)	1.000000	-2073519.
Y(169, 174)	1.000000	-2073564.
Y(170, 177)	1.000000	-2073404.
Y(171, 176)	1.000000	-2073519.
Y(172, 175)	1.000000	-2073591.
Y(173, 179)	1.000000	-2073500.
Y(174, 182)	1.000000	-2073591.
Y(175, 180)	1.000000	-2073591.
Y(176, 183)	1.000000	-2073600.
Y(177, 184)	1.000000	-2073591.
Y(178, 185)	1.000000	-2073591.
Y(179, 187)	1.000000	-2073564.
Y(180, 186)	1.000000	-2073564.
Y(181, 188)	1.000000	-2073519.
Y(182, 195)	1.000000	-2073479.
Y(183, 189)	1.000000	-2073456.
Y(184, 190)	1.000000	-2073024.
Y(185, 191)	1.000000	-2073276.
Y(186, 192)	1.000000	-2073456.
Y(187, 193)	1.000000	-2073375.
Y(188, 194)	1.000000	-2073591.
Y(189, 196)	1.000000	-2073591.
Y(190, 198)	1.000000	-2073591.
Y(191, 201)	1.000000	-2073519.
Y(192, 207)	1.000000	-2073600.
Y(193, 203)	1.000000	-2073564.
Y(194, 206)	1.000000	-2073591.
Y(195, 204)	1.000000	-2073456.
Y(196, 208)	1.000000	-2073591.
Y(198, 209)	1.000000	-2073564.
Y(201, 205)	1.000000	-2073591.
Y(203, 210)	1.000000	-2073599.
Y(204, 212)	1.000000	-2073456.
Y(205, 220)	1.000000	-2073404.
Y(206, 214)	1.000000	-2073600.
Y(207, 218)	1.000000	-2073591.

Y(208, 223)	1.000000	-2073276.
Y(209, 221)	1.000000	-2073375.
Y(210, 224)	1.000000	-2073456.
Y(212, 216)	1.000000	-2073591.
Y(214, 222)	1.000000	-2073159.
Y(216, 219)	1.000000	-2073375.
Y(218, 235)	1.000000	-2073564.
Y(219, 229)	1.000000	-2073456.
Y(220, 226)	1.000000	-2073456.
Y(221, 228)	1.000000	-2073456.
Y(222, 232)	1.000000	-2073519.
Y(223, 243)	1.000000	-2073519.
Y(224, 234)	1.000000	-2073564.
Y(226, 236)	1.000000	-2073564.
Y(228, 238)	1.000000	-2073375.
Y(229, 237)	1.000000	-2073276.
Y(232, 239)	1.000000	-2073276.
Y(234, 241)	1.000000	-2073519.
Y(235, 240)	1.000000	-2073276.
Y(236, 242)	1.000000	-2073456.
Y(237, 246)	1.000000	-2073564.
Y(238, 250)	1.000000	-2073024.
Y(239, 247)	1.000000	-2073600.
Y(240, 248)	1.000000	-2073591.
Y(241, 249)	1.000000	-2073596.
Y(242, 251)	1.000000	-2073024.
Y(243, 254)	1.000000	-2072700.
Y(246, 253)	1.000000	-2072700.
Y(247, 252)	1.000000	-2072871.
Y(248, 255)	1.000000	-2072700.
Y(249, 257)	1.000000	-2072759.
Y(250, 256)	1.000000	-2073564.
Y(251, 258)	1.000000	-2073564.
Y(252, 261)	1.000000	-2073564.
Y(253, 262)	1.000000	-2073584.
Y(254, 269)	1.000000	-2073375.
Y(255, 264)	1.000000	-2073564.
Y(256, 268)	1.000000	-2073564.
Y(257, 272)	1.000000	-2073456.
Y(258, 270)	1.000000	-2073591.
Y(261, 271)	1.000000	-2073500.
Y(262, 276)	1.000000	-2071296.
Y(264, 284)	1.000000	-2072924.
Y(268, 274)	1.000000	-2069631.
Y(269, 273)	1.000000	-2070684.
Y(270, 281)	1.000000	-2073456.

Y(271, 279)	1.000000	-2073276.
Y(272, 275)	1.000000	-2073600.
Y(273, 282)	1.000000	-2073024.
Y(274, 286)	1.000000	-2073456.
Y(275, 280)	1.000000	-2073159.
Y(276, 289)	1.000000	-2073456.
Y(279, 285)	1.000000	-2073375.
Y(280, 287)	1.000000	-2073479.
Y(281, 291)	1.000000	-2073591.
Y(282, 298)	1.000000	-2073591.
Y(284, 297)	1.000000	-2073591.
Y(285, 295)	1.000000	-2073584.
Y(286, 293)	1.000000	-2073600.
Y(287, 292)	1.000000	-2073600.
Y(289, 296)	1.000000	-2073600.
Y(291, 301)	1.000000	-2073584.
Y(292, 300)	1.000000	-2073591.
Y(293, 305)	1.000000	-2073564.
Y(295, 299)	1.000000	-2073596.
Y(296, 308)	1.000000	-2073564.
Y(297, 302)	1.000000	-2073519.
Y(298, 303)	1.000000	-2073519.
Y(299, 304)	1.000000	-2073564.
Y(300, 306)	1.000000	-2073564.
Y(301, 310)	1.000000	-2073591.
Y(302, 314)	1.000000	-2073591.
Y(303, 313)	1.000000	-2073591.
Y(304, 315)	1.000000	-2073575.
Y(305, 312)	1.000000	-2073600.
Y(306, 318)	1.000000	-2073591.
Y(308, 311)	1.000000	-2073600.
Y(310, 316)	1.000000	-2073591.
Y(311, 319)	1.000000	-2073591.
Y(312, 317)	1.000000	-2073599.
Y(313, 321)	1.000000	-2073591.
Y(314, 322)	1.000000	-2073575.
Y(315, 323)	1.000000	-2073564.
Y(316, 324)	1.000000	-2073591.
Y(317, 325)	1.000000	-2073591.
Y(318, 327)	1.000000	-2073591.
Y(319, 331)	1.000000	-2073024.
Y(321, 326)	1.000000	-2073600.
Y(322, 328)	1.000000	-2073519.
Y(323, 329)	1.000000	-2073575.
Y(324, 330)	1.000000	-2073159.
Y(325, 334)	1.000000	-2073239.

Y(326, 336)	1.000000	-2073276.
Y(327, 333)	1.000000	-2073159.
Y(328, 337)	1.000000	-2073375.
Y(329, 335)	1.000000	-2073519.
Y(330, 338)	1.000000	-2073375.
Y(331, 339)	1.000000	-2072079.
Y(333, 339)	1.000000	-2071391.
Y(334, 339)	1.000000	-2071575.
Y(335, 339)	1.000000	-2072079.
Y(336, 339)	1.000000	-2071296.
Y(337, 339)	1.000000	-2071836.
Y(338, 339)	1.000000	-2073024.

	GATE1			GATE2			GATE3			GATE4			GATE5			GATE6			GATE7		
		arr. time	dep.time		arr. time	dep.time		arr. time	dep.time		arr. time	dep.time		arr. time	dep.time		arr. time	dep.time		arr. time	dep.time
1	F1	0	50	F2	0	66	F3	0	84	F4	33	75	F5	36	66	F6	36	69	F7	39	66
2	F11	57	72	F16	83	96	F20	94	110	F19	84	108	F14	72	102	F18	84	99	F15	82	96
3	F17	84	96	F27	102	114	F31	114	132	F30	110	123	F29	108	186	F28	105	120	F26	101	118
4	F25	99	117	F32	117	132	F38	141	153	F36	134	147	F53	192	213	F34	132	168	F35	132	144
5	F33	120	156	F37	138	147	F42	156	168	F41	150	162	F60	235	358	F49	177	195	F39	144	159
6	F43	159	173	F40	150	162	F48	170	193	F46	168	185	F88	371	387	F57	227	346	F44	162	174
7	F51	180	201	F47	168	190	F56	222	243	F52	189	204	F98	390	416	F82	357	384	F50	180	192
8	F59	228	249	F54	204	215	F66	246	360	F58	228	239	F106	429	442	F94	388	411	F55	207	216
9	F67	252	267	F62	240	264	F89	371	387	F64	246	261	F114	444	468	F105	428	444	F61	240	333
10	F72	294	336	F71	276	324	F95	389	424	F69	267	282	F123	490	588	F115	450	465	F81	354	381
11	F77	330	348	F76	330	354	F108	431	452	F73	300	313	F143	612	624	F120	469	483	F93	384	408
12	F83	360	373	F84	360	376	F117	456	478	F75	330	357	F147	642	654	F127	501	522	F102	423	434
13	F90	378	393	F92	383	410	F125	499	516	F86	365	387	F154	654	675	F134	531	648	F109	435	453
14	F100	396	408	F103	427	443	F132	522	537	F97	390	411	F159	675	684	F151	654	687	F118	459	471
15	F101	408	422	F112	444	465	F138	544	612	F104	427	441	F168	687	714	F170	693	709	F124	498	515
16	F107	430	450	F121	469	489	F145	618	640	F113	444	462	F178	723	738	F177	723	735	F131	517	537
17	F116	453	467	F128	504	516	F149	643	657	F119	462	480	F185	741	762	F184	738	750	F140	558	638
18	F122	470	493	F133	525	642	F156	660	672	F126	501	513	F191	780	792	F190	774	786	F148	642	655
19	F129	508	526	F150	648	696	F158	672	684	F130	515	537	F201	801	810	F198	789	819	F155	660	675
20	F137	534	555	F172	696	708	F164	684	714	F139	550	571	F205	813	931	F209	825	930	F162	683	695
21	F141	564	609	F175	711	723	F181	726	744	F142	585	684	F220	945	954	F221	945	957	F173	698	716
22	F144	615	675	F180	726	744	F188	753	780	F169	688	702	F226	966	987	F228	969	990	F179	726	744
23	F160	678	690	F186	750	768	F194	783	816	F174	708	726	F236	993	1.005	F238	1.005	1.032	F187	750	768
24	F171	693	708	F192	780	819	F206	819	897	F182	729	772	F242	1.017	1.033	F250	1.056	1.068	F193	783	798
25	F176	717	732	F207	819	906	F214	897	924	F195	783	792	F251	1.057	1.074	F256	1.074	1.098	F203	804	827
26	F183	732	750	F218	909	978	F222	945	963	F204	804	828	F258	1.080	1.104	F268	1.104	1.125	F210	828	948
27	F189	762	780	F235	984	993	F232	972	990	F212	840	903	F270	1.107	1.212	F274	1.188	1.233	F224	960	975
28	F196	783	819	F240	1.011	1.026	F239	1.008	1.026	F216	906	921	F281	1.224	1.251	F286	1.245	1.260	F234	981	1.005
29	F208	822	936	F248	1.029	1.041	F247	1.026	1.035	F219	936	957	F291	1.254	1.278	F293	1.260	1.290	F241	1.014	1.029
30	F223	954	1.011	F255	1.071	1.086	F252	1.062	1.077	F229	969	987	F301	1.282	1.299	F305	1.296	1.308	F249	1.031	1.045
31	F243	1.020	1.038	F264	1.092	1.213	F261	1.083	1.112	F237	1.005	1.017	F310	1.302	1.314	F312	1.308	1.319	F257	1.074	1.116
32	F254	1.068	1.089	F284	1.239	1.269	F271	1.122	1.197	F246	1.023	1.038	F316	1.317	1.335	F317	1.320	1.335	F272	1.128	1.188
33	F269	1.104	1.122	F297	1.272	1.284	F279	1.215	1.227	F253	1.068	1.082	F324	1.338	1.350	F325	1.338	1.356	F275	1.188	1.203
34	F273	1.176	1.212	F302	1.293	1.308	F285	1.242	1.259	F262	1.086	1.140	F330	1.371	1.389	F334	1.375	1.395	F280	1.224	1.236
35	F282	1.236	1.269	F314	1.311	1.326	F295	1.263	1.274	F276	1.188	1.236	F338	1.404	1.416				F287	1.247	1.260
36	F298	1.272	1.287	F322	1.331	1.344	F299	1.276	1.290	F289	1.248	1.269							F292	1.260	1.275

37	F303	1.296	1.308	F328	1.353	1.368	F304	1.296	1.308	F296	1.269	1.293							F300	1.278	1.293
38	F313	1.311	1.326	F337	1.383	1.398	F315	1.313	1.329	F308	1.299	1.305							F306	1.302	1.326
39	F321	1.329	1.341				F323	1.335	1.349	F311	1.305	1.320							F318	1.320	1.338
40	F326	1.341	1.359				F329	1.354	1.368	F319	1.323	1.350							F327	1.341	1.353
41	F336	1.377	1.392				F335	1.377	1.401	F331	1.374	1.401							F333	1.374	1.393

Table A3 Flight Gate Schedule For Case Study 2