A NEW GATE ASSIGNMENT POLICY AND THE EFFECT OF GATE OCCUPANCY TIME ON THE LEVEL OF SERVICE AT AIRPORT TERMINALS

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ABSTRACT

Gate assignment is an important subject in air transportation management. Also gate occupancy time of airplanes which depend not only on the technical issues but also on the service quality of airports is the subject of many studies. The objective of this study is to determine the relationship between occupancy times and level of service (LOS) at baggage claim area and offer a new gate assignment policy. A case study is performed to test the validity of the models. With the proposed assignment policy and by decreasing the occupancy times, better LOS are achieved at the baggage reclaim area.

Keywords: Airplane-gate assignment, passenger waiting time, passenger walking time, level of service at terminals, gate occupancy time.

1. INTRODUCTION

Demand for air transportation increases every day. European air traffic was expected to grow by 4.3 % in 2011, followed by an annual average growth of 3.2% between 2010 and 2014. According to the statistics derived by DHMI (General Directorate of the Authority of State Airports in Turkey), between 2004 and 2013 the increase in passenger traffic is % 233 and %14,3 of increase is realized annually.in Turkey (Figure 1).

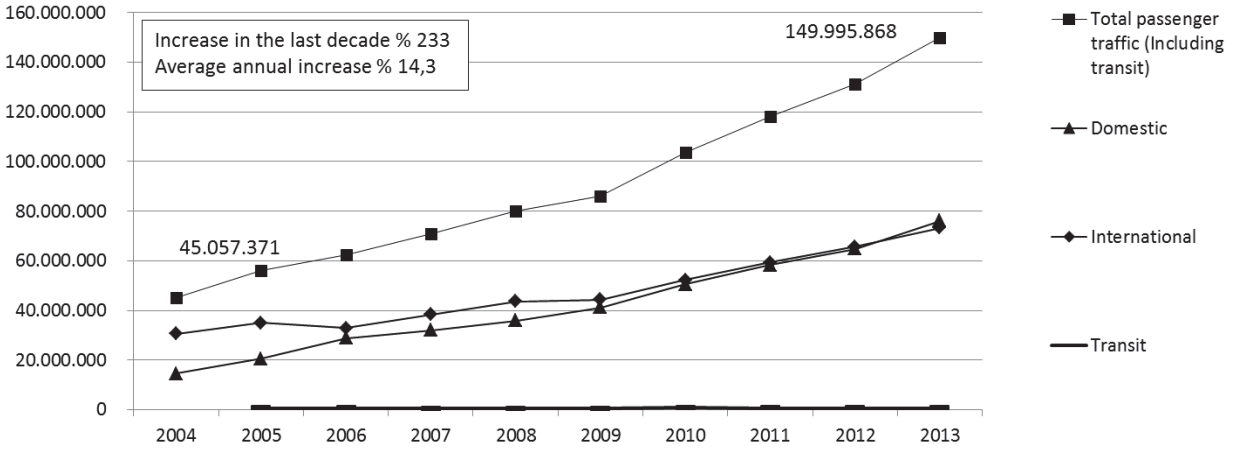


Figure 1 The growing trend in flights handled by DHMI between 2004-2013 (http://www.dhmi.gov.tr/istatistik.aspx)

Considering this traffic growth, enhancements in operations and management are required at airport terminals. One of the most important operational issue in airports is assigning airplanes to appropriate gates. The gate assignment operation has been handled as an optimization problem since the 1970's. The common objective of this problem in previous studies has been to minimize the walking distance for passengers. Lately, the gate assignment problem has usually been studied by applying new optimization techniques like genetic algorithms, rule-based models or simulation.

The paper is organized as follows. In Section 2 the gate assignment problem is defined and the related literature is summarized. Section 3 briefs the concept of level of service at the terminals and corridors. The proposed model and the case study analyses are detailed in Section 4. The conclusions are presented in the last section.

2. GATE ASSIGNMENT PROBLEM

Airport gate assignment is the process of selecting and allocating aircraft to gates to create an assignment schedule, and it is one of the major functions of airport operations (Cheng, 1997). The objectives to be accomplished in flight gate scheduling problems are summarized by Dorndorf et al. (2007-a) as; (1) 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 reduced, (2) the total walking distance for passengers has to be minimized, (3) the deviation of the current schedule from a reference schedule has to be minimized to increase schedule attractiveness and passenger comfort, (4) the number of un-gated (open) aircraft activities has to be minimized, (5) preferences of certain aircrafts for particular gates have to be maximized. Also, the constraints usually considered are stated in three classes; (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 (Dorndorf et al.,2007-a).

Dorndorf et al. (2007-b) classify the research directions of gate assignment problem (GAP) as following: *Single or multiple time slot models* - Gate assignment optimization models can be classified as single or multiple time slot models. Single time slot models consider the assignment of a batch of flights that arrive within a single given time period (slot) at gates. and can be stated as a linear integer program with the objective of minimizing the total walking distance for arriving and departing passengers. In multiple time slot models the entire time interval is divided into a fixed number of time slots. *Types of objectives:* Gate assignment optimization models can be classified with respect to the main objectives considered. For example, passenger walking distance minimization is the most frequently used goal, present not only in gate assignment, but also in the design of airport terminals. This objective is easily motivated and clearly understood, but it leads to models which can hardly be solved. *Mathematical models:* It is well-known, that the single slot GAP can be modeled in analogy to the NP-hard quadratic assignment problem, which is a facility location problem where the cost of placing a flight at a gate depends on the placement of other facilities and transport volume between two facilities (Dorndorf et al.2007-b).

Some of the studies about gate assignment problem are summarized according to the objective of the problem and the solution method in Table 1.

Table 1 A summary of studies about gate assignment problem

Author	*Objective of the problem*	*Solution method*	*Details*
Mangoubi and Mathasiel (1985)	Minimizing the walking distance of arriving, departing and transfer passengers.	Linear programming (LP) relexation of an integer formulation and a heuristic.	With the LP solution, % 32 lower walking distance is obtained compared to the original assignment on an average day at Toronto International Airport. With the heuristic method, an optimal walking distance which was only 3.9% greater than the minimum is obtained.
Cheng (1997)	Minimizing waiting delay of all the assigned aircraft, passenger walking and baggage handling distances, and maximizing the use of fixed gates	Knowledge-based airport gate assignment system integrated with mathematical programming techniques	The proposed approach detailed in the study is a mixed system which attempts to achieve a middle level solution with the advantages of both mathematical programming and human common sense.
Haghani and Chen (1997)	Minimizing the total passenger walking distances of transfer passengers and the total passenger walking distances of local passengers	A new integer programming and an efficient heuristic solution procedure	The proposed heuristic solution approach proved to be an efficient method for obtaining good solutions for large scale gate assignment problems in a very reasonable computation time.
Cheng (1998)	Implementing a methodology concerning the simulation of aircraft at gates in airport terminals.	Network-based method for a more efficient simulation and transforms all the sequence and constraint relations of aircraft at gates into a network.	The use of the network based method rather than the event driven mothod can reduce the computing time of simulation without reducing the accuracy of the simulation results. Also, it is found that the network based method is easier to program and more flexible to modify, and logical and constraint relations are easy to understand and verify.
Bolat (1999)	Minimising the difference between the maximum and minimum slack times	A mathematical model is developed to assign the flights with the minimum range of unutilised time periods of gates	Over randomly generated schedules, 74 flights can be optimally assigned to seven gates within 17 seconds when the gates are re-utilised within 30 minutes after each departure. Over data obtained from Riyadh's International Airport, on average, 72.03% and 54.28% improvements are obtained on the number of remote served aircraft and towed aircraft, respectively.
Yan and Huo (2001)	Minimizing both the passenger walking time and their waiting time.	The weighting method, the column generation approach, the simplex method and the branch and bound technique.	The results of a case study regarding the operation of Chinag Kai-Shek Airport are found to be useful as a reference for both airport authorities and researchers.

Author	Objective of the problem	Solution method	Details
Xu ve Bailey (2001)	Minimizing the overall connection times of transfer passengers walk.	A simple tabu search meta-heuristic	The results of the tests showed that significant savings on passengers' connection time compared with the static gate assignment in current airline operation is obtained.
Yan et al.(2002)	Minimizing the total passenger walking distance	The optimization model and two heuristics to solve for static assignment, than a simulation framework to evaluate the effects of sthocastic flight delays	Although the test results may be useful as references for other airport authorities, it is suggested that each airport authority use the simulation framework with its own real data to evaluate its gate assignments.
Ding et al. (2004)	Minimizing the number of ungated flights and the total walking distances.	A greedy algorithm and a Tabu Search (TS) meta-heuristic	Experiments were conducted using a range of test data sets that reflect realistic scenarios. The results obtained by the proposed model show better results compared with a recent TS heuristic adapted for over-constrained Airport Gate Assignment Problem in shorter running times, especially for the larger and dense data sets.
Ding et al. (2005)	Minimizing the number of ungated flights and total walking distances or connection times	First a greedy algorithm is used to minimize ungated flights. Simulated annealing and a hybrid of simulated annealing and tabu search are used.	Experimental results are good and exceed those previously obtained.

In this study, instead of applying a new optimization technique, it is aimed to ameliorate the service given to passengers, thus improving the level of service at the airport terminal by decreasing the gate occupancy times and promoting a new assignment policy.

3. LEVEL OF SERVICE AT THE TERMINALS

Level of service refers to the quality of the context in which a service takes place. With regard to passenger buildings, it refers specifically to the amount of space available for the activity (De Neufville and Odoni, 2003). Brunetta et al. (1999) define the level of service (LOS) as the service quality and conditions of one or more facilities as experienced by passengers. A set of letters from A (best) to F (unacceptable) are used to define the levels. Typical measures of LOS **are waiting time, processing time, walking time and crowding.**

A passenger arriving at the airport after a long flight is in a hurry to leave the terminal as soon as possible. As stated by Maister (2005):

"… *waiting for something of little value can be intolerable. This is amply illustrated by the eagerness with which airline passengers leap [from] their seats when the airplane reaches the gate, even though they know that it will take time to unload all the passengers ahead of them, and that they may well have to wait for their baggage to arrive at the claim area. The same passenger who sat patiently for some hours during the flight suddenly exhibits an intolerance for an extra minute or two to disembark, and a fury at an extra few minutes for delayed baggage. The point is that the service (the flight) is over, and waiting to get out when there is no more value to be received is aggravating".*

De Neufville and Odoni (2003) state that the physical environment has an important influence on the perception of delays. The more comfortable the environment (area per occupant, availability of seating, ventilation and temperature, ambience of space, etc.), the more tolerant airport users are of delays. The definitions of the levels of service standard are shown in Table 2.

Table 2 Definitions of level of service standards (De Neufville and Odoni, 2003)

LEVEL OF SERVICE	*DESCRIPTION OF STANDARTS*		
	Quality and comfort	**Flow condition**	**Delays**
A	Excellent	Free	None
B	High	Stable, steady	Very few
C	Good	Stable, steady	Acceptable
D	Adequate	Unstable; stop and go	Barely acceptable
E	Inadequate	Unstable; stop and go	Unacceptable
F	Unacceptable	Cross flows	Service breakdown

As mentioned by Pagani et al. (2002), the LOS concept was firstly used for analyzing the capacity of highways. Most airport agencies use time and space standards separately and do not take into account the perception of passengers. Generally, six different levels of service are proposed, as for highways. In Table 3, the level of service standards being used by Transport Canada and IATA (International Air Transport Association) according to space requirements are given (De Neufville and Odoni,2003). In addition, British Airport Authority, IATA and Aeroport de Paris accept the design standard that the time difference between the arrival of the first passenger and the last piece of baggage must not exceed 25 minutes. Also, IATA sets the rule that 90% of passengers should collect their baggage in less than 20 minutes.

Table 3 Space to be provided for passengers and corresponding Level of Service Classes (De Neufville and Odoni, 2003)

Facility	*Minimum LOS Area (m^2/passenger)*					
	A	**B**	**C**	**D**	**E**	**F**
Baggage Reclaim Area (without any device) (Transport Canada)	>1.6	1.4	1.2	1.0	0.8	<0.8
Baggage Reclaim Area (without any device) (IATA)	>2.0	1.8	1.6	1.4	1.2	<1.2

Passengers state the baggage handling process as one of the most important processes experienced during their travel (Pagani et al., 2002). Pagani et al. proposed a LOS model considering the variables of space requirements and service times in addition to user perception. Baggage handling facilities were examined to evaluate the following factors: airport layout, annual number of passengers, layout and dimensions of the baggage handling equipment and surrounding area, distance and time required for the passenger to reach the reclaim area, difference in time between the arrival of the baggage and the passengers.

The level of service of the baggage handling system was measured in 3 different time and space components by Pagani et al. (2002): the passenger's waiting time at the reclaim area, the area (m^2) per passenger in the reclaim area measured at the busiest time and the number of passengers per meter length of the conveyor at the busiest time. Results indicated that factors such as a passenger's expected waiting time and the walking distance between the arrival gate and the reclaim area influence the overall perceived LOS. As the demand increases for air transportation, the level of service concept will be more important because of the limited capacity of airports and airline companies.

In the study evaluating the baggage handling systems by Yen et al. (2002), it is shown that the regular arrival of passengers and fast

delivery of the baggage to the reclaim area enhance the performance of the baggage handling systems. The performance of the baggage handling system has an enormous effect on the passenger's perception of the airport. Of all the services a passenger goes through, like ticket registering and security control, passengers are least tolerant of the baggage reclaim service.

According to Brunetta et al. (1999) the capacity of the baggage reclaim area can be determined by comparing the average waiting time of the passengers and the size of the reclaim area with the number of passengers in the area. To evaluate the qualitative measurement of LOS, Brunetta et al. (1999) have introduced a new variable called the Index of Service (IOS). The LOS is a qualitative statement, whereas the IOS is the corresponding quantitative measurement of these qualitative statements. This is strictly related to the level of service (LOS) and can then be used to obtain the LOS of the facility. As an example, in a waiting lounge, the LOS B corresponds to 2.3 < IOS < 2.7 (m^2/person), that means to provide LOS B in a waiting lounge, a space between 2.3 and 2.7 m^2 should be ensured for each passenger . For a specific facility, a model of the IOS is calculated as follows (Brunetta et al., 1999):

$$IOS = \frac{\text{Area}}{\text{Number of Arriving Passengers} \times \text{Average Dwell Time}} \quad (1)$$

LOS in corridors The analysis used to obtain the general dimension of the corridors and stairs (passageways) is similar to the analysis for obtaining the dimensions of waiting areas. The LOS and the occupancy times are the considered parameters and, in the design of passageways, the width of the area is the dimension that has to be considered and focused on in the related formulae. The considered parameter of the passageways is the flow, which is defined by the width of the passageway. Flow is the number of passengers that pass through the unit width in a specific unit of time, which is also shown as passenger/meter/minutes in units (Fruin, 1971). De Neufville and Odoni (2003) defined the standards of the passageways by adopting the definitons of Fruin (1971) as in Table 4.

Table 4 Level of Service Standards for Passageways (De Neufville and Odoni, 2003)

Type of passageway	***Situation***	*Level of Service Standard (passenger/meter/minutes)*					
		A	**B**	**C**	**D**	**E**	**F**
Corridor	Regular pace	10	12.5	20	28	37	More
Stairs	Slower pace, longer dwell time	8	10	12.5	20	20	More

According to Fruin (1971), basic passenger (pedestrian) traffic flow is:

$$f = \frac{s}{a} \quad (2)$$

where:

f → passenger flow (passenger /meter-minute)

s → average pedestrian speed (meter/minute)

a → average area per pedestrian in the flow (m^2/passenger).

Time-space (TS) analysis can provide a better understanding of the dynamics of these more complicated spaces by combining the knowledge of personal area occupancies developed in the LOS standards with a more discrete analysis of pedestrian activities. With the TS method, the product of the time of the analysis period, for example, the peak 15 minutes, and the area of the analysis space in m^2 establishes a TS supply. The demand for this TS supply is determined by the product of the total number of

pedestrians using the analyzed space and their time of occupancy (Fruin, 1971).

The typical application of the TS analysis is the evaluation of a space where there is a forecasted demand of passengers and where the configuration and dimensions of the space and the passenger functions like walking and waiting are known. The area per pedestrian can be obtained by dividing the TS demand into the TS supply, as shown in Eq. (3):

$$a = \frac{TS_{supply}}{TS_{demand}} = \frac{T \times s}{n \times t} \quad (3)$$

where,

a → average area per pedestrian (m^2/passenger)

T → time of the analysis period (minute)

S → effective area of the analysis space (m^2)

n → number of pedestrians occupying the space (passenger)

t → the predicted occupancy times of pedestrians during the analysis period (minute)

Index of Service (IOS) for corridors The area per passenger (a) obtained from Eq. (2) can be used in Eq. (3) and the flow of passengers (f) which is used to obtain the LOS of the corridors can be derived as follows:

$$f = \frac{s \times n \times t}{T \times S} \quad (4)$$

4. THE PROPOSED GATE ASSIGNMENT MODEL

With the proposed model it is known that longer walking times are reached because the passengers are forced to spend time for walking instead of waiting, with the help of minimizing the gate delay times. This has been applied at some airports as a management policy of the operators, as de Neufville and Odoni (2003) stated. With this policy, airport terminal management direct the passengers according to the LOS standards of different parts of the terminal area. For example, LOS C corresponds to 1 m^2 per passenger at the passport control area and 1.6 m^2 per passenger at the baggage reclaim area. With a common decision by the passport control operators and terminal operators, the passengers are compelled to spend more time at the passport control area to ensure that the passengers and the baggage arrive at the reclaim area at the same or nearly the same time (De Neufville and Odoni, 2003).

In this study, the effect of both a different assignment rule and decreased gate occupancy time on passengers' waiting times and the level of service at the baggage reclaim area are analyzed.

The proposed new assignment rule is:

- Minimizing "the gate delay time", which is calculated for each gate separately, and described as the time between the passenger walking and baggage delivery time of each gate (Z_1).

The results of the models are compared to the results of the most used model which minimizes the passenger walking time (Z_w). For all of the models:

- Average passenger walking times (t^w),
- Average baggage waiting times of passengers at the baggage reclaim area (t^l),

are obtained by using the modelling program, GAMS (www.gams.com). The Cplex algorithm developed by IBM included in GAMS (www.gams.com) is used to solve the mathematical models.

Besides minimizing the gate delay time, the effect of gate occupancy times of airplanes is also investigated. The analyses of the flight assignment data of AIA (International Atatürk Airport) brought out the fact that there is an obvious difference between the occupancy times of airplanes of the main user (MU) of the airport and all the other airline companies (OC). For example, the average occupancy time of A320 model

airplane operated by the MU and the OC are 94 and 68 minutes, respectively. So, besides the comparison of the assignment rules, the effect of the occupancy times of the airplanes on the level of service at the baggage reclaim area is also analyzed. For this analysis, the occupancy times of the MU's airplanes are decreased to the OC's occupancy times of the same type of airplanes. The occupancy times of OC' airplanes are chosen as the decreased occupancy times because it is known for sure that at the same circumstances those occupancy times are achievable at the same airport with the same type of airplanes.

As a result, for two different situations, which are the gate assignments with the actual and with the decreased average occupancy times, four different time values, separately for passenger walking and waiting times are held with the objective of minimizing the passenger walking distance and minimizing the gate delay time (Table 8).

Model Assumptions

1. In this paper, level of service refers to the level of service at the baggage reclaim area.
2. Departing and transferring passengers are omitted because the change at the level of service of the baggage reclaim area is the main objective of this paper.
3. Passport control delay is assumed to be constant for it hasn't been possible to get the permissions to collect data within the area.
4. There are 22 gates and 102 remote stands at the airport studied.
5. If there is any available gate, it is forbidden to assign the airplane to the remote gates.

The notations

To express the mathematical models the following notations are used:

f_j : difference between the passenger walking and baggage delivery time of each gate, "the gate delay time" (minutes)

$t^b_{j,bb}$: average baggage delivery time from gate j to the reclaim area (minutes),

$t^y_{j,bb}$: average passenger walking time from gate j to the reclaim area (minutes),

$i \in I$ = {flight 1, flight 2, …, flight n}

I_G = {$i \in I$: i = flights with wide-body aircraft}

I_D = {$i \in I$: i = flights with narrow-body aircraft}

$j \in J$ = {gate 1, gate 2, …, gate m}

J_G = {$j \in J$: j = gates that can serve both wide or narrow body aircraft}

J_{GT} = {$j \in J$: j = restricted gates that can serve only wide-body aircraft}

J_{GTR} = {$j \in J$: j = gates at the right side of the restricted gates}

J_{GTL} = {$j \in J$: j = gates at the left side of the restricted gates}

J_S = {$j \in J$: j = open park gates}

$J_R : J_{GT} \rightarrow J_{GTR}$ (J_R is the function that gives the gate at the right of the gate $j \in J_{GT}$)

$J_L : J_{GT} \rightarrow J_{GTL}$ (J_L is the function that gives the gate at the left of the gate $j \in J_{GT}$)

J_{G0} = {$j \in J$: j = the gate that should be kept empty in case a wide-body aircraft is assigned to an adjacent gate}

t^a_i : arrival time of flight i

t^d_i : departure time of flight i

$U_{K1} = \{(i_1, i_2) \in I \times I : t^a_{i_2} - t^d_{i_1} \leq 15\}$

$U_{K2} = \{(i_1, i_2) \in I \times I : t^a_{i_1} < t^a_{i_2}\}$

sa : the area where the baggage is gathered before being conveyed to the belts,

$bs_{j,bb}$: number of pieces of baggage delivered from gate j to the reclaim area,

X_{ij} =1, if flight i is assigned to gate j; otherwise x_{ij} =0.

Modeling

In this study, minimization of "total gate delay time, $\sum f_j$", which is the sum of the difference between the passenger walking and baggage delivery time of each gate is proposed as a gate assignment model (Eq. 6).

$$Minimum\ Z_2 = \sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij} ys_{j,bb} f_j \quad (6)$$

Also, the model which minimizes the total passenger walking time (Eq. 7) is used to analyze the effects of the proposed model.

$$Minimum\ Z_w = \sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij} ys_{j,bb} t_{j,bb}^{y} \quad (7)$$

Subject to:

$$\sum_{j=1}^{m} X_{ij} = 1 \qquad i=1, 2, \ldots, n \qquad \forall_j \quad (8)$$

$$X_{i_1+j} + X_{i_2+j} \leq 1 \qquad j \notin J_s \qquad \forall_j, (i_1, i_2) \in U_K = U_{K1} \cap U_{K2} \quad (9)$$

$$\sum_{j=J'_G} X_{ij} = 0 \qquad \forall_i \in I_G \quad (10)$$

$$\sum_{j=j_1}^{i\in I_G} X_{ij} \leq m\left(1 - \sum_{j=J_R(j_1)}^{i\in I_G} X_{ij}\right) \qquad m=999 \qquad \forall j_1 \in (J_{GTR} \cap J_G) \quad (11)$$

$$\sum_{j=j_1}^{i\in I_G} X_{ij} \leq m\left(1 - \sum_{j=J_L(j_1)}^{i\in I_G} X_{ij}\right) \qquad m=999 \qquad \forall j_1 \in (J_{GTL} \cap J_G) \quad (12)$$

$$\sum_{j=J_R(j_1)}^{i\in I_G} X_{ij} \leq m\left(1 - \sum_{j=j_1}^{i\in I} X_{ij}\right) \qquad m=999 \qquad \forall j_1 \in J_{G0} \quad (13)$$

$$\sum_{j=J_L(j_1)}^{i\in I_G} X_{ij} \leq m\left(1 - \sum_{j=j_1}^{i\in I} X_{ij}\right) \qquad m=999 \qquad \forall j_1 \in J_{G0} \quad (14)$$

$$X_{ij} \in \{0, 1\} \qquad I= 1, 2, \ldots, n \quad j=1, 2, \ldots, m \quad (15)$$

Constraint 8 ensures that a flight can be assigned to one and only one gate. If there is less than 15 minutes between the arrival and the departure of two flights, then these two flights cannot be assigned to the same gate. This restriction is ensured by constraint 9. The wide-body aircraft can only be served at specific gates, which is stated in constraint 10. At AIA some of the gates can only serve or are limited to serving narrow-body aircraft in case a wide-body aircraft parks at the adjacent (on the right or left) gate. This restriction is expressed in constraints 11 and 12. Also, some of the gates should be kept empty during the parking time of a wide-body aircraft at the adjacent gates (at the right or left) as shown in constraints 13 and 14.

5. CASE STUDY

Data sets used in the study are chosen by analyzing the arriving airplane data of a six month period. As a result, it is seen that, at AIA, the maximum number of landings takes place between 15:00-18:00. Through the data of those 3-hour periods, 5 sets (DS 1-5) are chosen randomly to be used in the models. These data belong to the days: 3 April 2008 (DS 1), 17 April 2008 (DS 2), 11 May 2008 (DS 3), 8 June 2008 (DS 4) and 16 June 2008 (DS 5). Data sets include 37, 32, 36, 35 and 38 landings and assignments, respectively (Table 5).

Table 5 Summary of data sets used in the models including flights arrived at AIA between 15:00-18:00

Data Set	Number of flights	Number of airplanes operated by the main user	Number of flights assigned to the remote gates	Total number of passengers with %70 seat occupancy rate
DS1	37	18	7	4296
DS2	32	10	8	3631
DS3	36	20	9	4237
DS4	35	18	8	4204
DS5	38	22	10	4424

5.1. Flight Data

Between January and June 2008, 26,207 flights were given service at the international terminal of The International Atatürk Airport (AIA). 2,258 of these flights were directed to the domestic terminal. A small part of the data was collected incorrectly, and some types of aircraft which served during the six months period were rarely used (frequency <1%), so those flights are eliminated from the analysis. Therefore, the number of flights analyzed during the research is decreased to 21,221.

The gate occupancy times of the incoming flights were grouped in 20-minute time intervals. The flights that fall into intervals that have a frequency smaller than 1.5% were eliminated, so 87% of the flights are left to analyze. The frequency data showed that a great amount (25%) of the occupancy times last between 61-80 minutes and more than half (61%) of the airplanes occupy the gates between 41-100 minutes.

Airline companies using the Atatürk International Airport are grouped into two classes for this study: the main user of the airport (MU) which owns % 51 of flights landed at AIA and all the other companies (OC).

During this research there were 23 gates connected to the international terminal building of AIA. By analyzing the flights' average occupancy times according to gates and airline companies, it is determined that the total average gate occupancy time is 87 minutes for all flights. While the airplanes of the MU occupied the gates for 103 minutes on average, the OC's airplanes of the same type had an average occupation time of 73 minutes.

It can be seen that the MU's airplanes occupy the gates approximately 30% more than the OC's airplanes, even if they are the same type of aircraft. For example, the A320 airplanes of the MU have an average occupancy time of 94 minutes, while the OC's A320 airplanes occupy the gates on average for 68 minutes (Table 6).

Table 6 The average gate occupancy times of airplanes according to their company

Airplane type	*The average gate occupancy times of all airplanes (minutes)*	*The average gate occupancy times of the MU (minutes)*	*The average gate occupancy times of the OC (minutes)*
A320	75	94	68
A313	104	106	97
A319	62	89	62
A321	88	107	66
A330	110	112	107
A343	111	111	-
B734	60	106	53
B738	97	100	71
B733	55	-	55
B735	65	-	65
B752	88	-	88
B763	104	-	104
B773	89	-	89
AB6	86	-	86
M82	57	-	57

(The empty cells mean that the airline companies do not have that type of airplane in their fleet)

The authors have not noticed any study about the relationship between occupancy times and the level of service at passenger terminals in the literature. The occupancy time of an airplane depends on the airline company, the conditions of the airport, etc. For this reason, for a comparison of the models regarding types of airplane, the occupancy times of the airplanes are equated to the average occupancy times of the OC. Even if the occupancy times of the OC's airplanes are more than they should be, this reduction in occupancy times is found to be valid, because those "relatively short times" are achieved under the same circumstances.

5.2. Passenger Walking Times

Passenger walking time is the time spent by walking from the airplane parked at a gate to the baggage reclaim area. This time includes deplaning time of passengers, walking from gate to the passport control area, waiting for passport control and walking from the passport control area to the baggage claim area. Passenger walking time at AIA Terminal is calculated in four steps.

Deplaning time To determine the time of deplaning, two studies of Boeing are used (http://www.boeing.com/commercial/aeromagazine/aero_01/textonly/t01txt.html). Deplaning of passengers starts 0.5 minutes after the engine shutdown phase and ends in 4.2 minutes. In the study by Boeing, both of the doors of the plane are used for deplaning. For the airplanes that park at the gate of the terminal at AIA, the passengers can only deplane from one door. So, the times for the first and the last passenger leaving the airplane are 0.5 and 8 minutes, respectively. The same studies from Boeing are used to find out the deplaning time of the passengers of a wide-body airplane (B757-300). For the wide-body airplanes, the deplaning times for the first and the last passengers are 1 and 15 minutes, respectively. In the case of the wide-body aircraft, the deplaning process is done from one door, so the times of deplaning passengers are used, as given.

Walking Times from Gates to Passport Control Area ($t^{y}_{j,pk}$) Walking times from gates to passport control area are gained from the distances measured and calculated

on the plan of the terminal area assuming that the average walking speed of a pedestrian is 4.5 km/hr. Also the times are collected by walking the distances personally. It has been seen that the measured and the collected times are almost the same. The walking times of passengers of an airplane assigned to a remote gate are assumed to be 20 minutes (with the help of the airport authorities). That time includes the time spent on the service bus.

Passport Control Times (t^{y}_{pk}) It was not possible to get permission to measure the times spent by passengers at passport control booths. The average time spent by each passenger at the passport control area was assumed to be 5 minutes (including the waiting time in the queue), on advice from the managers of the baggage handling department. $t^{y}_{pk,bb}$

The walking time from passport control to the baggage reclaim area ($t^{y}_{pk,bb}$) The time spent by the passengers getting to the baggage reclaim area after passport control was measured and calculated using a scaled plan of the terminal. Assuming a passenger's average walking speed is 4.5 km/h, it was calculated that each passenger spends 1 minute on average to reach the baggage conveyor belts. The total walking time from the gates to the baggage claim area for each gate is the sum of the average walking time from gate to passport control area, from passport control area to the baggage reclaim area and the time spent at the passport control booths:

$$t^{y}_{j,bb} = t^{y}_{j,pk} + t^{y}_{pk} + t^{y}_{pk,bb} \qquad (5)$$

5.3. Baggage Delivery times

The data gained from The Baggage Handling Department of AIA is used to determine the baggage delivery times. The time an airplane parked at a gate and the time of the arrival of both the first piece of baggage and the last piece of baggage of this airplane were included in these data for each gate, including the open gates. According to the Baggage Handling Department, after the arrival of the baggage to the chute, the baggage is sent to the conveyor belts in 3 minutes.

5.4. Average baggage waiting time (Gate Delay Time)

The model implemented by Neufville and Odoni (2003), which assumes that the baggage and the passengers' arrival at the baggage claim area is uniform, is used to determine the waiting times of the passengers (WT) at the baggage reclaim area, which was also used by Brunetta et al (1999). The input parameters of the model are the area, the arrival distribution of the passengers (T^P), the arrival distribution of the baggage (T^B), the time of the arrival of the first and the last passenger (t^P_1, t^P_L), the time of the arrival of the first and the last piece of baggage (t^B_1, t^B_L), the average number of pieces of baggage for each passenger ($n_{baggage}$).

6 different combinations of different situations can be made by using the input parameters. In this study the combination where $t^P_L < t^B_1$ is used (Figure 2). The average waiting time of passengers for their baggage is calculated as:

$$E(WT)=E(T^B)-E(T^P)=[(t^B_1 + t^B_L)/2]-[(t^P_1+t^P_L)/2] \qquad (6)$$

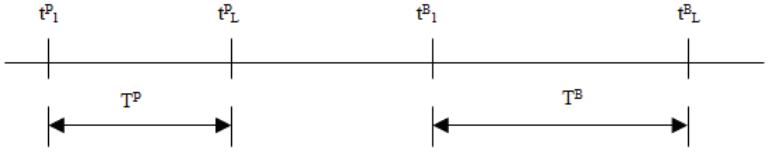


Figure 2 The combination of parameters (t^P_1, t^P_L, t^B_1, t^B_L) for the situation of $t^P_L < t^B_1$ (Brunetta et al., 1999)

For AIA airport, the passenger walking and baggage delivery times from airplanes to the baggage reclaim area and the waiting time for the passengers of the airplanes parked at each gate are summarized at Table 7.

Table 7 The passenger walking and baggage delivery times from airplanes to the baggage reclaim area

Gate No	Passenger walking time to reclaim area (minutes)	Baggage delivery time to reclaim area (minutes)	Gate delay times (minutes)
1	17.33	20.73	3.40
2	16.69	21.98	5.29
3	16.05	21.92	5.87
4	15.41	19.98	4.57
5	15.52	21.42	5.90
6	16.16	21.67	5.51
7	16.10	22.65	6.55
8	17.25	26.53	9.28
9	15.89	21.03	5.14
10	15.46	21.10	5.64
11	14.72	19.13	4.41
12	15.33	22.60	7.27
13	13.33	19.73	6.40
14	14.03	20.40	6.37
15	11.94	19.68	7.74
16	11.85	20.22	8.37
17	12.00	19.88	7.88
18	14.69	23.42	8.73
19	15.90	21.28	5.38
20	14.70	19.67	4.97
21	15.34	20.08	4.74
22	15.98	20.08	4.10
23	19.11	23.50	4.39
Remote	20	30	10

5.5. Model Results

The General Algebraic Modeling System (GAMS) is used to solve the models. GAMS is a high-level modeling system for mathematical programming and optimization. It consists of a language compiler and a stable of integrated high-performance solvers. The General Algebraic Modeling System (GAMS) is specifically designed for modeling linear, nonlinear and mixed integer optimization problems. The system is especially useful with large, complex problems. The Cplex algorithm developed by IBM included in GAMS [7] is automatically chosen according to the properties of the mathematical models (GAMS official website). For problems with integer variables, Cplex uses a branch and cut algorithm which solves a series of LP, subproblems. Because a single mixed integer problem generates many subproblems, even small mixed integer problems can be very compute intensive and require significant amounts of physical memory. (http://www.gams.com/dd/docs/solvers/cplex.pdf)

Table 8 Comparison of results determined by actual assignment, passenger walking time minimization and gate delay time minimization

		Number of flights assigned to remote gates			*Average passenger walking times (minutes)*			*Average passenger waiting times (minutes)*		
		Actual assign.	**Z_w**	**Z_1**	**Actual assign.**	**Z_w**	**Z_1**	**Actual assign.**	**Z_w**	**Z_1**
With actual gate occupancy times	**DS1**	7	2	3	23,13	20,93	***22,69***	9,33	***9,31***	8,09
	DS2	8	-	-	23,37	20,69	***22,26***	9,74	***9,09***	7,60
	DS3	9	-	-	23,71	20,77	***22,37***	10,07	***9,00***	7,70
	DS4	8	-	-	23,24	20,23	***22,26***	9,60	***9,21***	7,60
	DS5	10	7	7	23,29	21,96	***23,21***	10,24	***9,89***	8,76
With decreased gate occupancy times	**DS1**	7	-	-	23,13	***20,46***	22,33	9,33	9,11	***7,50***
	DS2	8	-	-	23,37	***20,44***	22,49	9,74	9,21	***7,40***
	DS3	9	-	-	23,71	***20,47***	22,49	10,07	9,17	***7,37***
	DS4	8	-	-	23,24	***20,11***	22,81	9,60	9,19	***7,01***
	DS5	10	-	-	23,29	***20,80***	22,34	10,24	8,93	***7,63***

The output of the models using 5 different data sets (DS) with actual and decreased occupancy times include the number of flights that are assigned to open gates, average walking times and waiting times per passenger (Table 8). The results in *italic* format show the maximum and minimum time values for walking and waiting. The rate of change in waiting and walking times according to the actual waiting time are also given in Figure 3 as normalized ratios according to actual results.

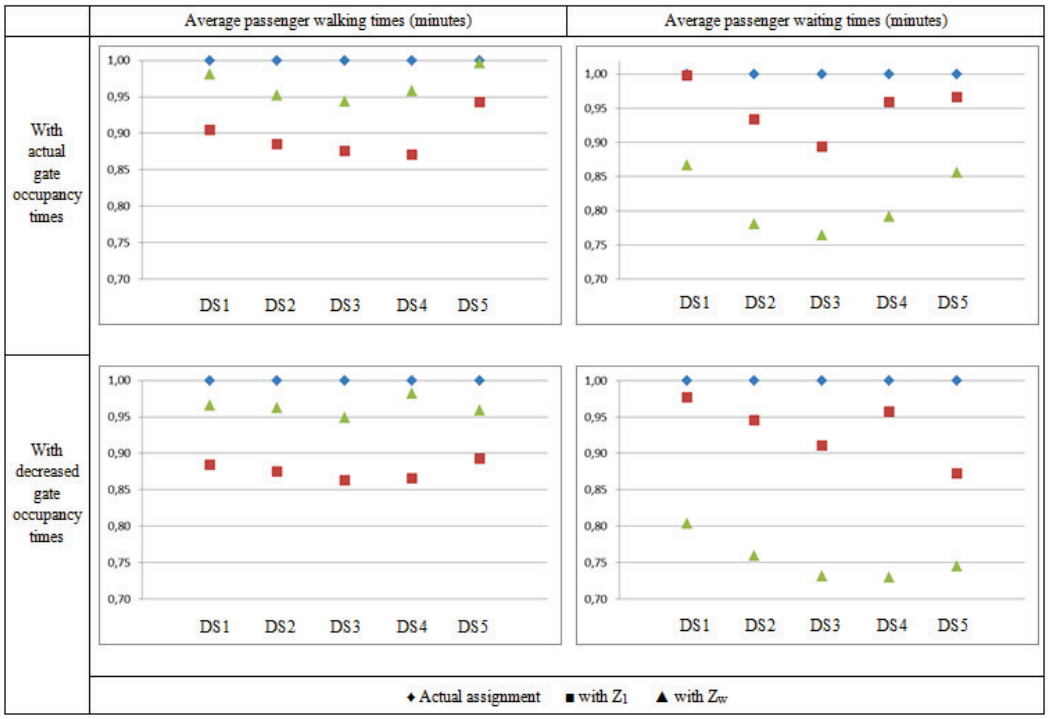


Figure 3 The ratio of change in passenger walking and waiting times when Z_w and Z_1 results are normalized to actual assignment results

The actual assignment has been done nearly random and it is known that some airline companies prefer their airplanes to be assigned to remote gates because of financial

reasons. But if the airport management establishes regulations to avoid parking at remote gates in case of available terminal gates, the passengers will get free from being transferred by terminal buses which is inconvenient from the point of passengers' service perception. As seen in Table 8, as the gate occupancy times of the airplanes are decreased, all of the airplanes are able to be serviced at the terminal gates. As mentioned before, the reduction in gate occupancy time is calculated by comparing the occupancy times of airplanes operated by MU and OC (Table 6).

The average walking time of passengers determined in the real time (actual) assignment is longer than the output of the models (Table 8 and Figure 3). The shortest walking time is reached with Z_w in which the objective is minimizing the walking time of passengers.

In Table 9, the rate of difference between the classes of LOS standards is given. The change between the waiting times determined by the models are compared to the rate of difference of LOS classes to see if the increase (or decrease) in walking times cause a change in LOS of the corridors (Table 9 and 10).

Table 9 Level of Service classes for corridors and waiting areas

	Corridors		Waiting Areas	
Level of Service	passenger/ meter/ minutes	Rate of change (%)	passenger/ m^2	Rate of change (%)
A	10		2	
		25,0		-10,0
B	12,5		1,8	
		60,0		-11,1
C	20		1,6	
		40,0		-12,5
D	28		1,4	
		32,1		-14,3
E	37		1,2	
F	More	-	Less	-

As seen from Tables 9 and 10, the change in the walking times determined by the objective function of passenger walking minimization (best results for walking times) and waiting minimization (worse results for walking times) is not effective enough to drop the level of service. The maximum change in walking times has occurred in Data Set 5 as an increase of % 11,59 which is smaller than any rate of change in LOS for corridors shown in Table 9.

Table 10 The maximum and minimum walking times gained by walking and waiting minimization (from Table 8)

	Minimum walking times gained (minutes)	Maximum walking times gained (minutes)	% increase in walking times
DS1	20,46	22,69	10,90%
DS2	20,44	22,26	8,90%
DS3	20,47	22,37	9,28%
DS4	20,11	22,26	10,69%
DS5	20,80	23,21	11,59%

However, in waiting areas, for example, to change LOS B to LOS A, 0,2 m^2 more place for each passenger is required which is equivalent to % 11,11 (calculated by Equation 1) amount of decrease in waiting time (Table 10). The maximum rate of change occurs between LOS E and LOS D, as % 16,66 . As seen in the Table 11, the minimum rate of change in waiting times is % 18,11 in Data Set 3 which is an enough amount to carry the LOS to the upper classes.

Table 11 The maximum and minimum waiting times gained by studied models (from Table 8)

	Minimum waiting times gained (minutes)	Maximum waiting times gained (minutes)	% decrease in waiting times
DS1	9,31	7,50	-19,44%
DS2	9,09	7,40	-18,59%
DS3	9,00	7,37	-18,11%
DS4	9,21	7,01	-23,89%
DS5	9,89	7,63	-22,85%

Table 10 and 11 includes the comparison of results of minimum walking and waiting objectives. Above all, when a comparison is

made between the model results and actual assignment results, the decrease in waiting time reaches a rate of %27.

6. CONCLUSIONS

Stone (2012) concludes that at a Houston airport, complaints of the passengers about the long waits at baggage reclaim area are dropped to zero by moving the arrival gates away from the main terminal. It is also stated that occupied time (walking to baggage reclaim area) feels shorter than the unoccupied time (standing at the carousel). Research on queueing has shown that, on average, people overestimate the time they have waited by 36 percent. According to Stone, the M.I.T. operations researcher Richard Larson notes that "Often the psychology of queuing is more important than the statistics of the wait itself".

The method of directing passenger flow according to the LOS of facilities is applied in this study. The effect of the occupancy times of the airplanes on passengers' waiting time is analyzed and it can be seen that even decreasing the occupancy times of some airplanes (the main user's in this study) just by 30% had the result of being able to assign all airplanes to terminal gates. Besides, decreases of 18%- 24% in average baggage waiting times are achieved by the decreased gate occupancy times.

With the proposed model, it is aimed to ameliorate the level of service given at the airport terminals. Although the model seems contrary to the concept of airport design, the results have shown that less waiting time at the baggage reclaim area is achievable with some managerial changes.

As stated before, the LOS concept for waiting areas is not as developed as for the LOS for highways. Further studies about the standards of LOS would afford the opportunity to evaluate new management policies. Effects of the proposed model and occupancy time on the other components of the airport, like, airport congestion, airlines operation costs, should be the subject of a further study.

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