Original Research

A New Mathematical Model for Gate Assignment Problem Considering Transit Passengers and Safety Constraints: Benders Decomposition Approach

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Abstract
Inappropriate gate assignment has some consequences such as flight delays, inefficient usage of resources and customer's dissatisfaction. Airports are service sectors and provide services to their customers. Passengers and airlines are two main customers of an airport. Current research presents a novel mathematical model for gate assignment problem to minimize customers' dissatisfaction. In other words, passengers walking time as well as flight delays are minimized in as objective function. In this model, transit and non-transit passengers and also arrival and departure flights are considered. Moreover, operational safety constraints are inserted to avoid collision of large aircrafts. The proposed model is solved by Benders decomposition approach. The model is applied in San Francisco International Airport for a 24-hour horizon. The result shows that walking time of non-transit passengers, walking time of transit passengers, delay in departure flights and delay in arrivals include 74.55, 23.32, 0.96 and 1.17 percent of the objective function, respectively.

Keywords - Gate Assignment Problem (GAP); Benders Decomposition; Mixed Integer Programming (MIP)

1. Introduction

Rapid increase in air transportation demand over the last four decades has faced airports to serious capacity problems in all over the world [1]. To overcome this problem and efficient management of airport resources, airports managers have extensively used operations research tools [1]. Operations research techniques have been used by the managers of aviation industry to make optimum decisions since 1950s [2]. There are a variety of problems and models in the aviation field such as: flight scheduling, fleet routing, aircraft maintenance, crew assignment, revenue management, gate assignment and irregular operations that are shown in Figure 1 [3]. Gate assignment problem is allocating available gates such as terminal and apron gates to the scheduled flights. Gates in airports are the places not only the passengers pass through during embarking and disembarking to and from an aircraft, but also a parking position for an aircraft which is in service [4].

As gates are main resources of each airport, proper gate assignment reduces flight delays and customers' dissatisfaction [5]. Gate assignment problem as an optimization problem connects airports management to their operations departments [6]. Moreover, proper gate assignment has other benefits such as reduction in delays for arriving unassigned flight. It is called gate conflict [7]. Considering operational safety constraint plays an important role in gate assigning models [8]. There are three types of conflicts between two aircrafts in two adjacent gates in taxi ways as follows: 1) Conflicting between taxi-in and push-back aircrafts, 2) Conflicting between aircrafts during taxiins and 3) Conflicting between aircrafts during push-outs, in which conflicting between large aircrafts is more probable. To avoid conflicting large aircrafts in two adjacent gates, operational safety constraints are considered in this research.

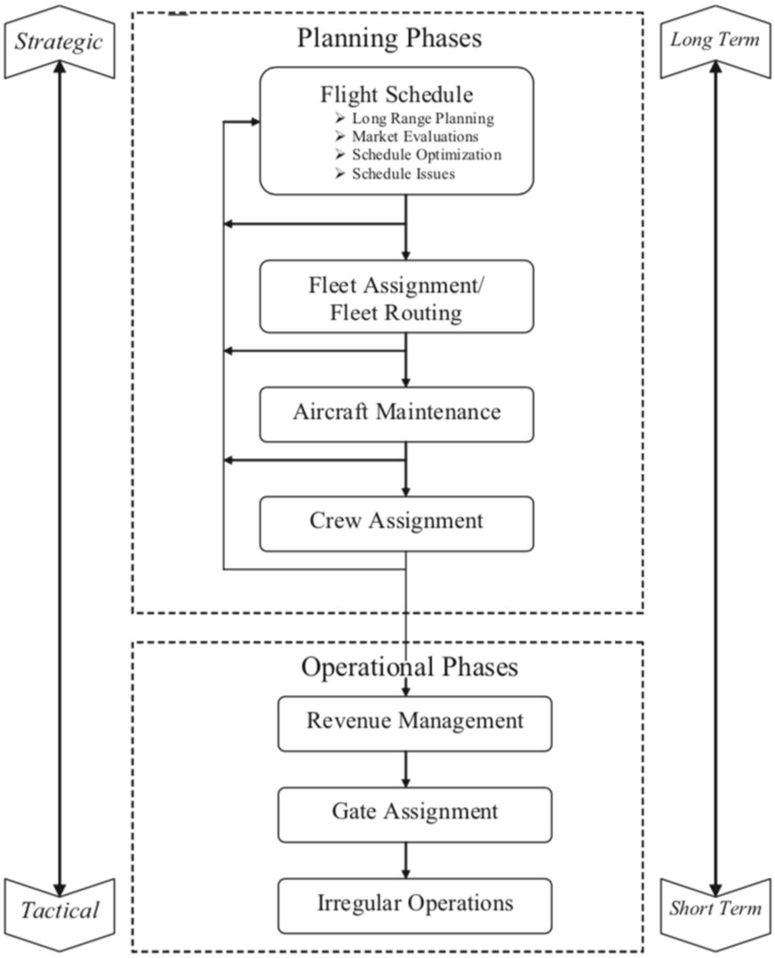

FIGURE 1.
THE HIERARCHY OF AVIATION PLANNING [3]

This research presents a novel mathematical model for gate assignment problem in order to minimize walking time of passengers as well as delay in departures and arrivals. In this model, both transit and non-transit passengers are considered. Transit passengers, who have limited time for boarding, have been rarely discussed in previous researches. Also, both arrivals and departures have been considered simultaneously. In order to prevent conflicting large aircrafts in adjacent gates, safety constraints are defined. Benders decomposition algorithm is the solution approach for this research and it is efficient one. The result of the model determines optimum assigning of gates to flights as well as arriving time of each aircraft to gates.

The remainder of the paper is organized as follows: In Section 2, literature of gate assignment problem is reviewed. In Section 3, problem statement is presented in details. Mathematical model is presented in Section 4. Benders decomposition algorithm is discussed in Section 5. Section 6 includes case study as well as computational results. Finally, concluding remarks are presented in Section 7.

2. LITERATURE REVIEW

The airport-based objectives in Gate Assignment Problem (GAP) focused on gate utilization improving and robustness of assignment for dealing with uncertainties. Unplanned interruptive actions either earliness or tardiness of arrival, or delay in departure, face the predetermined plan with trouble. Hence, instead of using parameters, which have inherent random input to represent the stochastic disruptions, some parameters for robustness achievement like: idle time, buffering time and gate conflict; are presented [9]-[11]. In other point of view for increasing passengers' satisfaction, researchers mainly focused on minimization of passengers walking distance between check-in counter and embarking gate, and also between arriving gate and baggage area, were considered in different previous researches [12]-[16].

Besides, using various methods for improvement the computational efficiency on problem solving in those studies have been considered.

From airport's point of view, following researches have been done. Behrends and Usher [17] proposed a framework in gate assignment problem which integrated the movement of passengers or freight in a terminal with the aircraft taxiing. Moreover, they presented a technique based on job shop scheduling problem which solved large scale problems in a short time. Yu et al. [18] formulated integrated gate reassignment and taxiway scheduling considering runway restriction and taxiway conflicts. They offered a new heuristic approach to solve the model. Deng et al. [19] presented an improved ant colony optimization algorithm to solve large scale gate assignment problems. Kim and Feron [20] analyzed gate delays and suggested a robust approach for gate assignment. Van Schaijk and Visser [21] presented a new method for improving the robustness of gate assignment problem solutions to unexpected disturbances in flight schedules. Zhang et al. [22] presented a multi-objective model for gate assignment problem to minimize the number of assigned apron gates to flights and flight conflict probability. Millar and Zhang [23] presented a binary model to maximize total preference value of flight-gate assignment. Phong and Van Hai [24] focused on the scheduling of aircraft landing and take-off on multiple runways at an airport in Vietnam. The objective function was minimization of total deviation from the preferred schedule of flights considering safety constraints. Ornek et al. [25] developed an integer programming model to assign check-in counters to arrivals and applied a decomposition algorithm to solve the problem. Behrends and Usher [26] presented a framework for assigning a departure gate to flight with the objective function of minimization delays due to freight or passengers movement to the departure flights and delays during taxiing from gate to runway. Genc et al. [16] tried to minimize total time of flights which are still un-gated and presented a heuristic approach in stochastic view instead of purely probabilistic. Li and Xu [27] used genetic algorithm to improve the available gates and terminals utilization. Seker and Noyan [28] developed a stochastic programming model and considered uncertainty in gate assignment problem during flight departing and arriving time. Maharjan and Matis [29] presented a multi-commodity based model for gate assignment on minimization of burning fuel cost of aircraft taxing as well as passenger discomfort for transit flights. Cheng et al. [12] applied different metaheuristics namely, Genetic Algorithm (GA), Tabu Search (TS) and Simulated Annealing (SA) to solve gate assignment problem. They compared the performance of the algorithms to a hybrid approach based on SA and TS using real world data. Kim and Feron [7] applied simulation and queuing theory to minimize gate conflict and assessed the influence of gate-holding departure control on the model. Liu et al. [8] presented a model to minimize the dispersion of gate idle time periods and considered operational safety constraints. They solved the model by genetic algorithm. Zhang et al. [22] presented a methodology for gate re-assigning by objective functions of: minimization the weighted sum of the total flight delays, minimization of the number of missed passenger, and minimization of the number of gate re-assignment operations.

From the passengers' point of view, following studies have been done previously. Aktel et al. [30] proposed a multi-objective model for gate assignment problem to minimize total passengers walking distances and the number of unassigned flights. For solving the model, a new Tabu Search (TS) algorithm was presented. Azmi et al. [31] studied the gate assignment problem with the objective of minimization total walking distance. Deng et al. [32] addressed gate assignment problem as multi-commodity network flow model and presented a robust multi-objective optimization model. Moreover, they proposed ILOG CPLEX optimizer to solve the model. Genc et al. [33] presented a multi-objective gate assignment problem (MOGAP). The objective functions were to maximize gate allocation, minimize total walking distance and maximize gate to flight preference. Khakzar Bafrue et al. [34] formulated a mixed-integer multi-objective model to minimize total cost of earliness, tardiness, delay and the compression. Because of the complexity of problem, two multi-objective meta-heuristic algorithms, i.e. Multi-Objective Harmony Search Algorithm (MOHSA) and Non-Dominated Sorting Genetic Algorithm II (NSGA-II) were used as solution approaches. Pternea and Haghani [35] proposed an integrated framework based on a binary model for reassigning gates to flights in disruptions. Pternea and Haghani [36] formulated a new mathematical model for gate to flight reassignment considering passenger connections by heuristic approach. They improved the performance of existing models by modifying their formulation and introducing valid inequalities. Dijk et al. [37] presented an innovative approach to the tactical planning of aircraft remote and contact-stands allocation at airports and also the recoverable robustness solutions was considered. The objective functions of the model were minimizing the passenger walking distance, minimizing tows, maximizing the number of passengers allocated to contact-stands, and maximizing the potential airport commercial revenue. Marinelli et al. [38] focused on finding a new methodology to solve gate assignment problem in order to minimize the number of remote terminals assignment to flights as well as passenger walking distance. Nik et al. [39] studied assigning and scheduling of runways and gates simultaneously. Moreover, this research considered the unavailability of runway's constraint and uncertain parameters relating to both areas of runway and gate assignment. Stollenwerk et al. [40] formulated airport gate assignment as a quadratic assignment problem to minimize total transit time of passengers. Sun et al. [41] suggested a Greedy-Based Pareto Local Search (GB-PLS) algorithm for bi-objective robust airport gate assignment problem which minimized total cost of gate assignment as well as total passenger walking distance. Drexl and Nikulin [42] presented a multi-objective model to minimize the number of un-gated flights, minimizing total passenger walking distances and maximizing total gate assignment preferences. Then Simulated Annealing was used to solve the model.

Wei and Liu [43] proposed a fuzzy model by objective function of minimization the total walking distance for passengers and maximization of robustness of assignment and then the model was solved by Genetic Algorithm. Jiang et al. [44] presented a model and its objective function was minimization of total walking distance of all passengers. Prem Kumar and Bierlaire [4] formulated a multi-objective model by objective functions of maximization of passengers connection revenues, maximization of gate plan robustness and minimization of zone usage costs.

Drexl and Nikulin [42] presented a multi-objective model to minimize the number of un-gated flights, minimizing total passenger walking distances and maximizing total gate assignment preferences. Then Simulated Annealing was used to solve the model. Wei and Liu [43] proposed a fuzzy model by objective function of minimization the total walking distance for passengers and maximization of robustness of assignment and then the model was solved by Genetic Algorithm. Hu and Di Paolo [45] applied an efficient Genetic Algorithm for solving a multi-objective gate assignment model.

3. Problem statement

Airports and airlines, as two main parts of air transportation network, try to manage their resources optimally. These resources are gates (for airports) and aircraft and crew (for airlines). In an airport, Gate Assignment Problem (GAP) is a critical issue that assigns gates to flights on an optimal manner based on flight scheduling. In GAP, flight scheduling is assumed given and deterministic. In this model, both passengers walking time and flights delay are minimized. Also, both arrival and departure flights are considered. In a departure flight, passengers are divided in to two groups: transit and non-transit passengers. Transit passengers arrive to the airport by different arrival flights and go directly to the gate assigned to their next (departure) flight. Clearly, transit passengers may walk from different arrival gates to a single departure one. The model tries to minimize their total walking time. For non-transit passengers of a departure flight, walking time from the check-in counter to the assigned gate is minimized. Naturally, walking time of transit passengers is much more important than non-transit one. Therefore, weight coefficients are used in the model to handle this issue. In addition to walking time, objective function of the model considers minimization of arrival and departure flights delay. Again, weight coefficients are used to distinguish importance of delay minimization in departures and arrivals.

For better clarification of the problem, it should be note that there should be a time interval between to consequent flights assigned to a single gate for crew change over. Also, a gate cannot be assigned to a flight earlier than a pre-defined time (for example 60 minutes before departure time or 30 minutes before arrival time for departures and arrivals respectively). Moreover, some aircrafts cannot be assigned to adjacent gates simultaneously due to prevent conflicting and crashing.

Some of the parameters used in the model are planned arrival / departure time of a flight, gate occupation time by each flight, the time interval between two consequent flights assigned to a single gate, the walking time matrix, number of passengers, weight coefficients of objective function terms. The proposed model is solved using Benders Decomposition technique with real world data. Below, mathematical model is presented in detail.

4. Mathematical model

At first, model assumptions are stated as follows:

1) Both arrival and departure flights are considered in the model.
2) Both transit and non-transit passengers are considered in the model.
3) Large aircrafts cannot be assigned to two adjacent gates simultaneously.
4) Flight scheduling is assumed given and deterministic.
5) There is no priority preference between different airlines' flights.
6) Some flights may be assigned to certain gates due to the number of passengers and type of aircraft.

4.1. Sets and indices

F	Set of all flights
AF	Set of arrival flights
DF	Set of departure flights
f , f'	Index of flight
G	Set of all gates
g , g'	Index of gate
G_f	Set of all gates which are compatible with flight f (with regard to the number of passengers and type of aircraft)

AG	Set of all adjacent gates
FL	Set of all flights handled by large aircrafts

4.2. Parameters and scalars

A_f	The earliest time that a gate can be assigned to arrival flight f (30 minutes before scheduled arrival time)
D_f	The earliest time that a gate can be assigned to departure flight f (60 minutes before scheduled departure time)
$Time_f$	Gate occupation time by flight f
BT	Time Interval between two consecutive flights assigned to a gate
WT_g	Walking time from check-in counter to gate g
$WT'_{gg'}$	Walking time from gate g to g' for a transit passenger
N_f	Number of non-transit passengers of departure flight f
$N'_{ff'}$	Number of passengers of arrival flight f who are transited to departure flight f '
α	Weight of walking time of non-transit passengers
β	Weight of walking time of transit passengers
γ	Weight of delay in departure flights
θ	Weight of delay in arrival flights
M	A big number

4.3. Decision variables

X_{fg}	Binary variable equals one if flight f is assigned to gate g, and zero otherwise.
$Z_{ff'g}$	Binary variable equals one if flight f is assigned to gate g before flight f ', and zero otherwise.
T_{fg}	Boarding time of flight f in gate g (the time of opening gate g to flight f).
$Y_{ff'gg'}$	Binary variable equals one if flight f is assigned to gate g earlier than assigning f ' to g', and zero otherwise.

4.4. Model formulation

$$Min\ \alpha \sum_{f\in DF}\sum_{g\in G_f} WT_g N_f X_{fg} + \beta \sum_{f\in AF}\sum_{g\in G_f}\sum_{f'\in DF}\sum_{g'\in G_{f'}} WT'_{gg'} N'_{ff'} Y_{ff'gg'} + \gamma \sum_{f\in DF}\sum_{g\in G_f}\left(T_{fg} - D_f X_{fg}\right) + \theta \sum_{f\in AF}\sum_{g\in G_f}\left(T_{fg} - A_f X_{fg}\right) \quad (1)$$

s.t.

$$\sum_{g\in G_f} X_{fg} = 1 \qquad \forall f \in F \qquad (2)$$

$$T_{fg} \ge A_f X_{fg} \qquad \forall f \in AF, \forall g \in G_f \qquad (3)$$

$$T_{fg} \ge D_f X_{fg} \qquad \forall f \in DF, \forall g \in G_f \qquad (4)$$

$$T_{fg} \ge T_{f'g} + Time_f + BT - MZ_{ff'g} - M\left(2 - X_{fg} - X_{f'g}\right) \quad \forall f, f' \in F, f \ne f', \forall g \in G_f \cap G_{f'} \qquad (5)$$

$$T_{f'g} \ge T_{fg} + Time_f + BT - M\left(1 - Z_{ff'g}\right) - M\left(2 - X_{fg} - X_{f'g}\right) \quad \forall f, f' \in F, f \ne f', \forall g \in G_f \cap G_{f'} \qquad (6)$$

$$T_{fg} \ge T_{f'g'} + Time_{f'} - M(2 - X_{fg} - X_{f'g'}) - MY_{ff'gg'} \quad \forall f, f' \in FL\ , f \ne f', \forall g \in G_f, g' \in G_{f'}\ \&\ g, g' \in AG \qquad (7)$$

$$T_{f'g'} \ge T_{fg} + Time_f - M(2 - X_{fg} - X_{f'g'}) - M(1 - Y_{ff'gg'}) \quad \forall f, f' \in FL\ , f \ne f'\ , g \in G_f, g' \in G_{f'}\ \&\ g, g' \in AG \qquad (8)$$

$$2Z_{ff'g} \le X_{fg} + X_{f'g} \qquad \forall f, f' \in F, f \ne f', \forall g \in G_f \cap G_{f'} \qquad (9)$$

$$X_{fg} + X_{f'g} \le Z_{ff'g} + Z_{f'fg} + 1 \qquad \forall f, f' \in F, f < f', \forall g \in G_f \cap G_{f'} \qquad (10)$$

$$2Y_{ff'gg'} \le X_{fg} + X_{f'g'} \quad \forall f, f' \in F, f \ne f', \forall g \in G_f, g' \in G_{f'}\ \&\ g \ne g' \qquad (11)$$

$$X_{fg} + X_{f'g'} \le Y_{ff'gg'} + Y_{f'fg'g} + 1 \quad \forall f, f' \in F, f \ne f', \forall g \in G_f, g' \in G_{f'}\ \&\ g \ne g' \qquad (12)$$

$$X_{fg}, Z_{ff'g}, Y_{ff'gg'} : Binary\ \&\ T_{fg} \ge 0 \qquad (13)$$

The objective function is time minimization and includes four terms. The first term is walking time of non-transit passengers from check-in counter to departure gate. The second term is walking time of transit passengers from gate *g* to *g'*. The third and fourth terms are delay in departure and arrival flights. As these four terms have different priorities, objective function is weighted sum of these terms. Equation (2) ensures that all flights are assigned to a gate. Relations (3) and (4) show that the actual time of opening a gate to a flight cannot be earlier than the scheduled time. Constraints (5) and (6) prevent conflict in assigning two flights to a single gate. Constraints (7) and (8) indicate operational safety constraints to prevent conflict between large aircrafts in adjacent gates. Relations (9) to (12) state relations between decision variables. Constraint (13) indicates type of decision variables.

5. Benders Decomposition Algorithm

Benders decomposition algorithm is an efficient method in solving large scale problems including complicating variables; i.e. integer or binary ones. The approach is dividing original problem into master and sub-problems. Master problem includes constraints that merely have complicating variables while Sub-problem includes constraints with at least one non-complicating variable. The logic is iteratively solving master problem, fixing complicating variables in dual sub-problem and calculating lower and upper bounds. The process is terminated if the difference of upper and lower bounds is ignorable.

As all variables in constraints (9) to (12) are binary (complicating variables), master problem is formulated as follows:

$$\text{Min } Z_{lower} \tag{14}$$

s.t. (9) to (12)

$$X_{fg}, Z_{ff'g}, Y_{ff'gg'}: \text{Binary} \tag{15}$$

To formulate sub-problem, complicating variables are assumed as fixed values. For simplicity, X_{fg}, $Z_{ff'g}$ and $Y_{ff'gg'}$ are fixed and shown by $\bar{X}_{fg}$, $\bar{Z}_{ff'g}$ and $\bar{Y}_{ff'gg'}$, respectively.

$$Min\ \gamma \sum_{f\in DF}\sum_{g\in G_f} T_{fg} + \theta \sum_{f\in AF}\sum_{g\in G_f} T_{fg} \tag{16}$$

$$T_{fg} \geq A_f \bar{X}_{fg} \qquad \forall f \in AF, \forall g \in G_f \tag{17}$$

$$T_{fg} \geq D_f \bar{X}_{fg} \qquad \forall f \in DF, \forall g \in G_f \tag{18}$$

$$T_{fg} - T_{f'g} \geq Time_f + BT - M\bar{Z}_{ff'g} - M\left(2 - \bar{X}_{fg} - \bar{X}_{f'g}\right) \ \forall f, f' \in F, f \neq f', \quad \forall g \in G_f \cap G_{f'} \tag{19}$$

$$T_{f'g} - T_{fg} \geq Time_{f'} + BT - M\left(1 - \bar{Z}_{ff'g}\right) - M\left(2 - \bar{X}_{fg} - \bar{X}_{f'g}\right) \quad \forall f, f' \in F, f \neq f', \forall g \in G_f \cap G_{f'} \tag{20}$$

$$T_{fg} - T_{f'g'} \geq Time_{f'} - M(2 - \bar{X}_{fg} - \bar{X}_{f'g'}) - M\bar{Y}_{ff'gg'} \quad \forall f, f' \in FL\ , f \neq f'\ , g \in G_f, g' \in G_{f'}\ \&\ g, g' \in AG \tag{21}$$

$$T_{f'g'} - T_{fg} \geq Time_f - M(2 - \bar{X}_{fg} - \bar{X}_{f'g'}) - M(1 - \bar{Y}_{ff'gg'}) \quad \forall f, f' \in FL\ , f \neq f'\ , g \in G_f, g' \in G_{f'}\ \&\ g, g' \in AG \tag{22}$$

$$T_{fg} \geq 0 \tag{23}$$

In order to formulate dual sub-problem, new dual variables should be defined. To do this, U_{fg}, V_{fg}, $W_{ff'g}$, $P_{ff'g}$, $Q_{ff'gg'}$ and $R_{ff'gg'}$ are associate to constraints (17) to (22), respectively. Finally, dual sub-problem is formulated as follows:

$$\begin{aligned} Max\ & \sum_{f\in AF}\sum_{g\in G_f} A_f \bar{X}_{fg} U_{fg} + \sum_{f\in DF}\sum_{g\in G_f} D_f \bar{X}_{fg} V_{fg} \\ & + \sum_{f\in F}\sum_{\substack{f'\in F:\\ f\neq f'}}\sum_{g\in G_f\cap G_{f'}} (Time_f + BT - M\bar{Z}_{ff'g} - M(2 - \bar{X}_{fg} - \bar{X}_{f'g}))\, W_{ff'g} \\ & + \sum_{f\in F}\sum_{\substack{f'\in F:\\ f\neq f'}}\sum_{g\in G_f\cap G_{f'}} (Time_{f'} + BT - M(1 - \bar{Z}_{ff'g}) - M(2 - \bar{X}_{fg} - \bar{X}_{f'g}))\, P_{ff'g} \\ & + \sum_{f\in FL}\sum_{\substack{f'\in FL:\\ f\neq f'}}\sum_{g\in G_f}\sum_{\substack{g'\in G_{f'}:\\ g,g'\in AG}} (Time_{f'} - M(2 - \bar{X}_{fg} - \bar{X}_{f'g'}) - M\bar{Y}_{ff'gg'})\, Q_{ff'gg'} \\ & + \sum_{f\in FL}\sum_{\substack{f'\in FL:\\ f\neq f'}}\sum_{g\in G_f}\sum_{\substack{g'\in G_{f'}:\\ g,g'\in AG}} (Time_f - M(2 - \bar{X}_{fg} - \bar{X}_{f'g'}) - M(1 - \bar{Y}_{ff'gg'}))\, R_{ff'gg'} \end{aligned} \tag{24}$$

s.t.

$$\begin{aligned} & U_{fg} + V_{fg} + \sum_{\substack{f'\in F_g:\\ f'\neq f}} W_{ff'g} - \sum_{\substack{f'\in F_g:\\ f'\neq f}} W_{f'fg} + \sum_{\substack{f'\in F_g:\\ f'\neq f}} P_{f'fg} - \sum_{\substack{f'\in F_g:\\ f'\neq f}} P_{ff'g} + \sum_{\substack{f'\in FL:\\ f'\neq f}}\sum_{\substack{g'\in G_{f'}:\\ g,g'\in AG}} Q_{ff'gg'} \\ & - \sum_{\substack{f'\in FL:\\ f'\neq f}}\sum_{\substack{g'\in G_{f'}:\\ g,g'\in AG}} Q_{f'fg'g} + \sum_{\substack{f'\in FL:\\ f'\neq f}}\sum_{\substack{g'\in G_{f'}:\\ g,g'\in AG}} R_{f'fg'g} - \sum_{\substack{f'\in FL:\\ f'\neq f}}\sum_{\substack{g'\in G_{f'}:\\ g,g'\in AG}} R_{ff'gg'} \leq \gamma + \theta \quad \forall f \in F, g \in G_f \end{aligned} \tag{25}$$

6. Case study: San Francisco International Airport

San Francisco International Airport (SFO) is located 13 miles (21 km) south of downtown San Francisco, California, United States. It has many flights specifically throughout North America and is a major gateway to Europe and Asia as well. Figure 2 shows SFO's map which illustrates the overall dimension of airport and its gates for each terminal. The proposed model of this study is tested by real data of SFO for the first day of January 2015. In SFO, there are two terminals for domestic and international flights. As this research also considered transit passengers, only international terminal is focused. International terminal includes gates G (G1 to G14) and A (A1 to A15), which are shown in Figure 3. The problem includes 97 and 96 arrival and departure flights, respectively. There are 29 gates available to assign flights in the international terminal. 'G' Gates are used for arrivals while 'A' gates are dedicated to departures. There are 12,162 non-transit and 2,499 transit passengers.

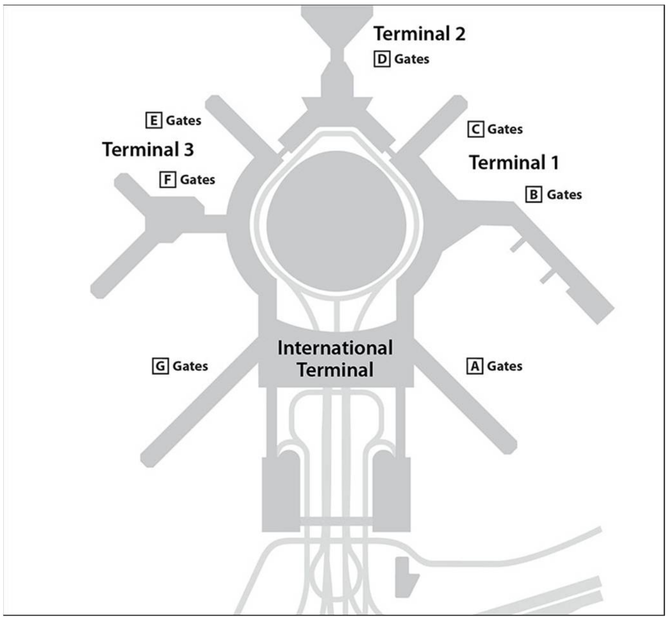

FIGURE 2.
SAN FRANCISCO INTERNATIONAL AIRPORT MAP

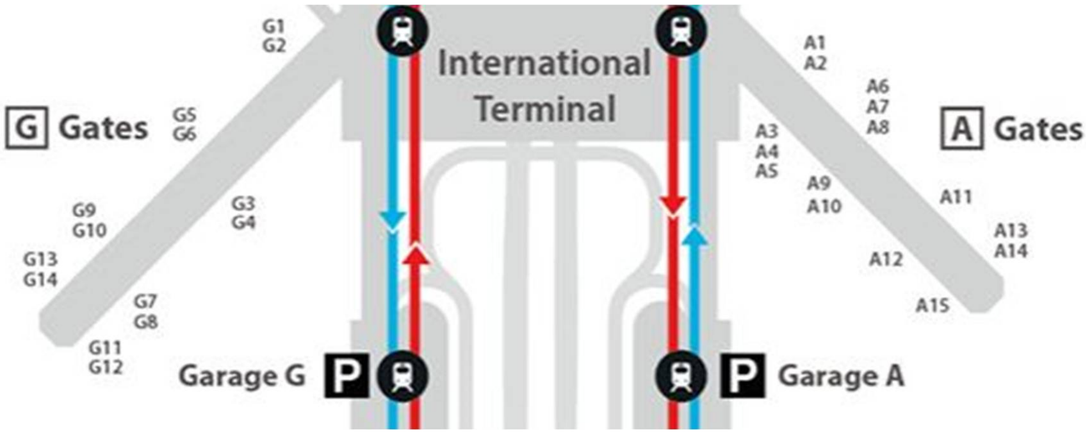

FIGURE 3.
GATES LOCATION IN INTERNATIONAL TERMINAL

The problem was solved using GAMS 25.2 operating on a system with 64 GB RAM. Figures 4 and 5 show the assignment of gates to arrival and departure flights in different time slots. Each time slot includes four hours. The objective function that includes walking time as well as delay is 287016 minutes. Table 1 shows that walking time of non-transit passengers from check-in counters to departure gates, walking time of transit passengers, delay in departure flights and delay in arrivals include 74.55, 23.32, 0.96 and 1.17 percent of the objective function, respectively. As shown in Table 1, delay times constitute only 2.13 percent of objective function.

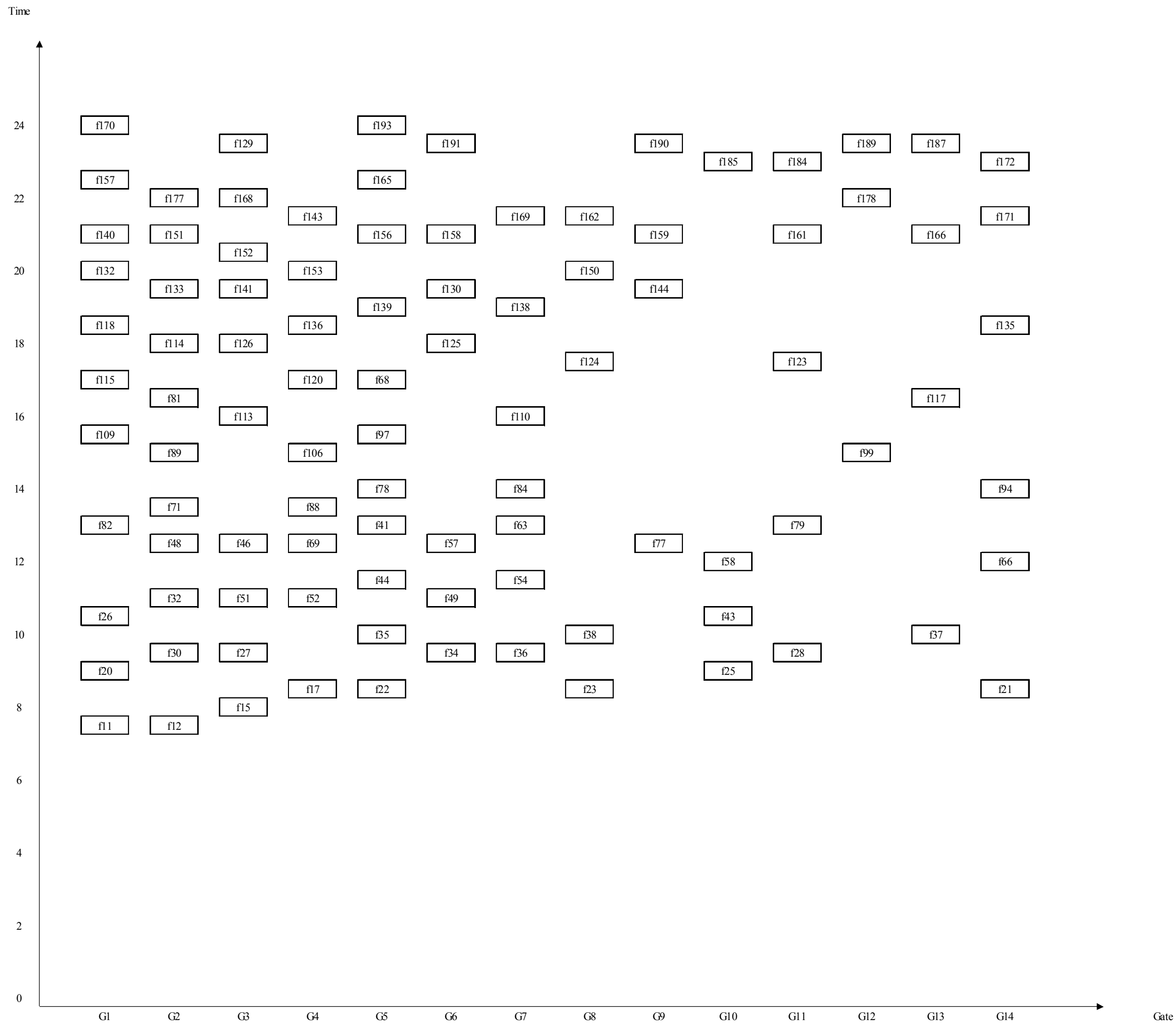

FIGURE 4.
ASSIGNMENT OF GATES TO ARRIVAL FLIGHTS.

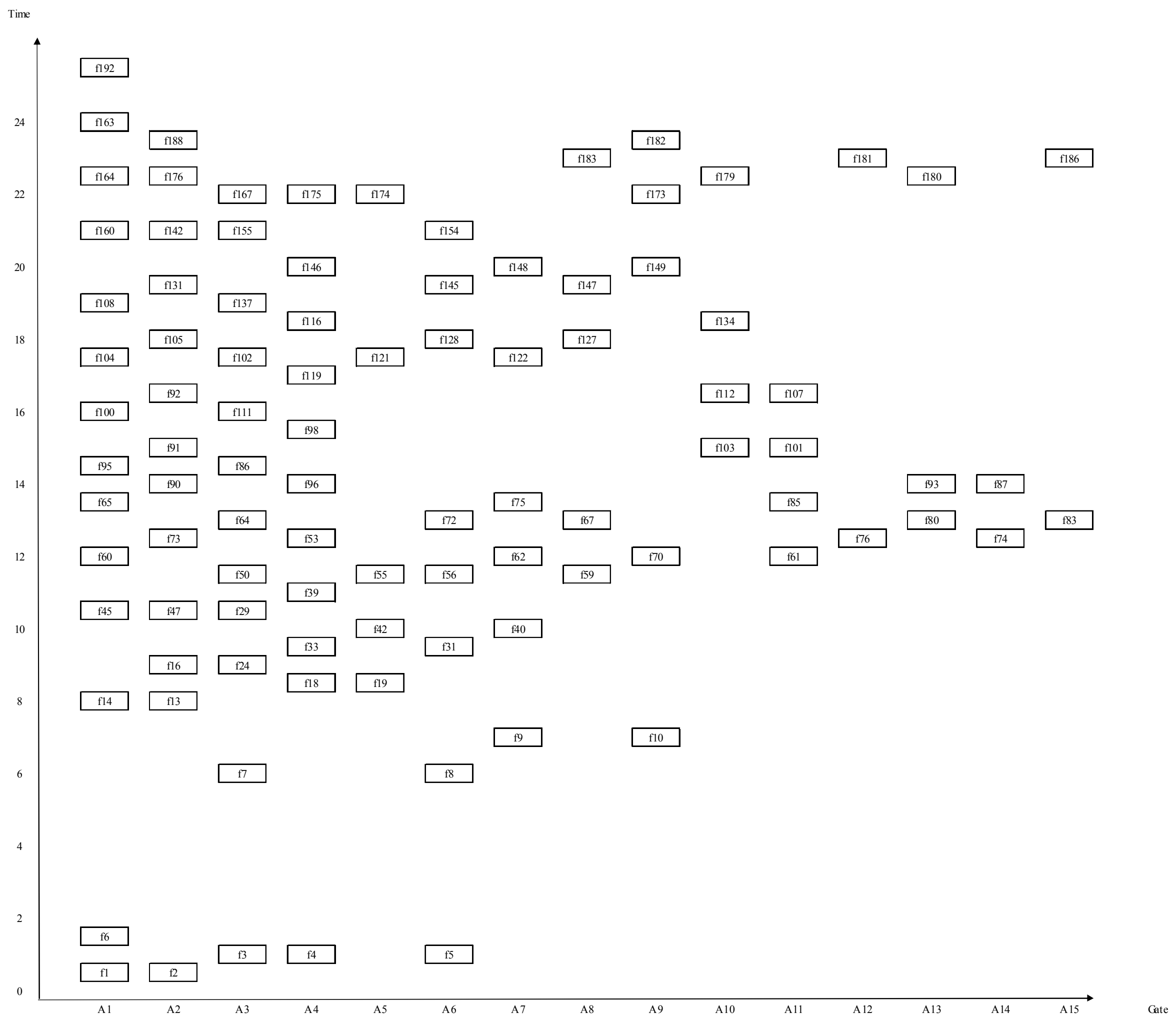

FIGURE 5.
ASSIGNMENT OF GATES TO DEPARTURE FLIGHTS.

TABLE I.
OBJECTIVE FUNCTION VALUE IN DETAILS

	Time (minutes)	Percent
Walking time of non-transit passengers	213978	74.55
Walking time of transit passengers	66919	23.32
Delay in departure flights	2767	0.96
Delay in arrival flights	3352	1.17
Objective function value	287016	100

7. CONCLUSION

In this paper, a new mathematical model for gate assignment problem has been developed. The model aims to minimize walking time of passengers as well as delay in departure and arrival flights. Both transit and non-transit passengers as well as safety constraints have been considered in the model. The model was applied in SFO with 29 gates (including 14 arrival and 15 departure ones), 193 flights (including 97 arrival and 96 departure ones) and 14661 passengers (including 12,162 non-transit and 2,499 transit ones). Due to the scale of the problem, Benders decomposition algorithm was applied as the solution approach. The results show that walking time of non-transit passengers, walking time of transit passengers, delay in departure flights and delay in arrivals include 74.55, 23.32, 0.96 and 1.17 percent of the objective function, respectively.

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