Gate Assignment Solution (GAM) Using Hybrid Heuristics Algorithm

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Abstract— Efficient airport operations depend in part on gating aircraft for a smooth flow of arriving and departing flights. Reducing fuel burn, facilitating less wait time and optimizing passenger walking distance vis-à-vis optimizing passenger satisfaction are the key components of an effective gate system that drives airlines in the current economic downturn scenario.

As the gate assignment is a type of job-shop scheduling problem, its complexity increases exponentially if constraint size such as number of flights, available gates, aircrafts, flight block time etc. changes which is very realistic assumption in airport operation. So, this is a NP-hard problem which implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In practice, a major airline's airport hub may handle more than 1000 daily flights at more than 50 gates which results in billions of variables. Given the huge size, the model can't be handled by any available optimization solver within a reasonable time bound. We have solved this complex problem using a hybrid heuristics algorithm guided by Simulated Annealing Heuristic accompanying with Greedy Heuristic and Tabu Search Heuristic and is implemented with industry best available algorithms and software.

We have also developed an innovative IT solution. It complements the experience and judgment of gate planners to help create more robust, optimal and efficient gate schedules. With our IT solution, gate planners are able to define, analyze and improve different modeling parameters to provide an optimized gate-flight assignment with high flexibility and adaptability to environmental changes. They can also act proactively with best reporting available in the solution on timely manner.

***Index Terms*—**GAM – Gate Assignment Solution, Simulated Annealing Heuristics, Tabu Search Heuristics, Greedy Heuristics, Operations Research, IT Solution, Hybrid Heuristics

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I. Introduction

Purpose of an airport is to provide safe, comfortable and enjoyable experience to passengers traveling by airplane. An airport manages wide range of activities like air traffic control, assigning right flights to right gates, passenger check-in and check out, baggage handling, security checks, shopping alleys, and entertainment. Growing air travel and increasing service level expectations are posing a major challenge for airports all over the world.

The problem of assigning gates to flights of various types (arrival, departure, connection and intermediate parking flights) is an important decision problem in daily operations at major airports all over the world. Strong competitions between airlines and increasing demand of passengers for more comfort have made the measures of quality of these decisions at an airport as important performance indices of airport management. The massive scale of operations even increases the complexity of the problem given that some of busy airports handle more than 1000 flights daily.

The dynamic operational environment in modern busy airports, increasing number of flights and volumes of traffic, uncertainty (random deviations in data elements like arrival, departure times from flight time table and schedules), its multi-objective nature, and its combinatorial complexity make the flight-gate allocation a very complicated decision problem both from a theoretical and a practical point of view. That is why mathematical modeling of this problem and the application of Operations Research (OR) methods to solve these models have been crucial.

Responsibility for gate allocations to flights rests with different agencies at different airports. At some airports gate allocation decisions are made by the airport management themselves for all their customer airlines. At others, some airlines lease gates from the airport on long term contracts. Then those airlines make gate allocation decision for their flight themselves.

In this paper, we discuss the process of developing a decision support solution, and appropriate mathematical models and algorithms to use for making gate allocation decision optimally, robust and flexible way.

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This paper is organized as follows. In section III, we provide a generic model for Gate Assignment Problem. In section IV, we discuss different techniques to solve the model. In section V, we discuss our hybrid approach to solve the model. In section VI, we discuss about the phases of our solution development. In section VII, we have shown the performance of our solution. In section VIII, we discuss about the different solution features. In section IX, we summarized our solution findings and suggest future work.

II. Previous work

Various decision support systems have been developed for the design and operations of airports. The gate assignment problem is the type of job shop scheduling problem in which generally a job (i.e. a flight) is served once by an available machine (i.e. an idle gate), with various constraints and objectives in matching the jobs to machines. The details of the problem change with its constraints (including size of flights, ready times of flights, closeness of gates to land side facilities, etc.), objectives (including walking distance of passengers, to carousels, during transit, or both, waiting time of flights in taxiways for gates, etc.), division of time horizon (the whole time horizon as a single time slot, or divided into multiple time slots), solution methods (i.e. optimization, rule-based techniques, meta-heuristics, simulation etc.) and purpose (i.e., planning or real-time dispatching).

For a single slot problem that matches flights to gates without any additional constraint, the problem is a standard assignment problem if the components of the objective function depend on allocating a gate to flight. The single-slot problem becomes a quadratic assignment problem if the components of the objective function depend on allocating a pair of gates to a pair of flights, e.g., to minimize the walking distance of transfer passengers needs to simultaneously consider the gate allocation of two or more flights.

As a handy objective, most papers include the walking distance of passengers as a component of the objective function; see, e.g., the pure distance-based objective in Haghani and Chen (1998); the passenger distance and passenger waiting time in Yan and Hue (2001) and Yan et al. (2002); the number of assigned gates and passenger walking distance in Ding et al. (2004a) and Ding et al. (2004b). Bolat (1999, 2000a, 2000b) do not consider walking distance in their objective functions. To handle the uncontrollable nature of flight arrivals and to find the best trade-off between utilization of gates and waiting of planes for them, Bolat (1999, 2000a, 2000b) propose to minimize some functional of slack times between successive usage of gates – the maximum slack time in Bolat (1999) and the sum of variances of slack times in Bolat (2000a, 2000b)

All the above papers formulate computationally hard models, either as variants of quadratic assignment problems or non-network type linear integer problem. The problems are solved with combination of optimization and approximation procedures (e.g. Yan and Huo (2001), heuristics (e.g. Bolat (1999, 2000a), Haghani and Chen (1998), meta-heuristics (e.g. genetic algorithm in Bolat (2000b), Simulated Annealing and Tabu Search in Ding et al. (2004a), simulation (e.g. Yan at al. (2002)).

The mathematical model that we will use for making the gate assignment decisions in our IT solution is described in the following sections. As discussed earlier, some of the important aspects in which our model differs from those in previous literature are the following.

1. We do not rely on large scale integer programming models for this problem that require long solution times and complex software, which makes them impractical for routine daily use. The model that we use is a simple transportation model that takes less time to solve, and is in fact more appropriate for the real problem.
2. In our gate assignment decisions, we have attempted to optimize three objective functions together keeping minimizing walking distance as primary objective and maximizing number of gated flights and minimizing flight delays as secondary objective. While the primary objective is increasing the customer satisfaction, the secondary objectives are to reduce flight delay and waiting times by reducing the total number of visits to apron because of unavailability of gates.
3. In our gate assignment decisions, we take into account the "first arrived, first assigned" policy that all airport claim to practice. That is why our approach is close to on-line decision making. This also simplifies the model significantly. The previous literature seems to ignore this policy.
4. Our approach takes into account the uncertainty in flight arrival/departure times, and avoids the need to forecast data elements characterized by high uncertainty. Models in the previous literature assume that data elements are given; presumably they depend on forecasts which tend to be unreliable.

III. Problem description

The primary purpose of flight-to-gate assignments in airports is to assign aircrafts to gates to meet operational requirements while minimizing inconveniences to passengers. Planners seek to minimize distances passengers have to walk to departure gates, baggage belts and connecting flights since this is a key quality performance measure of any airport. For connecting flights, minimizing distances is key to smooth operations due to short connection times common in many international airports. While certain walking distances are fixed when schedules can be conformed to, others can change from time to time. For example, the distances traversed by transfer or connecting passengers from gate to gate can change due to changing gate assignments resulting from randomness in operations. Airlines, ground-handling agents and airport authorities, therefore need to assign gates to flights dynamically to minimize walking distances and consequently, connection times. A flight-to-gate assignment policy satisfying operational requirements can be derived at the start of each

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planning day based on published flight schedules and booked passenger loads.
In the GAM, our objective is to find a feasible flight-to-gate assignments which finds out the maximum number of flights which can be accommodated for a given set of gates and predefined flight schedule and minimizes total passenger walking distance. Typically, distances include the distance a passenger walks to departure gates, to baggage belts, between connecting flights and also distance from the apron or tarmac to the terminal.

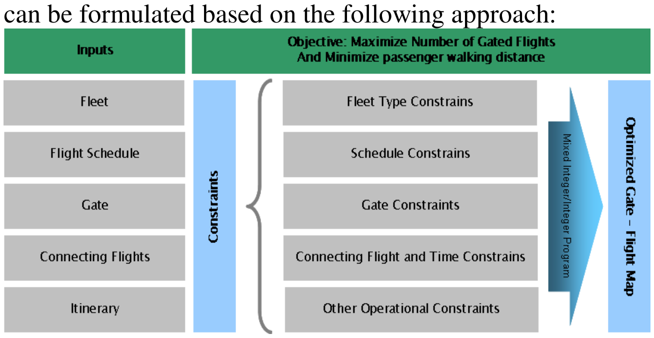
Currently most of airlines use manual assignment of gates to the flights. It is quite effort intensive and often inaccurate because of the complex nature of the problem. Though this provides a workable gate assignment of flights, there are several areas of improvement specifically in terms meeting the operational limitation of the airport as well as of the airlines, minimizing inconvenience to passengers and maximizing the airlines profit (by minimizing total routing costs to transfer passengers' luggage), etc.

IV. MODEL

The above stated problem can be formulated as an optimization problem considering the following facts:

- Number of flights for each fleet type arriving and taking off from a particular station
- Number of gates available/leased to airline and the fleet types it can accommodate
- Arrival time of the flights
- Departure time of the flights
- Preceding or next flight of a connecting flight
- Connection time for the passengers
- Number of passengers taking the connecting flights
- Boarding time
- Required buffer time (between arrival and departure) at gate for rest-time, loading and unloading time, refueling time etc.

Based on the objective and the above mentioned considerations, a Mixed Integer Programming (MIP) problem can be formulated based on the following approach:



The formulated model is a NP-hard problem which implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In practice, a major airline's airport hub may handle of 1000 daily flights at more than 50 gates which, in the formulation, results in billions of binary variables. Given the huge size of data, this model can't be handled by any MIP solver within a reasonable time bound. Thus we have designed an efficient meta-heuristic algorithm (the mix of greedy heuristic, simulated annealing (SA) and Tabu Search (TS) algorithms to solve the above problem).

V. FORMULATION

A. Definition of Sets

N: Set of flights arriving at (and/or departing from) the airport
K: Set of gates available at the airport
K_i: Set of gates can't be assigned for flight i because of fleet size requirement
K_k: Set of adjacent gates for gate k
N_i: Set of adjacent flights for flight i
n: Total number of flights |N|
m: Total number of gates |K|
0, m+1: The dummy gates. Here 0 represents entrance or exit gate of the airport and gate m+1 is the apron or tarmac where the flights arrive when no gates are available (assumed to be a single point).

B. Definition of Parameters

a_i: Arrival time of flight i
d_i: Departure time of flight i
$c_{k,l}$: Connection time for passengers from arrival gate k to departure gate l
$f_{i,j}$: Number of passengers transferring from arrival flight i to departure flight j
θ_i : Average boarding time per passenger for flight i
α : Buffer time between the aircraft's arrival time and the start time for passenger boarding
β : Buffer time between the aircraft's departure time & the next aircraft's arrival time at same gate
M : A sufficiently large number

C. Definition of decision variable

y_{ik} = 1, When the flight i is assigned to gate k (0<k<=m+1)
= 0, otherwise
z_{ijk} = 1, If and only if both flights i and j are assigned to gate k (0 < k <=m+1) and flight i immediately precedes flight j
= 0, otherwise
t_i = Time the gate starts to open for boarding for flight i

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D. Generic Model

$$\text{Minimize} \sum_{i\in N} y_{i(m+1)} \quad (1)$$

$$Minimize \sum_{i,j\in N}\sum_{k,l\in K} f_{ij} c_{kl} y_{ik} y_{jl} \quad (2)$$

ST

$$\sum_{k\in K} y_{ik} = 1, \forall i \in N \quad (3)$$

$$y_{ik} = 0, \forall i \in N, \forall k \in K_i \quad (4)$$

$$y_{ik} > y_{jl}, \forall i \in N, \forall k \in K, \forall j \in N_i, \forall l \in K_k \quad (5)$$

$$(y_{ik} + y_{jl}) \le 1, \forall i \in N, \forall k \in K, \forall j \in N_i, \forall l \in K_k \quad (6)$$

$$y_{ik} = \sum_{j\in N} z_{ijk}, \forall i \in N, \forall k \in K \quad (7)$$

$$y_{ik} = \sum_{i\in N} z_{ijk}, \forall j \in N, \forall k \in K \quad (8)$$

$$t_i \ge a_i + \alpha, \forall i \in N \quad (9)$$

$$t_i \le d_i - \theta_i * \sum_{j\in N} f_{ji}, \forall i \in N \quad (10)$$

$$(t_i + \theta_i * \sum_{j\in N} f_{ji}) \le (t_j + (1 - z_{ijk}) * M), \forall i, j \in N \quad (11)$$

$$(a_j + (1 - z_{ijk}) * M) \ge (d_i + \beta), \forall i, j \in N, \forall k \in K \quad (12)$$

$$y_{ik}, z_{ijk} \in \{0,1\}, \forall i, j \in N, \forall k, l \in K \quad (13)$$

$$t_i \ge 0, \forall i \in N \quad (14)$$

The objective function (1) seeks to minimize the number of flights that must be assigned to the apron, i.e. those left un-gated.
The objective function (2) seeks to minimize the total connection times by passengers.

Constraint (3) specifies that every flight must be assigned to one gate.

Constraint (4) specifies the equipment restriction on certain gates.
Constraint (5) and (6) restricts the assignment of specific adjacent flights to adjacent gates.

Constraint (7) and (8) indicate that every flight can have at most one flight immediately following and at most one flight immediately proceeding, at the same gate.

Constraint (9) and (10) stipulate that a gate must open for boarding on a flight during the time between its arrival and departure, and it also must allow sufficient time for handling the passenger/luggage boarding, which is assumed to be proportional to the number of passengers going on board.
Constraint (11) ensures that each gate only serves one flight at any particular time i.e. if flight i is assigned immediately before flight j at the same gate k, the gate must open for flight i earlier than flight j.

Constraint (12) further states the aircraft can only arrive at the gate when the previous flight has departed, while also including the buffer time between the flights.

Constraint (13) & (14) specifies the binary and non-negative requirements for the decision variables.

The above-mentioned model is a 0-1 Multiple Objective Integer Quadratic programming model with a quadratic objective function. We use a common approach to reformulate the model into a mixed 0-1 integer problem with a linear objective functions and constraints.
Let

x_{ijkl} = 1 if and only if fight i is assigned to gate k (0<k<=m+1) and fight j is assigned to gate l (0<l<=m+1)
= 0, otherwise

Then the above formulation can be reformulated as follows.

Minimize

(1).*will.remain.same*

$$Z = \sum_{i,j\in N}\sum_{k,l\in K} f_{ij} c_{kl} x_{ijkl} \quad (15)$$

ST

Constraint..(3) – (14) from..generic model

$$x_{ijkl} \le y_{ik}, \forall i, j \in N, \forall k, l \in K \quad (16)$$

$$x_{ijkl} \le y_{jl}, \forall i, j \in N, \forall k, l \in K \quad (17)$$

$$(y_{ik} + y_{jl} - 1) \le x_{ijkl} \le \forall i, j \in N, \forall k, l \in K \quad (18)$$

$$x_{ijkl} \in \{0,1\}, \forall i, j \in N, \forall k, l \in K \quad (19)$$

Constraint (16), (17) and (18) specify that x_{ijkl} can be equal to one if and only if the flight i is assigned to gate k and flight j is assigned to gate l.
Constraint (19) specifies binary requirement for the decision variable x_{ijkl}.

Both the models (Generic and Reformulated Model) are NP-Hard, which implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In practice, a major airline hub terminal may handle more than 1000 daily flights at more than 50 gates, which in our formulation would result in billions of binary variables. Due to such a huge size, this model can not be handled by branch-and-bound based MIP solvers within a reasonable time bound.

Thus we have designed an efficient meta-heuristic algorithm (the mix of greedy heuristic, simulated annealing (SA) and Tabu Search (TS) algorithms) to solve the above problem.

VI. SOLUTION ALGORITHM

We have implemented a hybrid algorithm guided by Simulated Algorithm Heuristic with using Greedy Heuristic and Tabu Search heuristic is described below:

A. Greedy Heuristic Algorithm

To find out an initial feasible solution, we will use a Greedy Algorithm as given below. The objective is to minimize the number of flights that needs to be assigned to the apron.
After sorting all the flights by departure time, flights are assigned to the gates one by one. An incoming flight is assigned to an available gate with latest departure time, and if

no gates are available; the flight is assigned to the apron. The basic steps are:

1. Sort flights by departure time di (1 <= i <= n). Let gk (1 <= k <= m) represent the earliest available time (the departure of last flight) of gate k. Set gk = -1 for all k.
2. For each flight i,
   a. Find gate k such that gk < ai and gk is maximized
      i. If such k exists, assign flight i to gate k, update gk = di
      ii. Else assign flight i to apron

B. Tabu Search Algorithm

Step 1:

Select the current assignment ($x_{current}$) and its objective value ($Z_{current}$). Set x_{best} = $x_{current}$ and Let Z_{best} = $Z_{current}$ and iter = 0.

Step 2:
If iter > max_iter,

Terminate with x_{best} and Z_{best}.
Else, go to step 3.
Step 3:
Determine the type of neighborhood move by a uniform probability. Generate the neighborhood set $N(x_{current})$.

Evaluate each candidate solution x_{trial} as $f(x_{trial})$ for some evaluation function f.

If $f(x_{trial}) < f(x_{best})$

Accept and Set x_{next} = x_{trial} (Aspiration criteria)
Else

Select $x_{next} = Min_{x_{trial} \in N(x_{current})} f(x_{trial})$

$iter > tabu(x_{current} \rightarrow x_{trial})$.

Step 4:
Update the Tabu memory by

$tabu(x_{current} \rightarrow x_{trial}) = iter + U(a,b)$ where

$U(a,b)$ denotes a random number generated between a & b.

Set $x_{current}$ = x_{next}

If $f(x_{current}) < f(x_{best})$,

Set $f(x_{best})$ = $f(x_{current})$ i.e. Z_{best} = $Z_{current}$
iter = iter+1
Go to step 2

C. Simulated Annealing Algorithm (Master Algorithm)

Step 1:

Find a feasible (initial) assignment (x_{now}) and its objective value (Z_{now}) with a Greedy heuristic algorithm (section 4.1.1). Set x_{best} = x_{now} and Let Z_{best} = Z_{now}

Step 2:
Set the annealing temperature T as a linear function to the input size.

$T = T_{const} * n$, where T_{const} the starting temperature and n be is total number of aircrafts to be assigned in the gates of the airport.

Variables unimproved and unaccepted are defined to record the number of iterations for which the cost structure has not improved, and the number of iterations where no neighborhood move is performed, respectively.

Step 3:
Determine the type of neighborhood move by uniform probability. Randomly generate a neighborhood of the type and calculate delta distance (Δ = $Z_{current}$ - Z_{best}) if the neighborhood move is performed.

Step 4:
Decide whether to perform the neighborhood move generated with probability $p_0 = a * e^{-\left(\frac{\Delta}{kT}\right)}$ where a & k are the constants that determine the accept rate. Generate a uniform random number (let be r) from the interval [0, 1].

If (Δ<0) or (r< p_0),

Then Z_{best} = $Z_{current}$ and x_{best} = $x_{current}$
Update Variables unimproved and unaccepted

Step 5:
If (unimproved > max_improved) or (unaccepted > max_unaccepted),
Perform Tabu Search (TS) as described below TS algorithm (section 4.1.2).
Reheat the temperature by a factor,
reheat: $T = T * reheat$
Else
Decrease the temperature by cool rate d: $T = T * d$

Step 6:
If the termination requirement is not met, return to Step 3.

D. Master Algorithm Pseudocode Sample

Database Tables:
FlightScheduleData
GateDesignData
GateBlockTimeData
PassengerData
DistanceData

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Decision Objective Value Calculation:
Walking distance_obj ()
FlightDelayTime_obj ()
GateIdleTime_obj ()
#FlightsAtApron_obj ()

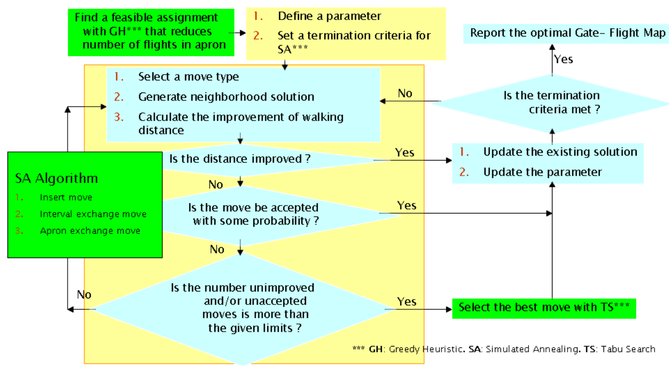
Parameter Setting:
TConst = 2
n = number of flights
k = 2.25
a = 2
CoolRate = 0.9999
ReheatFactor = 1.25
TTerminate = 0.01
MaxUnimproved = 500
MaxUnaccepted = 500

Main
{
Call **GreedyHeuristics** (FlightScheduleData, GateDesignData, GateBlockTimeData)

Calculate **Walking distance_obj** (GateFlightMap, Passenger, Distance)
Set the AnnealingTemp = TConst * n
Set *unimproved* = 0 and *unaccepted* = 0
Best_GateFlightMap = GateFlightMap
Best_WalkingDistance = Walking distance_obj
Do
{
Generate a **TypeOfNeighbourhoodMove** ()
Generate a **Neighbourhood** (TypeOfNeighbourhoodMove)
Calculate **Walking distance_obj** (Neighbourhood, Passengers, Distance)
Calculate DiffDistance = Walking distance_obj – Best_WalkingDistance
Calculate CutOffProbability = a*exp(-DiffDistance/(k*AnnealingTemp))
Draw a random number R
If (DiffDistance < 0)
Best_GateFlightMap = Neighbourhood
Best_WalkingDistance = Walking distance_obj
Else if (R < CutOffProbability)
Best_GateFlightMap = Neighbourhood
Best_WalkingDistance = Walking distance_obj
unimproved = +1
Else
unaccepted = +1
If ((unimproved > MaxUnimproved) or (unaccepted > MaxUnaccepted))
Calculate Best_GateFlightMap = **TabuSearch** ()
Calculate Best_WalkingDistance = **TabuSearch** ()
AnnealingTemp = AnnealingTemp * ReheatFactor
Else
AnnealingTemp = AnnealingTemp * CoolRate
GateFlightMap = Best_GateFlightMap
WalkingDistance = Best_WalkingDistance
} While (AnnealingTemp > TTerminate)

Report the GateFlightMap
Report the WalkingDistance
Calculate **FlightDelayTime_obj** (GateFlightMap)
Calculate **GateIdleTime_obj** (GateFlightMap)
Calculate **#FlightsAtApron_obj** (GateFlightMap)
}

E. Master Algorithm Flow Diagram



VII. SOLUTION DEVELOPMENT

We have developed a web-based solution with the following features:

1. Solution can take input from flat files or from any external system such as flight scheduling system, airport management system, etc
2. Solution has the flexibility to choose any gate assignment horizon, specified solution performance and gating system efficiency
3. Solution with its in-build algorithm can check or verify if any operational requirement or policies have been violated during the assignment process
4. Solution can support very user-friendly reports for proactive decision
5. Solution can also support on different facilities for strategic decision on gate assignment policies, staff assignment, improvement in parking stands, ground vehicle management
6. Solution can also be very much adaptable to environmental changes

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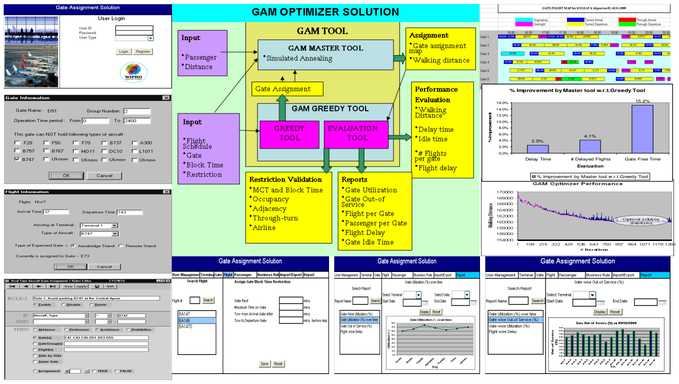
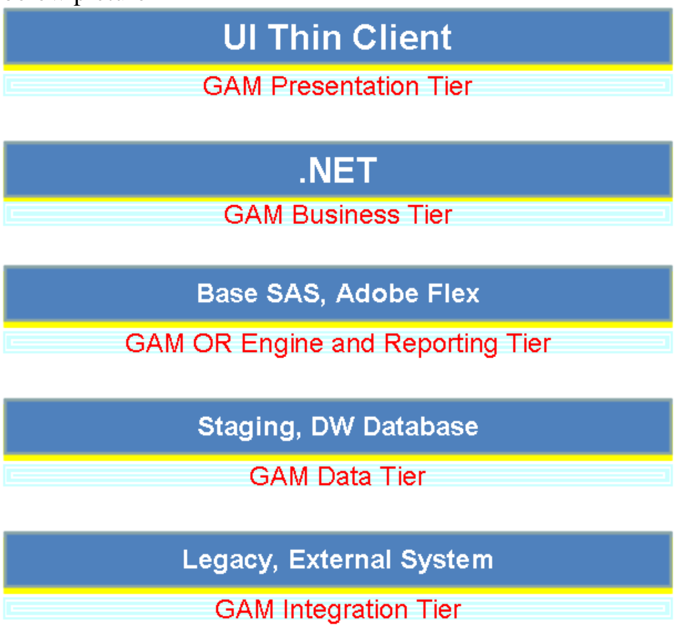


Solution design architecture has been followed as per the below picture

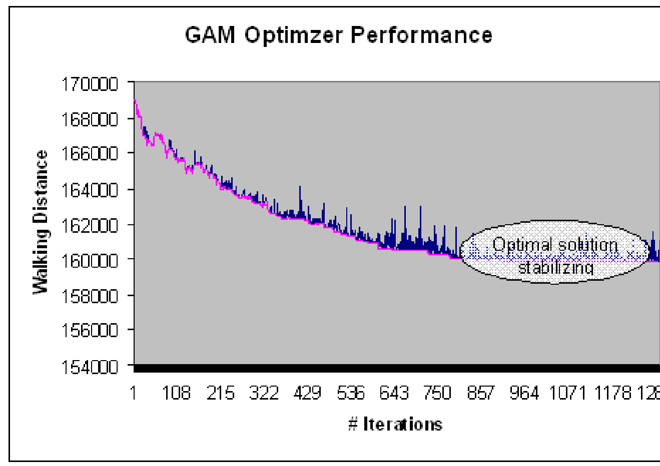


VIII. SOLUTION PERFORMANCE

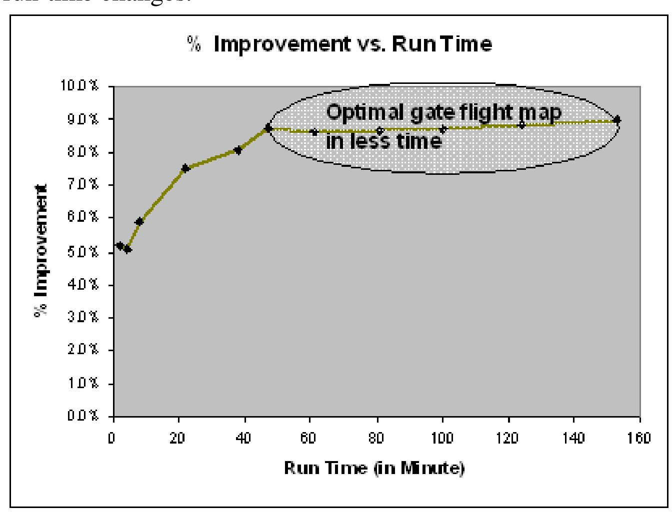
One can find the following key success metrics from the solution as below:

1. Optimized Gate-Flight Map
2. Optimum business objective function value
    a. Minimized walking distance
    b. Minimized flight delay time
    c. Minimized number of delayed flights
    d. Maximized gate free time
    e. Uniform assignment of flights to gates
3. Verification of meeting operational parameters
    a. MCT of flights
    b. Minimum required block time required of flights
    c. Occupancy of flights at the same gate at any point of time
    d. Adjacency of flights at the adjacent gates
    e. Through/turn flights assignment in the same gate if requires
    f. Airline restrictions in certain gates
4. Optimal setting of modeling parameters
    a. Termination setting
    b. Run-time setting
    c. Mix of different moves
5. Strategic trends
    a. Gate utilization
    b. Gate out-of service
    c. Flight traffic
    d. Connecting passenger traffic
6. Strategic performance comparison
    a. Gate utilization
    b. Gate out-of service
    c. Gate wise flight traffic vs. delayed flight
    d. Gate wise arrival/departing flights
    e. Gate wise passenger traffic
    f. Gate to Gate connecting passenger traffic
    g. Gate free time
    h. Flight delay

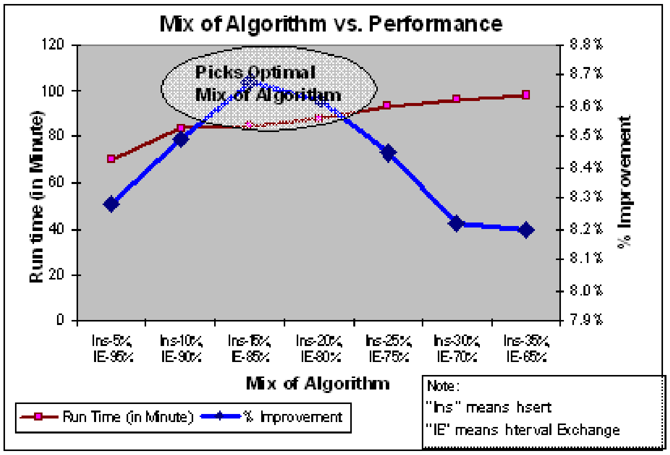
Solution checks the stability of optimization results as given below



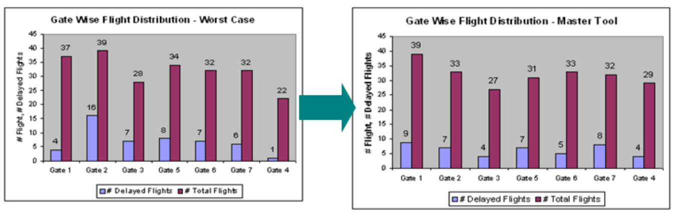
It also verifies the performance of the solution if the solution run-time changes.



You can also select the optimal mix of algorithm to be implemented in for optimal solution performance



Solution can also check the uniform assignment or even loading of flights to different gates as below diagram.



IX. CONCLUSION

In this paper, we consider an Airport Gate Assignment Problem that dynamically assigns airport gates to scheduled flights based on passengers' O&D flow data. Though our primary objective is to minimize the overall walking distance that passengers walk to catch the connection flights, the distance traveled within the airport terminal for originating or departing to other destination, but we have also attempted to maximize number of gated flights and minimize flight delays keeping as secondary objective. While the primary objective is increasing the customer satisfaction, the secondary objectives are to reduce flight delay and waiting times by reducing the total number of visits to apron because of unavailability of gates. We first formulated this problem as a mixed 0-1 quadratic integer programming problem, then we re-formulated it as a mixed 0-1 integer problem with a linear objective function and constraints. Both the models are NP-Hard, which implies that there is no known algorithm for finding the optimal solution within a polynomial-bounded amount of time. In practice, a major airline hub terminal may handle more than 1000 daily flights at more than 50 gates, which in our formulation would result in billions of binary variables. Due to such a huge size, this model can not be handled by branch-and-bound based MIP solvers within a reasonable time bound.

We have implemented a hybrid heuristics algorithm guided by Simulated Algorithm Heuristic supported with Greedy Heuristic and Tabu Search heuristic to solve the assignment problem. The results obtained by the hybrid heuristics algorithm may not be optimal compared to the standard available MIP solver. But, the approach has advantages in running time since it was able to reach relatively low values in short times. We took advantage of this property and consequently developed an innovative IT solution with the usage of standard software available in industry.

As like any other assignment system, the constraints of gate assignment decisions such as number of flights, available gates, aircrafts, flight block time etc. changes very frequently. The ability to deal with the change in the data elements is critical to the quality of gate assignment plan despite the occurrences of unforeseen events. The quality of gate assignment plans has a variety of measures in the aviation industry, authority, and research. Care should be taken to prioritize different measures as is done in this research. With our high-end reporting module of the solution, one can take proactive action beforehand for betterment of results**.**

Though the solution provides a feasible solution for gate assignment decisions with the near optimal business outcome and high-end reporting for proactive decision, the team is working on the followings for the improvement of solution

1. Incorporating apron exchange move for betterment of flight delays
2. Incorporating Tabu Search as part hybrid heuristics algorithm to improve solution run time

REFERENCES

[1] *H. Ding, A. Lim, B. Rodrigues, Y. Zhu*, "The over-constrained airport gate assignment problem," Computers & Operations Research 32 (2005) 1867–1880

[2] Jiefeng Xu and Glenn Bailey, "The Airport Gate Assignment Problem: Mathematical Model and a Tabu Search Algorithm," *Proceedings of the 34th Hawaii International Conference on System Sciences – 2001*

[3] Bolat, A. (1999) Assigning arriving aircraft flights at an airport to available gates, Journal of the Operational Research Society, 50, 23-34J.

[4] Bolat, A. (2000a) Models and a genetic algorithm for static aircraft gate assignment problem, Journal of the Operational Research Society, 52, 1107-20.

[5] Bolat, A. (2000b) Procedures for providing robust gate assignments for arriving aircraft, European Journal of Operations Research, 120, 63-80.

[6] Cheng, Y. (1997), "A knowledge-based airport gate assignment system integrated with mathematical programming," Computers & Industrial Engineering, 32, 837-852.

[7] Yan, S., and Huo, C. (2001), "Optimization of multiple objective gate assignments," Transportation Research - Part A, 35, 413-432.

[8] G. Diepen, J.M. van den Akker, J.A. Hoogeveen, and J.W. Smeltink, "Using column generation for gate planning at Amsterdam Airport Schiphol," *Supported by BSIK grant 03018 (BRICKS: Basic Research in Informatics for Creating the Knowledge Society).*

[9] Xu, J. and Bailey, T. G. (2001). The airport gate assignment problem: Mathematical model and a tabu search algorithm., HICSS

[10] Haghani, A. and Chen, M.-C. (1998), "Optimizing gate assignments at airport terminals," Transportation Research Part A: Policy and Practice 32: 437–454.

[11] Michel Turcotte, Gillian M. Mann, Aaron L. Nsakanda, "Impact Of Connection Bank Redesign on Airport Gate Assignment," Proceedings of the 1999 Winter Simulation Conference

[12] X. B. Hu, and E. Di Paolo,"An Efficient Genetic Algorithm with Uniform Crossover for the Multi-Objective Airport Gate Assignment Problem,"

[13] Katta G. Murty, Yat-wah Wan, Vincent F. Yu, Jerry Dann, and Robin Lee, "Developing a DSS for Allocating Gates to Flights At An International Airport,"

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[14] Alexander Verbraeck, Edwin Valentin, "Smulation Building Blocks For Airport Terminal Modeling," Proceedings of the 2002 Winter Simulation Conference
[15] Francis Carr, Georg Theis, Eric Feron and John-Paul Clarke, "Evaluation of Improved Pushback Forecasts Derived from Airline Ground Operations Data," International Center for Air Transportation
[16] Jorge Bonilla, Hassan Mohammed, Joel Norris, Thang Phung, Ingrid Zegada-Frias, "Ramp Operations Monitoring System," Proceedings of the 2005 Systems and Information Engineering Design Symposium

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