Developing a DSS for Allocating Gates to Flights at an International Airport

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Abstract

Typically international airports have features quite distinct from those of regional airports. We discuss the process of developing a Decision Support System, and appropriate mathematical models and algorithms to use for making gate allocation decisions at an international airport. As an example, we describe the application of this process at Taiwan Taoyuan International Airport to develop a DSS for making gate allocation decisions for their passenger flights.

Keywords: Airport operations, international airport, gate allocations to flights, DSS (Decision Support System).

1. Introduction

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 competition between

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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. That is why mathematical modeling of this problem and the application of OR (Operations Research) methods to solve those models have been studied widely in OR literature.

The dynamic operational environment in modern busy airports, increasing numbers of flights and volumes of traffic, uncertainty (random deviations in data elements like arrival, departure times from flight time tables and schedules), its multi-objective nature, and its combinatorial complexity make the flight-gate allocation a very complicated decision problem both from a theoretical and a practical point of view.

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 decisions for their flights themselves.

Typically international airports have features quite distinct from those of regional airports. The common characteristics of busy international airports all over the world are: they usually serve a large number of different airlines; they normally serve a large number of flights spreading over most of the 24-hour day; they have to accommodate planes of various types and sizes, and a considerable percentage of their flights are long haul flights coming from long distances. These features, and the fact that international airports are much bigger and have much higher volumes of traffic compared to regional or domestic airports, make the problem of assigning gates to flights at an international airport somewhat harder in practice than that at a regional airport.

In this paper we discuss the process of developing a DSS (Decision Support System), and appropriate mathematical models and algorithms to use for making gate allocation decisions at an international airport. Normally international airports have both cargo and passenger flights, but in this paper we will only consider gate allocation decisions for passenger flights.

As an example, we describe the on-going work being carried out to develop a DSS at TPE (Taiwan Taoyuan International Airport), the busiest international airport that serves all of Taiwan; to help the team of Gate Allocation Officers make their decisions optimally and efficiently.

Being the busiest airport in Taiwan, TPE has all the characteristics mentioned above. Here is a quick summary on the most important characteristics for the gate allocation decision at TPE. TPE serves about 40 international airlines, gate allocation decisions for all the flights at this airport are handled by the airport itself. TPE has a team of 18 flight operations officers (working three shifts) responsible for these decisions.

TPE handles on average about 420 regularly scheduled flights/normal working day (this average varies from 390 to 450/day), and 20 irregular (i.e., unscheduled) flights/day (this average varies from 10 to 40/day); depending on the day of the week. Friday is usually the busiest day of the week, and holidays (Saturdays, Sundays, and other national holidays) are also busy days in comparison to the other working days. The Chinese (Lunar calendar) New Year vacation (which usually occurs in the months of January or February) days are the busiest days of the year at TPE. The number of flights some days before and after the Chinese New Year may be well over 500. A more complete description of the gate allocation problem at TPE is given in the next section.

We describe the procedures being used currently at TPE, the mathematical models being developed, and procedures that will be used to solve these models when the DSS is fully implemented, and the expected benefits. We will discuss important design features of the DSS and how it will be incorporated into daily operations.

2. The Nature of the Gate Allocation Problem at TPE

TPE is located approximately 40 kilometers south of Taipei City, the capital and the largest city of Taiwan. Currently there are two terminals at the TPE.

Terminal 1 started operations in 1979, in a period of the most dramatic economy growth in Taiwan history. As a result, the traffic volume at the TPE grew rapidly and soon exceeded its original designed capacity. The situation was temporarily relieved after Terminal 2 was put into operation in 2000. As the volume of airline traffic has been going up steadily, TPE will face capacity problems in the near future. Actually, even now during national holidays and the typhoon season, the current capacity is tight.

During national holidays such as the Lunar New Year, many non-regular chartered flights are scheduled so that business persons can return to Taiwan from Mainland China to spend the holidays with their families. During the typhoon season (normally from June to September) regular flight schedules are often disrupted as many flights are delayed or cannot land or depart because of the weather condition. Even during normal days, the airport is often covered by severe fog; then the airport may require extra space for parking planes to avoid serious flight delays.

In view of this, the government is planning for a third terminal. However the new terminal may not be ready in the near future due to legislation issues, long construction time, and budget constraints, etc. Improving the operational efficiency of existing facilities seems to be the only way to mitigate the capacity issues faced by TPE. One of the most critical operating issues is the allocation of gates to flights. A good gate allocation plan may greatly improve the airport's operations and increase customer satisfaction.

Current Gate Allocation Process at TPE

At present, the gate allocation plan at TPE is generated semi-manually by the 18 flight operations officers (FOOs) of the Flight Operations Section (FOS) who work three shifts around the clock. Normally the FOS receives the arrival/departure flight schedule for the next day from the airlines around 2 PM in the afternoon. The flight schedule information may be on a floppy disk or on a piece of paper. In the latter case, the FOOs on duty need to manually input the data into their computer system, flight by flight. The computer will then make initial gate allocations for each of the flights, subject to manual adjustments by the FOOs on duty. The initial gate allocation plan for the next day's flights is completed by 10 PM and distributed to the respective airlines.

The computer system employed by TPE for making gate allocations is an on-line heuristic rule based system which incorporates rules originating from FOOs' experiences. Basically the gate allocation is done in a fashion similar to the “first come first serve” strategy. The airport authority and the airlines have an agreement on the preference of gates for their flights. Each airline has its own set of first preference gates and second preference gates for its flights. If all these gates are occupied at the arrival/departure time of the flight, the flight may be allocated a gate not in the two aforementioned categories. Therefore, for each flight, the system will first try to find a gate that belongs to the first preference category at the time of arrival/departure of the flight. If none of them are available, it will try to find a gate in the second preference category for the flight. Such a process goes down to the third and even the fourth preference category (emergency gates) to look for an available gate. Presently, this process almost never fails to find a gate for a flight.

The FOO also has the authority to manually shorten flight gate occupancy time so that all flights have a gate to use at their arrival/departure times. Most of such adjustments of gate occupancy time occur during peak periods for flights. The system also incorporates other rules that deal with flight-gate compatibility, overnight transit flights, gate maintenance schedule, private jets, and emergency gates.

Due to the uncertainty in flight departure/arrival time, the initial plan needs to be adjusted throughout the course of the planning day. The FOOs try not to make too many changes to the initial plan to reduce additional communication work and disturbance to the airlines and passengers. For this part, the work is done manually and there are no well defined rules for these adjustments. According to the airport personnel, about 90% of the original gate allocations are unchanged during normal days. During unusual periods of time, such as national holidays or severe weather conditions, this number may go down significantly.

In gate allocation, the main concern of the airport is making sure that all flights are gated upon their arrival/departure, and if possible, allocate the most preferred gates to flights; at present most airports in general do not pay too much attention to other aspects associated with gate allocations.

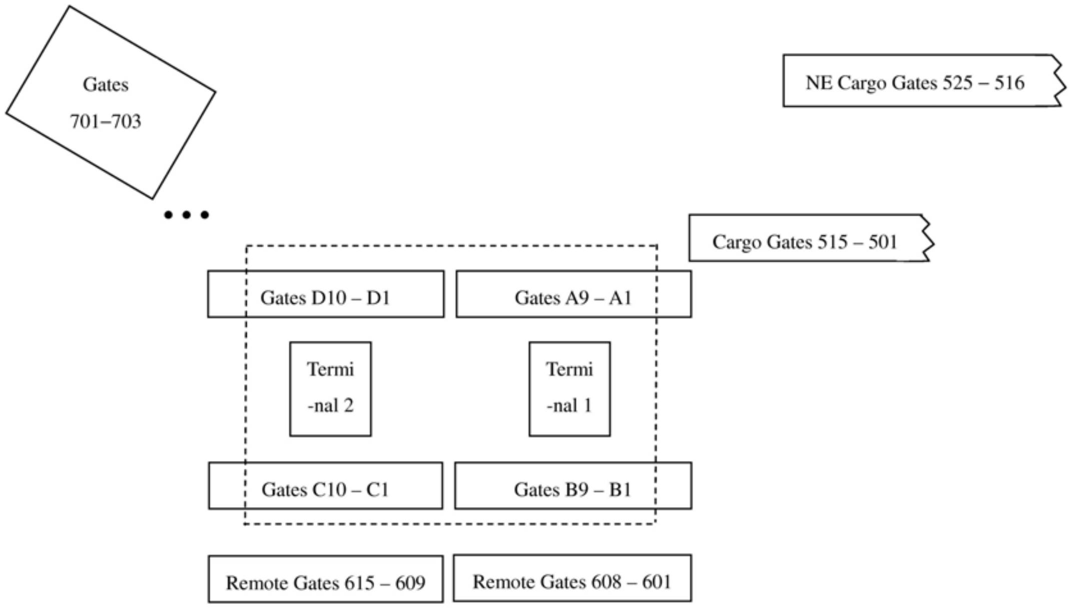
At TPE, airport charges, navigation aids service charge, and noise charge are set by Taiwan's aviation authority (CAA; Civil Aeronautics Administration) which include overfly noise charge, landing charge and bridge fees, use of ground handling area and facilities and other charges [CAA 2007]. These charges do not vary with respect to gate locations. For example, the noise charge is calculated in accordance with each aircraft's maximum take-off weight and take-off noise level where the aviation noise control area of an airport is announced by the city or municipality government. The boarding bridge or bus charge is calculated in accordance with the aircraft's number of seats and frequency of use. Therefore, these charges are not relevant to making gate allocation decisions.

TPE's Concern about the Current Practice

The current gate allocation planning process at the TPE seems to work just fine, as most flights are allocated to gates in sufficient time before their arrival/departure time. However, it is labor intensive, and it keeps at least 3 FOOs occupied during each shift (i.e., a total of 9 man-days of FOO's time daily). With all this work, the FOOs are really hard pressed for time, particularly during peak periods of the day. Also, as the traffic volume grows continuously, the current practice may not be viable for too long in the future. In addition, the airport authority also wonders whether the current system does give the best gate allocation plan or not, and what the quality of the plan is in terms of the many objectives employed by other airports and proposed by researchers.

Soon after one of the authors had just completed an experimental study on gate assignment problem for the Kaohsiung International Airport in 2006 (Yu and Chen, 2007), a small team of the authors from several universities in Taiwan and the U.S. started this project with the TPE's FOS. Since then, the authors from academia had met with the authors from the TPE several times to clarify the operational constraints, considerations, and objectives, before proposing the mathematical model and heuristics and getting them approved by the airport officials.

We now summarize the current operating conditions relevant to the gate allocations operation at TPE, before giving detailed description of our mathematical models and heuristics for solving the gate allocation problem at international airports in general, and TPE in particular, in subsequent sections.



Note: Gates within the dash-line rectangle are considered as the central gates.

Figure 1. Gate Layout of TPE. Gates in the A, B, C, D sections are those with passenger bridges (also referred to as "regular gates"). All other gates are apron gates, i.e. open air locations without any passenger bridges. Emergency gates 701-703 are much farther than other gates from the terminals, and hence are used only when no other gates are available. "Central gates" refers to gates considered to be in the central portion of TPE. TPE has an operating Skytrain line between Terminals 1 and Terminal 2, with a train running back and forth every 2 to 5 minutes. Using this if necessary, passengers can get from any of these central gates to any other, within 10 to 15 minutes.

Gates and Aircraft Types

Currently TPE uses 78 gates (A1-A9, B1-B9, C1-C10, D1-D10, 501-525, and 601-615) regularly to serve 27 different types of flights ranging from the smallest

CL-604 to the largest Boeing 777 and Airbus 380. Among the 78 gates, 30 are apron gates (501-525, and 601-615) (i.e. open air gates without a bridge, passengers have to be taken by coach to and from inside the airport to these gate positions) as shown in Figure 1. In addition there are also three emergency gates 701-703 which are also apron gates.

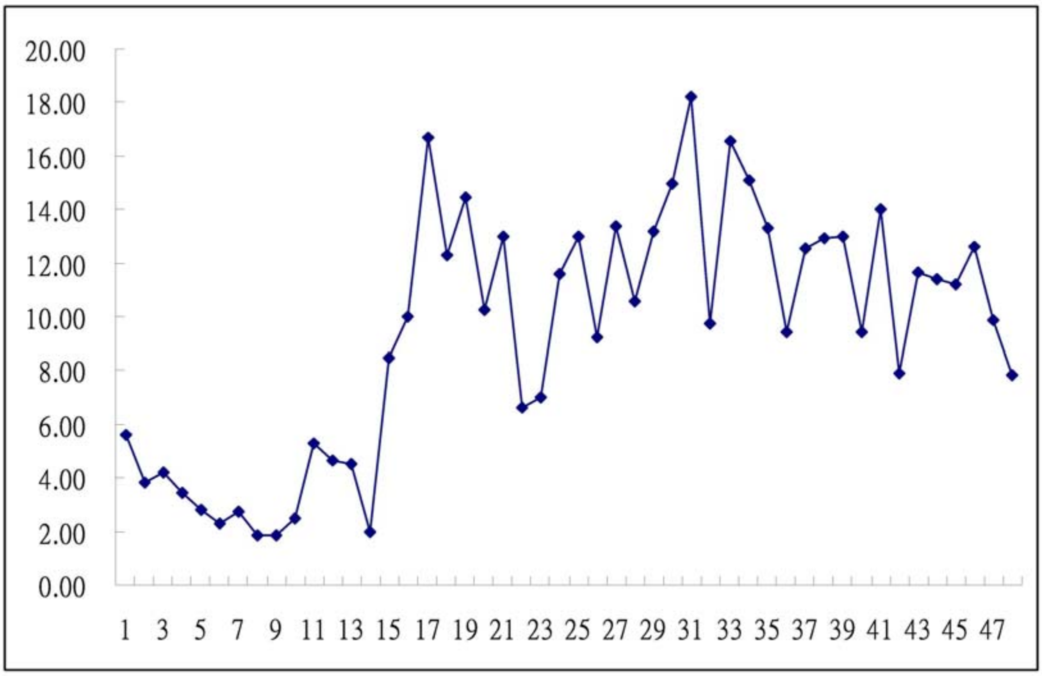


Figure 2. This figure shows the typical averages of the total number of flights arriving, departing in each 30-minute interval of a day. Time intervals are numbered serially 1 to 48 (1 is the time slot from midnight to 12:30 AM) are shown on the horizontal axis. On the vertical axis we plot the number of flights arriving, departing in the interval.

Various Flight Types

The TPE services 40 international airlines and on average 420 regular flights and 20 irregular flights (chartered flights, private planes, etc. that do not operate on a regular schedule) every day. During weekends (Fridays and Saturdays) and holidays, the flight numbers increase to about 450 regular flights and 40 irregular flights. Generally speaking the number of regular flights ranges from 390 to 450, and the number of irregular flights is between 10 and 40.

There are three types of flights in terms of their origin and final destination: arrival flights whose final destination is TPE; departure flights whose origin is TPE; and transit flights which take a brief stop at the TPE, and then depart for their final destination. On average, there are about 91 arrival flights, 93 departure flights and 132 transit flights per day. Recall that each transit flight needs both an arrival gate, and a departure gate; so each transit flight involves two gate allocation decisions, though as far as possible, a transit flight stays at the same gate for arrival and departure.

Peak and off-peak periods

We divide the day into 48 thirty-minute intervals and number them serially 1 to 48 with 1 representing the 12 midnight to 12:30AM interval. In Figure 2, we plot the average number of flights arriving/departing in each half-hour interval of the day based on June 2007 data at TPE. From this we see that there are two peak periods of the day for number of flights arriving/departing, one between 7 - 10 AM, and another between 3 - 5 PM. Corresponding charts for the data in various months of 2007 confirm the same observation. However, this pattern is somewhat different for different days of the week (Sunday to Saturday).

For solving the gate allocation problem, these peak periods offer most challenge; in off-peak periods the problem is relatively easy to solve.

Gate Allocation Policy

The airport does not give any preference to any airline in making the gate allocations (however see Section 9, which explains that TPE gives preference to flights with larger passenger volumes, and to regular flights, independent of the airline). Basically they employ the “first arrival/departure first assigned policy” for all the flights, regardless of the airline.

TPE normally allocates 60 minutes gate time to arrival flights, 90 minutes gate time to departure flights for flight preparation, passenger disembarking, embarking, flight clean up, ground service to the plane, etc. For transit flights, the allocated gate time is 150 minutes, the sum of gate times of an arrival flight and a departure flight. However, these times may vary depend on the size of the aircraft and the time of the day. During peak times, the FOOs may shorten the gate time to accommodate more flights. On average, a 30-minute buffer time is scheduled between two flights using the same gate to take into account the uncertainty in flights' actual arrival/departure time. This time may also be cut short during peak hours, as the FOOs try to persuade flights occupying gates to finish up their work soon if possible. The FOS has the full cooperation of all the airlines in this effort during peak periods.

Frequency of Gate Shortages

As stated earlier, currently, most of the flights are gated in sufficient time before their arrival/departure. Besides, few minutes waiting on the taxiway is acceptable to the airlines. The few occasions that a flight needs to wait for available gates usually occur during peak times as many national carriers' flights are returning to their base. As for the case when the airport is too congested so that the arrival flight has to circle around the airport, it never happened at the TPE so far.

Organization of the Paper

The paper is organized as follows. In Section 3, we discuss the data elements and uncertainties associated with them. In Section 4, various objectives to be optimized are explained in detail. We briefly review the mathematical models for the gate allocation problem, and algorithms to solve these models, discussed in previous work on the gate allocation problem in Section 5. In Section 6, we describe the outputs desired by the airport authorities and the scheme used in our solution approach. The strategy used for making gate allocation decisions for a Planning Day in our approach is given in Section 7. Section 8 describes the mathematical models and procedures for gate assignments to flights in a planning interval in our approach. In Section 9, we summarize some of the important design features of the new DSS under development at TPE. Finally, in Section 10 we summarize the expected benefits, and some intermediate results of this ongoing project and draw conclusions in Section 11.

3. Data Elements, and Uncertainties in Them

Flights use different types of planes (large wingspan planes, short wingspan planes, planes for long haul flights, short haul flights, etc., etc.) depending on the expected passenger volume on the flight, length of the flight, and several other considerations. As mentioned above, airport gates are also classified into different types depending on their size, location in the airport (those in the central portion of the airport, remote gates, etc.), etc.; these gate characteristics determine their desirability to airlines for their flights.

So, for each flight for which a gate is to be assigned, we need the set of all the gates to which it can be assigned. This set of gates eligible to be assigned to a flight is classified into 1st (most preferred by airline), 2nd (second most preferred), and 3rd (least preferred) categories in order of their preference by the airlines. Sometimes at some airports there may also be a 4th category of gates in decreasing order of preference. This data is available, and it will be used in constructing the objective function to optimize, for determining the allocation of gates to flights (discussed later in Section 4).

At TPE even though the classification of gates into 1st, 2nd, and 3rd categories mentioned above for their flights differs from airline to airline, it tends to be very similar. Airlines like to have their flights use gates in the terminal in which most of their activities take place. So, in general for most airlines the first category gates are those among the A, B, C, D sections in the terminal in which they have their operations. Remote gates 601 to 615 are in the 2nd category (most preferred when no 1st category gates are available) for their flights. Most airlines tend to place Cargo gates (numbers 501 to 525) in the 3rd category (least preferred gates, used only when no 1st or 2nd category gates are available). Emergency gates numbered 701 to 703 may be considered in the 4th category (least preferred among all the gates) for almost all the airlines, they are for emergency use, and will only be used if no other gates are available.

The other input data for gate assignment decisions are flight arrival and departure times. This data is subject to considerable uncertainty. As the difference between the actual landing/departure time of a flight and its scheduled landing/departure time is a random variable, gate allocations for flights on a day cannot be finalized based on information available the previous day about their landing/departure times. That is why on day $t-1$ the airport makes a tentative gate allocation plan for all the flights on the next day t based on the information about their landing/departure times available on day $t-1$; and on day t they revise these tentative gate allocations as needed by changes in flight landing/departure times. Normally on day $t-1$, by 2 PM all the tentative landing/departure time information for all the flights on day t becomes available. Using this information, the airport prepares the tentative gate allocation plan for day t by 10 PM on day $t-1$.

4. The Various Objectives to be Optimized

There are various costs associated with gate assignments which need to be optimized simultaneously. We discuss these in decreasing order of importance.

Since the gate allocation problem is a multi-objective problem, we solve it by combining the various objectives into a single penalty function, and then determining the gate allocations to minimize the combined penalty function. In this section we will discuss the various objective functions considered, and the penalty coefficients corresponding to them being used in the DSS being developed at TPE.

An Objective Commonly Considered in the Literature

In published literature on the gate allocation problem in OR journals, the most frequently used objective is minimization of the walking distance of all the passengers inside the airport. This is also used as the most important goal in the design of airport terminals. This appealing objective is easily motivated and clearly understood, but it leads to very difficult models that can hardly be solved.

A disturbing fact that has surfaced in the last few years is the large number of airline passengers feeling various degrees of uneasiness and actual sickness (some even suffering severe health consequences) from sitting without any physical activity for considerable periods of time on medium to long airline flights. In view of this, we feel that it is inappropriate to place a great emphasis on minimizing the total walking distance of all airline passengers inside airports. On the contrary, maybe encouragements should be provided for passengers to walk around when they have the time. Moreover this objective does not measure any real cost, and is not high on either the airport's or any airlines list of important objective functions to be optimized. Also the availability at many international airports nowadays, of rapid transit (also called Skytrain and other names) service between various terminals in the airport, or clusters or centers of gates separated by some distance, and walking belts inside each terminal to cover long distances, makes this objective function even less important. Airline managers that we talked to, tell us that even though this objective function is emphasized heavily in OR literature, their current practice of assigning gates to flights automatically takes care of this objective function because in it, gates that are far away from the central part of the airport are assigned only when there is no gate in the central part available at the time of landing a flight.

Compared to this objective function, the other objective functions like OBJ 1, 2 discussed below are real costs that are considered high priority objectives by both the airport and all the airlines. So, we will not consider this objective function in our model.

However there is a class of passengers, transfer passengers, who only have a limited time (like an hour or so), who are greatly inconvenienced by having to walk a long distance between their arrival and destination gates. One objective that we will consider is minimizing **OBJ** = the total walking distance that transfer passengers with a limited time to walk between their arrival and departure gates.

The number of passengers on each flight, and the destination of each of them in the airport (either the exit, or the gate assigned to some other flights) fluctuate randomly and widely from day to day. So, to evaluate this objective function reasonably accurately, we need data on the number of passengers transferring between every pair of gates; and hence modeling the problem of minimizing this objective function needs binary variables with 4 subscripts; and consequently a large 0-1 integer programming model which is hard to solve.

So, we will handle this OBJ indirectly. One way of achieving this objective is to make sure that arriving flights carrying more than a certain number of transfer passengers are assigned to gates in the *central part of the terminal* i.e., gates more or less equidistant from gates in all corners of the terminal (this guarantees that wherever the departure gate may be, transfer passengers on those flights have to travel only a small distance to reach them). At TPE, the central part of the airport consists of the A, B, C, D sections.

We can identify the set of those centrally located gates in the terminal. For an arriving flight j with more than the prescribed number of transfer passengers, and an eligible gate i outside this central set, include a penalty term corresponding to this objective function in the penalty cost coefficient c_{ij} corresponding to this assignment.

At TPE we incorporate this OBJ into OBJ 1 considered below. The 1st category gates mentioned above are all gates in the central part of TPE; the 2nd category gates are at some distance to the central part; and the 3rd category gates are much farther away. So, the penalty terms corresponding to the allocation of 2nd and 3rd category gates to such flights in OBJ 1 will reflect the impact of this objective OBJ in the penalty function.

OBJ 1:

This objective measures the costs or penalties associated with the gate assigned to a flight.

Emergency, cargo gates may only be used during periods of heavy flight traffic when regular passenger gates (i.e., those with jetties or passenger bridges) are not available for assignment, and only for certain types of flights for which such gates are suitable. If such a gate i is eligible to be assigned to a flight j, then OBJ 1 measures the penalty term corresponding to this assignment. Also, such an assignment usually results in charges to airlines for coaches and sometimes towing charges, etc. These are real costs that the airlines and the airport want to minimize. So, whenever towing, coach charges are incurred in the assignment of an eligible gate i to a flight j, we include these costs (scaled appropriately) in the penalty coefficient c_{ij}^1 corresponding to this assignment.

Even when a regular gate i is assigned to a flight j, there may be a penalty corresponding to this assignment depending on whether gate i is in the central part of the airport are not if flight j is carrying a lot of transfer passengers, and the preference category (1st, 2nd, or 3rd as mentioned above) to which gate i belongs for flight j. All these penalty terms corresponding to various gate assignments to flights are to be determined by the decision makers.

However, the team of flight operations officers at TPE has not reached a consensus on what the numerical values for the penalty terms c_{ij}^1 for allocating an eligible gate i to a flight j should be corresponding to this objective function. So, for the moment, we are experimenting with the following values:

$$c_{ij}^1 = \begin{cases} 0, \text{ if gate } i \text{ is in } 1^{\text{st}} \text{ category for flight } j, \\ 1, \text{ if it is in } 2^{\text{nd}} \text{ category,} \\ 3, \text{ if it is in } 3^{\text{rd}} \text{ category,} \\ 5, \text{ if it is an emergency gate } (4^{\text{th}} \text{ category}). \end{cases}$$

OBJ 2:

This objective measures the cost associated with the time the plane spends circling around the airport, and waiting on the ground after landing before beginning to taxi to the gate.

The plane is asked to circle the airport when there is no gate to receive it if it lands right away, and even the taxiway is too full for it to wait after landing. In the past this type of “necessity for the plane circling around the airport” used to occur sometimes, but nowadays at most airports around the world, this has become an extremely rare event. So, we ignore this in our mathematical model.

After landing, the plane will be asked to wait on the taxiway, if the gate i to which it is assigned is either not free momentarily, or the path from the landing point on the runway to gate i is blocked momentarily by some obstruction.

So in OBJ 2, we will consider only the costs and penalties for planes having to wait on taxiways before beginning taxiing to the gate. If a flight lands at 8 PM say, but the gate allocated to it is not going to be free until 8:15 pm, and taxiing needs only 5 minutes; then the plane will be asked to wait on the taxiway for 10 minutes before beginning to taxi to the gate. Such events occur during peak times of the day at most busy airports. They cause inconvenience to the passengers and the flight crew on the plane.

We can measure the penalty for such an event by $c_j^2 t_{ij}$ where:

t_{ij} = time in minutes that flight j plane has to wait on the taxiway after landing before beginning to taxi to gate i if it is allotted to gate i.

c_j^2 = the penalty/minute waiting time on taxiway for flight j.

The penalty coefficient c_j^2 may depend on the plane size, average passenger load in flight j, etc. Suitable values for c_j^2 have to be determined by airport management, or the concerned decision makers.

At TPE, the consensus is that up to 10 minute waiting time on the taxiway is acceptable for any flight, but occurrences of such waiting time beyond 10 minutes are a cause for concern. Instead of minimizing a linear function of actual waiting times, the goal at TPE has been to minimize the number of such occurrences. So, if the allocation of a gate i to a flight j implies that this waiting time for flight j will be t_{ij} minutes, then we include a penalty term c_{ij}^2 in the objective function, where:

$$c_{ij}^2 = \begin{cases} 0, & \text{if } t_{ij} \leq 10, \\ 1, & \text{if } t_{ij} > 10. \end{cases}$$

OBJ 3:

On each planning day this objective plays a role only in updating the tentative gate allocations made the day before for this day. At TPE they want to make as few changes as possible in the tentative gate allocations made already. At present, on average for 90% of their flights, the final gate allocation is the same as the tentative gate allocation made for that flight the day before, and TPE would like to keep as a goal that for 90% or more of their flights this should happen. Other airports may not consider this objective as important as TPE does.

We will handle this objective by trying to minimize the number of changes made in the tentative gate allocations. While updating the gate allocations on the planning day we will include a penalty term c_{ij}^3 for choosing gate i for flight j in the final allocations, where: $c_{ij}^3 = 0$, if gate i is the tentative gate allotted to flight j; 1 otherwise.

5. Brief Review of Previous Work on the Gate Allocation Problem, and How our Model for the Problem Differs From Those in Previous Work

Various decision support systems have been developed for the design and the operations of airports. Some of them provide comprehensive decision support for planning and operations of an airport (e.g., Foster, Ashford, and Ndoh (1995), Zografos and Madas (2007), Wijnen, Walker, and Kwakkel (2008)). Other decision support systems are more specific; for example, the disruption management of the aircraft turnaround in Kuster and Jannach (2006)), the movement of planes between gateways and runway in Herrero, Berlanga, Molina, and Casar (2005), the safety of runways under heavy rainstorms in Benedetto (2002), and the decision support for airport expansion in Vreeker, Nijkamp, and Ter Welle (2002). This paper focuses on the decision support for gate allocation, which will be the subject for our subsequent discussion.

The gate allocation 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 distances 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 a 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.

Flights are ready at different time slots in a multiple-slot gate allocation problem. Such problems are generally computationally hard integer programs. Optimization-, simulation-, and rule-based heuristics have been applied to solve these problems. See

Dorndorf *et al*. (2007) for a systematic overview of the gate allocation problem. The review Qi *et al*. (2004) covers general scheduling problems in the airline industry with gate assignment considered in some problems.

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 Huo (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 tradeoff between utilization of gates and waiting of planes for them, Bolat (1999, 2000a, 2000b) propose to minimize some functionals of slack times between successive usages 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 programs. 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)), and simulation (e.g., Yan *et al*. (2002)).

Other airport management functions are a by-product of gate assignment; for example, the simulation framework in Yan and Huo (2001) can evaluate the effect of flexible buffer time for stochastic arrival of flights and can be used for real-time gate assignment.

There are many rule-based systems that solve the gate allocation system. Here we only mention Cheng (1997) that combines rules with optimization techniques. Readers interested in rule-based systems can check the references of Dorndorf *et al*. (2007).

Features of the Mathematical Model That Will be Used in our DSS

The mathematical model that we will use for making gate allocation decisions in our DSS 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) Minimizing the total walking distance of all the passengers inside the airport is the main focus of most of the publications in previous literature. Our model does not

consider this objective function at all. The many reasons for it are explained in Section 4. We do consider the total walking distance of all the transfer passengers (who have limited time to get from their arrival gate to their departure gate), but handle it indirectly.

(2) 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 only seconds to solve, and is in fact more appropriate for the real problem.

(3) In our gate allocation decisions, we take into account the "first arrived, first assigned" policy that all airports 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.

6. Outputs Needed and the Planning Scheme that we will Use

Outputs Needed

Experience at TPE indicates that for approximately 90% of the flights on each planning day, their landing time information available the previous day remains correct. Also, for most of the flights, updated information about their landing time available about 3 hours before their actual landing is accurate. Keeping these in mind, TPE has developed the following goals for the gate allocation effort.

Each day by 2 PM the airport has all the information on the scheduled landing times for all the flights next day. Using this data, prepare by 10 PM a tentative gate allocation plan for all the flights next day.

For each arriving, departing flight on the planning day, the gate allocation for it should be finalized about 2 hours before its actual arrival, departure based on the latest information available about it.

The Planning Scheme to be Used

Flights arrive and land, and depart continuously over time. So, arriving, departing flights form a continuous stream, and before a flight arrives or departs, we need to make a decision about its gate allocation.

Suppose a flight A arrives at 8 PM and a gate, 1 say, is allotted to it. Then gate 1 will be occupied by this flight in the period 8 – 10 PM say, and is unavailable for allocation to other flights arriving in this interval. Thus the allocation of a particular gate to a flight limits the choice of gates for some flights arriving after it. Consequently, in the above example, the allocation of gate 1 to flight A at 8 PM, may lead to undesirable allocations to other flights arriving between 8 PM to 10 PM.

For this reason almost all the publications in the literature on the gate allocation problem, insist on making the gate allocation decisions for all the flights in a day simultaneously using a large mathematical model covering the whole day. Because of this, they claim that their model outputs the global optimum gate allocation plan for the whole day, without getting trapped in sub-optimal plans over shorter intervals of time.

At TPE the airport is committed to treating all its customer airlines equally, and not giving special privilege or preference to any particular airline. This implies that "**first arrived, first assigned"** policy should be adhered to strictly; similar policy also holds for departing flights. This means that each flight should be allotted to the best gate available for allocation at the time of its arrival, departure, irrespective of how it affects the availability of gates to flights arriving, departing after this flight.

For example, suppose two gates 1, 2 are the only ones available between 5 PM to 5:30 PM; of these 1 is a 1st category gate and 2 is a 3rd category gate. Suppose flight A lands at 5 PM, and flight B lands at 5:15 PM. By this policy, we must assign gate 1 to flight A. It would violate the "first arrived, first assigned" policy to assign gate 2 to flight A for the sake of assigning the 1st category gate 1 to flight B arriving later than flight A.

The "first arrived, first assigned" policy is one that all the airports in the world claim to adhere to. In our conversations with airport officials, we were told that they have to follow this policy in order to maintain good business relations with all their customer airlines. This policy implies that each flight should be allotted the best gate for it available at the time of its arrival, departure; and hence ideally it is best to determine gate allocations by an on-line algorithm which makes real-time decisions for each flight based on availability of gates at the time of its arrival, departure.

However, with lots of flights arriving, departing in short durations, and the necessity to announce gate allocations 2 hours before the beginning of the planning interval based on the best information available at that time, and the desire to keep a large percentage of these allocation decisions unchanged as far as possible; it is very difficult to make gate allocations totally on-line for each flight just in time for its arrival, departure. So, we adopt the following practical strategy that is close in spirit to on-line decision making, and yet is easy to implement in practice. We select a short planning interval (like a 15 minute or 30 minute interval), and determine the best gate assignments for all flights arriving, departing in this interval, at gates that will be available for assignment at some point of time in this interval, minimizing the penalty function discussed in Section 4, using a simple static mathematical model. If the optimum solution obtained violates the “first arrived, first assigned” policy for some flights, then it is easy to modify that solution (using swapping and other manual moves) into one which satisfies that property, since the planning interval is short and at the time of decision making all the necessary data for this interval is known accurately.

For this reason we have developed the following planning scheme for making gate allocation decisions. In contrast, models in the literature for gate allocation totally ignore the “first arrived, first assigned” policy.

Selection of the Planning Interval

We divide the day into short planning intervals, for gate allocation decisions. Decisions are made for the intervals in chronological order, and decisions made for an interval are taken as fixed in making decisions for future intervals.

In the spirit of keeping close to on-line decision making, we find that taking the planning interval length as 30 minutes is convenient and works well. So, we describe the mathematical model in terms of 30-minute planning intervals (interval length can be changed from 30 minutes to similar short duration as appropriate).

When interval k is the planning interval, gate allocation solutions for flights arriving in time intervals $\leq k-1$ are fully known, that information can be used to simplify many of the gate assignment constraints in the model for planning interval k.

For example, the assignment of a large aircraft to a particular gate may imply that adjacent gates can only accept aircraft of a certain size, or are even completely blocked. So, if Gate 1 is going to be used by a large aircraft flight in time interval $k-1$, and that plane will continue to stay at that gate for some time during interval k, then adjacent gates of Gate 1 can simply be made ineligible for allocation to flights using planes of non-acceptable size during planning interval k.

Thus, the choice of our short duration planning interval allows us to both avoid the effects of uncertainty in data elements, and also makes it possible to solve the problem using a simpler mathematical model that is easier to solve. Also, it is easier to make simple modifications in the output allocation manually for implementation.

7. Strategy Used for Making Gate Allocation Decisions for a Planning Day

In the next section, we will discuss a **procedure** which gives the mathematical model for making gate allocation decisions in a single 30-minute planning interval assuming that the arrival, departure times for all the flights arriving, departing in that interval are known exactly, and discusses how to solve it. Here we will discuss how to use that procedure to generate the outputs needed for the planning day.

To make the tentative gate allocation plan for all the flights on the planning day:

This plan has to be prepared by 10 PM of the day before the planning day. The data used for making this tentative plan are the scheduled arrival, departure times for all the flights on the planning day, which becomes available by 2 PM of the day before the planning day.

The planning day consists of k = 1 to 48 thirty-minute planning intervals. The allocation decisions in these intervals are made in chronological order one after the other, starting with the first planning interval (00:00 hours to 00:30 hours), using the procedure described in the next section.

To update and make final gate allocation decisions for a planning interval on the planning day:

Consider the k^{th} planning interval. Gate allocation decisions for flights arriving, departing in this interval are finalized 2 hours before the beginning of this interval.

Nowadays flight arrival and departure information is being continuously updated, and this real time information is delivered continuously to all airport organizations that use it. About 2.5 hours before the beginning of the planning interval, the k^{th}, the arrival, departure times for flights in the planning interval are known reasonably precisely. Gate allocation decisions for the planning interval are finalized using that data with the procedure discussed in the next section.

It is possible that some last minute changes occur in the arrival, departure times of flights in the planning interval, after the gate allocation plan for this interval is finalized. Nowadays such changes are rare, and only few in number. Any necessary changes in gate allocations to accommodate these last minute changes in arrival, departure times, are carried out by the gate allocation officers manually.

8. Procedure for Gate Assignments to Flights in a Planning Interval

Consider the k^{th} planning interval on the planning day. In the tentative plan, gate allocation decisions in this interval are made using the scheduled arrival, departure times of flights, which are available at the time of making this tentative plan, with the procedure described below.

Working on finalizing the gate assignments for flights in this interval is carried out 2.5 hours before the beginning of this planning interval. By this time gate allocations for flights in the $(k-1)^{th}$ interval would have been finalized and are known, and also the updated arrival, departure times of flights in this interval are quite precise. This is the data, and the procedure described below will be used.

There may be some flights expected to arrive towards the end of the $(k-1)^{th}$ interval for which gates have not been assigned in the planning work for that interval. These flights will also be considered for gate assignment in this k^{th} planning interval. Let

> J, n: n is the number of flights that need to have a gate assigned in this planning interval k. This includes flights which depart or land at some point of time in this planning interval, and flights that are expected to land before but have not been assigned to a gate in the previous interval. J denotes the set of these flights, and the index j is used to denote a general flight in J.
>
> i: is the index used to denote a gate in the airport (includes all gates, remote and emergency gates also if they can be used by some flights during heavy peak times), that are expected to be available for assignment to flights in this interval. If a flight is going to be occupied for the entire k^{th} planning interval by a flight assignment made in earlier periods, then it is not even considered in this model.
>
> x_{ij}: is the decision variable defined for gate i and flight $j \in J$; this variable takes the value 1 if flight j is assigned to gate i in this planning interval, or 0 otherwise.

If a gate i is not suitable to assign to flight j for whatever reason (for example if flight j uses a large plane and gate i is not of a size appropriate for it, etc.), then it is made ineligible for assignment to flight j, and the corresponding variable x_{ij} is not even considered in the model for planning interval k.

Similarly, several of the gate assignment constraints can be taken care of by this ineligibility classification. For example, as mentioned in the previous section, if Gate i is adjacent to a gate occupied by a large plane, and that plane will be there for some time during interval k, then it is made ineligible for all flights $j \in J$ with planes of unacceptable size during planning interval k, and the corresponding variables x_{ij} do not appear in the gate assignment model for this interval. Let

G_j = Set of gates i which are eligible to be assigned to flight $j \in J$ in planning interval k.

$I = \bigcup_{j \in J} G_j$ = Set of gates i which are eligible to be assigned to at least one flight $j \in J$ in this planning interval.

F_i = Set of flights $j \in J$ for which gate $i \in I$ is eligible to be assigned in this planning interval.

As discussed in Section 4, we will combine the various objectives into a single penalty function to be minimized, to determine an appropriate compromise between the various objectives, while assuring some of the hard constraints in gate assignment. Let

c_{ij}: The combined positive penalty coefficient associated with the decision variable x_{ij}. It is the sum of positive penalty coefficients associated with x_{ij} corresponding to the various objectives; these are determined based on trade-offs between the various objectives.

When considering gate allocations in planning interval k, flights that are expected to arrive in time interval $k-1$, but have not been assigned to gates then, should be given preference. Also, the airport may consider giving preference to certain flights that arrive in planning period k itself.

So, partition the set of flights J that need gate assignments in this planning interval k into $J_1 \bigcup J_2$ where

J_1 = subset of the flights in J that have to be given first preference for gate assignments

J_2 = the remaining flights in J.

We first determine the maximum number r of flights to which gates can be assigned in this planning period k, subject to the constraints mentioned in the previous sections. It leads to the following *transportation model*.

There is a constraint corresponding to each flight that needs a gate assigned in this planning interval k, the one corresponding to each flight $j \in J_1$ is an equality constraint specifying that each of these flights must be assigned one gate for itself (because we are required to give these flights first preference for gate allocation); the one corresponding to each flight $j \in J_2$ is an inequality constraint specifying that this flight needs one gate for itself if an eligible one for it can be found.

There is one constraint corresponding to each gate that becomes free at some point of time in this planning interval k and can receive a flight from that time onwards. The one corresponding to gate i is an inequality constraint specifying that this gate can accommodate at most one flight for which it is eligible to be assigned.

The objective in this model is to maximize the total number of eligible flight-gate assignments that can be made in this planning interval. The model is

$$r = \text{Maximum value of } \sum_{j \in J} \sum_{i \in G_j} x_{ij}$$

Subject to

$$\sum_{i \in G_j} x_{ij} = 1, \text{ for each } j \in J_1$$

$$\sum_{i \in G_j} x_{ij} \leq 1, \text{ for each } j \in J_2$$

$$\sum_{j \in F_i} x_{ij} \leq 1, \text{ for each gate } i \in I$$

$$x_{ij} \geq 0, \text{ for each } j \in J,\ i \in G_j$$

If this model turns out to be infeasible, it is an indication that there are not enough number of eligible gates available in this planning interval to even assign to all the flights $j \in J_1$. Then, the airport authorities can modify and relax some of the eligibility requirements for gate assignments if possible, or modify the set J_1 as appropriate, and solve the model with revised information.

When this model is feasible, the maximum objective value r in it gives the maximum number of flights among those needing gates in this planning interval, for which gates eligible for them can be assigned in this interval. If $r < n = |J|$, the remaining $n - r$ flights in J for which eligible gates cannot be assigned in this planning interval will have to be transferred to the next interval for gate assignments.

The above model only provides the maximum number of gate assignments that can be made in the planning interval k. It does not try to find optimal gate assignments. When the above model is feasible, the optimum gate allocations are found by solving another mathematical model which is also a transportation (or network flow) model. It tries to minimize the composite penalty function constructed above, subject to the same constraints as in the above model, and the additional constraint that the total number of flight-gate assignments should equal the maximum possible number r found above. It is

$$\text{Minimize} \quad \sum_{j \in J} \sum_{i \in G_j} c_{ij} x_{ij}$$

Subject to

$$\sum_{i \in G_j} x_{ij} = 1, \text{ for each } j \in J_1$$

$$\sum_{i \in G_j} x_{ij} \leq 1, \text{ for each } j \in J_2$$

$$\sum_{j \in F_i} x_{ij} \leq 1, \text{ for each gate } i \in I$$

$$\sum_{j \in J} \sum_{i \in G_j} x_{ij} = r$$

$$x_{ij} \geq 0, \text{ for each } j \in J, \; i \in G_j$$

Transportation (network flow) models are easy to solve. Typically, we can expect to have at most 100 to 200 flights to deal with in any planning interval at busy international airports. For problems of this size, either of the above models will require at most 0.5 seconds of a common PC time to solve, using software programs available today. An optimum solution $\bar{x} = (\bar{x}_{ij})$ obtained for the 2nd model provides an optimum gate allocation through the interpretation that

flight $j \in J$ is assigned to gate i in the optimum gate allocation $\bar{x}$ if $\bar{x}_{ij} = 1$.

There may be other constraints that have not been included in this model. If so, they can be added to the model. Or the gate assignment team may use their expert judgment to modify an optimum solution of this model into another that can be implemented.

How is This Model Used at TPE Currently

TPE has the policy of giving higher priority for the allocation of passenger and better category gates to flights with larger number of passengers over those with small number of passengers; and to regular flights over irregular ones. So, even though they have preferences between these classes of flights, for flights within each class they adhere to the first arrived first assigned policy. These preferences between classes are used in the process of making manual adjustments to the gate assignment solutions obtained by the mathematical model in each planning interval, to satisfy the “first arrived first assigned” policy.

At present TPEs main focus in gate allocations is to have gates allocated to the maximum number (preferably all) the flights while minimizing OBJ 1. Instead of solving the transportation models given in the previous section exactly, they have developed several simple heuristic rules to obtain a good solution of them heuristically. The combination of these rules actually constitutes a heuristic on-line algorithm for gate allocation, which makes gate allocations to flights close to their arrival, departure times based on the availability of gates at that time. Few computational experiments that we carried out on past data indicates that this heuristic method always gives either an optimum solution, or one very close to it under existing volumes of traffic, for minimizing OBJ 1. But as the volume of traffic goes up, the approach using the mathematical model developed here gives much better results and takes much shorter time to obtain them.

At the moment gate allocation decisions at TPE are made using this heuristic method, but in the near future TPE plans to begin using the exact solutions of these models and train all gate allocation officers to make them familiar with how to use those solutions in daily operations. This should relieve some of the work pressures on the gate allocation officers.

Revised On-Line Heuristic Method

Before the DSS can be put into use, the heuristic used currently can be improved by using a revised heuristic method given below.

In each planning interval, we allocate gates to flights in chronological order of starting gate time, i.e. the latest time a gate need to be allocated to the arrival/departure flight to avoid delay.

Consider flight i needs a gate at time t_i.

1. Find all gates which are available for assignment (and not assigned to another flight earlier) at time t_i or soon after t_i. Suppose this set of gates is J.
2. For each $j \in J$, calculate the objective value for assigning gate j to flight i; c_{ij} say. Find $\overline{c} = \min\{c_{ij} : j \in J\}$. Among all $j \in J$ with $c_{ij} \in [\overline{c}, \overline{c} + \delta]$, find a gate which is in the 1st category for the smallest number of flights, and allocate that gate to flight i. In case of a tie, find a gate among those tied which is in the 2nd category for the smallest number of flights. Break ties arbitrarily if there is still a tie.

Here δ is some tolerance to be chosen appropriately, depending on the range of values that the objective function takes. We could take $\delta = 0$, or some small value. A preliminary test shows that this approach can reduce OBJ 1 for the planning day while keeping all flights gated when they need a gate.

9. Design Features of the New DSS Under Development at TPE

At present in TPE, the gate allocation decisions are made semi-manually, based on a set of heuristic rules that try to minimize OBJ 1 discussed in Section 4. Some of the data needed for the model is entered manually, while the heuristic rules are applied through a computer program, with manual adjustment of the output from the computer. The whole process is labor intensive. Among the 6 FOOs on duty in each shift of the day, the time of at least 3 is used up for making and updating the gate allocation decisions. With the result the FOOs are hard pressed for time, particularly during peak periods of the day. The position gets worse as the volume of traffic is increasing with time. This is one of the motivations for the development of this DSS. The goal of the DSS is to take all the objective functions into account; and to automate the process at least to some extent to relieve FOOs for looking after the many other important things in their daily work.

The development of the DSS has just started, and work on it will be on-going over the next several years. So, we will just discuss some of the important features that will be incorporated initially. The most important component in it is assembling the data needed for the models as far as possible automatically.

An Overview of the Proposed DSS

	DSS			
System Modules	FOO Control Module	Gate Allocation Engine	Report Generation	System Maintenance
Working Databases	Daily Log Sheets	Flight Information	Gate Information	Gate Allocation
System Databases	Gate Types	Plane Types	Airline Info.	Operations Rule Set

Figure 3. A Schematic Diagram of the DSS

Figure 3 is a schematic diagram of the proposed DSS. The system and the working databases provide information for the system modules to plan, manage, and control tasks for gate allocation.

Content of the System Databases

- Gate Types Database: locations of gates, characteristics such as the sizes, facilities (e.g., fixed bridge, if available), plane types, etc. of gates;
- Plane Types Database: types, capacities, wing spans, etc, of planes;
- Airline Database: locations of facilities and contacts of airlines;
- Operations Rules Database: the preference and constraints of planes on gates, the set of rules to assign gates to planes, the system parameters such as the value of the coefficients of the objective functions in gate allocation.

Content of the Working Databases

- Daily Log Sheets: a record of flight and gate information; the information for flights includes the latest revised arrival or departure times data, with information from airlines, airport authorities interacting with TPE, on-board flight equipment of planes, airport controller, etc.; the information for gates includes any change of status of gates, with information from airlines and FOOs;
- Flight Information: the status of all scheduled and chartered flights, with different versions generated based on the most up-to-date information in the Daily Log

Sheets Database;

- Gate Information: the status of the gate and the assignment as from the Daily Log Sheet Database;
- Gate Allocation: the record of allocation of gates to planes based on the current flight information, with different versions generated at scheduled time of a day, or at some special epochs after disruption of planned schedules.

Content of the System Modules

- FOO Control Module: this is main panel for FOO to control the DSS, including allocating gates, making manual changes to allocation suggested by the DSS, and maintaining the system;
- Gate Allocation Engine: based on the information of Flight Information, Gate Information, Gate Allocation, and Operations Rules Database, the engine generates optimization model with appropriate objective functions and constraints to make gate allocation (or to allocate gates based on rules);
- Report Generations: this module generates all sort of reports for gate allocation, including the allocation of gates, utilization of gates and of bridges, statistics with respect to airlines and to flights, and the objective function values of the various gate allocations;
- System maintenance: this module changes the content of the system databases, including rules to for the Gate Allocation Engine to generate its optimization models.

Data Capture with Minimal Manual Intervention

When fully implemented, the DSS requires minimum effort to capture data. By design, the System Modules are applications automatically taking data inputs from modules and databases of the system. The content of the System Databases need not be changed unless there is any change in infrastructure on gates, planes, or airlines, or in rules of practices. Among the working databases, the Daily Log Sheets Database is the only interface to collection data, to convert it into useful information for the other three working databases.

The most important data elements needed for the Daily Log Sheets Database are:

(a) **Most recent updates of arrival/departure times** of flights expected to arrive/depart in each half-hour planning interval of the planning day.

(b) **Occupancy status** of each gate in the half-hour planning interval (will it be occupied during entire interval, and if so by which flight and plane; if not, at what time point in interval will it be available for reassignment).

Ideally, the FOS and all airlines can access to the DSS on the web, with different priorities, security controls, and functionalities for different bodies. For data elements in (a), each airline is continually updating the arrival/departure times of its flights through (a graphic user interface of) the Daily Log Sheets Database. Such information immediately becomes public to all bodies, though only the FOS has the authority to revise the gate allocation, if necessary. Similarly, for data elements in (b), whenever an FOO makes a gate allocation to a flight, or alters the gate allocation made earlier for a flight, that information is immediately becomes public. Also, whenever an airline's work team vacates a gate after work for the flight that arrived/departed from that gate is finished, then the airline enters this gate vacating information into the Daily Log Sheets Database to inform the FOS. Basically, airlines provide inputs of the latest flight information and gate status into the DSS, and in return, they get the gate allocation and the status of gates through the system. With the information from the Daily Log Sheet Database, the FOS serves as the central controller to allocate gates to flights.

The Automatic Data Processing and Decision Support by the Gate Allocation Engine

The Gate Allocation Engine serves dual purposes, to prepare the data relevant for the gate allocation decision and actually to make such decisions for the FOOs to endorse or to revise. Using the latest flight and gate information, the Gate Allocation Engine generates the set of gates that will be available for assignment to flights, and the time at which they will be available; in the planning interval. Then, it generates all the constraints and the objective function for the model to determine gate allocations for flights during the planning interval. Finally, it solves the model and generates the gate allocations. The FOOs can then look it over and manually make any changes needed. Once the system is in operation, the whole process to generate and update gate allocations should take no more than one or two man-days of FOO time per day.

10. Summary of Preliminary Results Obtained at TPE and Expected Benefits From the DSS

At TPE, at present volume of traffic, most flights are allocated a gate in sufficient time before their landing or takeoff even during peak periods, and the waiting time on the taxi-ways after landing for most flights is within 10-15 minutes; and the need for a plane to circle the airport on arrival is extremely rare. During peak traffic periods some planes wait after landing on the taxiway for up to 30 minutes, but the percentage of flight planes that have to wait more than 20 minutes on the taxiway is small.

Most of the flights (over 95%) are assigned gates within their 1^{st} and 2^{nd} preference categories. For over 90% of flights on a normal planning day, the gate allocation made for it during the previous day remains unchanged.

As the traffic volume is growing, this research is motivated by a desire to plan for the future to get the best utilization of existing facilities; and to provide decision support help to the FOS to make better quality decisions.

Besides reducing the manual effort to generate/update gate allocations, the results obtained from this DSS are expected to be of much better quality in terms of OBJ 1, than those obtained by the current heuristic approach while maintain the current level of OBJ 2 as can be seen in Table 1. A preliminary computational study, using data retrieved from TPE’s computer system in February 2007, indicates that the revised on-line heuristic approach is able to reduce OBJ 1 if the traffic level remains about the same as today. However, as the number of flights increases, the proposed assignment models will give better results. Thus, TPE will benefit from this DSS when the airport reaches its designed capacity in the near future. Our computational experiments indicate that the number of planes waiting on taxiway after landing, and those waiting for more than 10 minutes during peak times are zero for all approaches.

	Revised On-line Heuristic	Heuristic used in Current Practice	Proposed Assignment Models
OBJ 1 for the day	127	130	131
OBJ 1 for peak time	77	70	67

Table 1. OBJ 1 for the three approaches. OBJ 2 is zero for each of these approaches.

11. Conclusions

In this paper we described an ongoing project at TPE for developing a DSS to allocate gates to flights; discussed the approach and mathematical model to use for gate allocation decisions, and implementation of the proposed mathematical models in the DSS. As in the case of other major international airports, the gate allocations to flights at the TPE are planned in an uncertain environment. The ability to deal with uncertainty in the data elements is critical to the quality of gate allocation plan despite the occurrences of unforeseen events. The quality of gate allocation 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. While the airport authority may not fully realize the importance of dealing with uncertainty to the operational efficiency, they generally agree that uncertainty need to be taken into account in making the gate allocations. The large scale combinatorial nature of the gate allocation problem; the stochastic nature of the flight arrival/departure times; the need for quick and quality decisions; necessitates the development of a robust gate allocation model that is simple to use, and one that generates solutions that have the property of flexibility to changes of input data that airports and airlines demand.

The rescheduling of gate allocations due to flight schedule disruptions is a hard problem to solve by conventional mathematical models because of the limited time available for it. Since the number of flights involved is typically not high, FOOs are able to handle these heuristically using on-line heuristic approaches discussed earlier. In this paper, we proposed a rolling horizon framework for dealing with the uncertainty continuously during the course of the gate allocation process for TPE, which also includes manual adjustments of the solution produced by the model by FOOs. Although this work is still an ongoing project, the strategy proposed in this paper for developing the DSS is generally favored and approved by the TPE officials. Soon after the computer program is fully developed, a full scale side-by-side comparison will be conducted and statistics on various objectives will be collected and compared to validate this model. For security and safety reason, full implementation and integration with TPE's current information system will be done by the TPE's own IT team in the near future.

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