A SIMULATION MODEL FOR AIRPORT GATE ASSIGNMENT

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abstract: This paper presents the results of a simulation model for airport gate assignment. Data from the C.K.S. international airport was used to develop the model. Four heuristic assignments were employed for comparison. They are assignment by 1. scheduled aircraft arriving time, 2. gate occupancy time, 3. number of passengers onboard, and 4. minimum elapse time between aircraft departure and arrival. The Spline statistical analysis method was also used to model characteristics of aircraft arrival pattern, on-time performance, impact of aircraft size on gate occupancy time, etc.

1. INSTRUCTION

In recent years, the economic growth has caused dramatic increase in aviation demand in Taiwan as well as in Asia. Both international and domestic airports in Taiwan have reached their full capacities. Therefore, it is necessary not only to expand the facilities but also to improve efficiency of airport operations to meet the future challenge.

The facilities which affect airport landside capacity include runway, gate-apron, terminal building, etc. Capacity determination at terminal building is a combination of hardware handling capabilities and passengers perception which is a relative subjective issue. Uses of runway and gate-apron are determined by both air traffic safe regulation and facility configuration. On contrary to terminal building, runway capacity and gate-apron capacity are relative simple to estimate. For most of the airports, such as New York Kennedy airport and Chicago O'Hare airport, configuration of airport terminal building is either in finger type or satellite type which provides sufficient gate-aprons to serve airplanes. Therefore, gate-apron seldom becomes a bottleneck. However, at linear (or frontal) type airport, the number of gate-aprons are limited and often become a bottleneck. Because modification of the airport layout is often difficult, it is thus necessary to improve utilization of existing facilities by management. Table 1 illustrates usage of airport facilities for most of Asian international airports. It is seen most Asian airports have bottleneck occurred at either terminal building or gate-apron.

Airport gate and apron are two sides of a coin. To passenger, it is gate. To aircraft, it is apron. In order to improve management of the gate and to study impact of gate assignment on airport operations, this study developed a simulation system to investigate those possible gate assignment methods. As analysis of gate-apron assignment problem includes viewpoints from passengers, airline, and airport administration, this study considered only influence of the following factors: 1. of airplane dimension, 2. concourse walking distance, 3. airplane arrival schedule and pattern, 4. gate-occupancy time, and 5. waiting delay.

This study first used the data from Chiang Kai-Shek (C.K.S.) international airport to analyze characteristics of current gate use and to employ spline regression technique to develop gate use statistical models. Thereafter, the spline model and SlamII simulation language (SLAMSYSTEM 1990) are used to develop a simulation system in order to conduct analysis for the proposed four assignment algorithms.

Table 1. Asian International Airport Facility Utilization Index

Airport	Runway	Terminal	Gate-Apron
Thailand Bangkok	75	92	111
Singapore Changi	61	63	58
Hong Kong Kai Tak	107	164	100
Korea Seoul	88	80	73
Japan Narita	100	138	161
Taiwan CKS	67	95	90
Taiwan Kaohsiung	60	200	150

Note: Unit: %, when utilization factor greater than 100%, airplanes were parked on remote aprons, Source(IOT 1993, IATA 1989)

2. AIRPLANE GATE USE CHARACTERISTICS

In statistics, there are linear regression, polynomial regression, nonlinear regression, etc. to model data of interest. However, these regression methods are unsatisfactory to fit data with significant variation. The technique of spline regression was thus developed to fit curves for such kinds of data(Eubank 1988).

In an airport, airplanes often run into many unpredictable situations, such as mechanic failures, human errors, weather changes, etc., which might prevent landing or departure of an aircraft. When such situations occur, gate occupancy time is changed. The distribution of gate occupancy time thus forms a very special shape. Common regression techniques become inappropriate to depict airplane gate phenomena and therefore the spline regression is employed to model them.

2.1 Arrival Time Analysis

Figure 1 illustrates airplane arrival times at C.K.S. airport on a Saturday. It is learned that there were two peaks. The first peak occurred from 12:00 a.m. to 00:30 p.m. and the second peak was from 3:00 p.m. to 3:30 p.m. The shape of the plot also tells that such a distribution is difficult to fit a smooth curve.

Because the peak hours of an international airport are dependent on its geographic location in the globe and are influenced by fleet management of an airline company. The schedule of an international airport might and indeed will change from day to day. In this research, it was assumed that the arrival/departure schedule had no significant change in a week to simplify development of the simulation system. Such an assumption was statistically tested with Chow Test. After checking the residuals, degree of freedom, and F test value, the null hypothesis can not be rejected(Lin 1993). With such an assumption, the spline model for airplane arrival was established as formula (1) in Table 3.

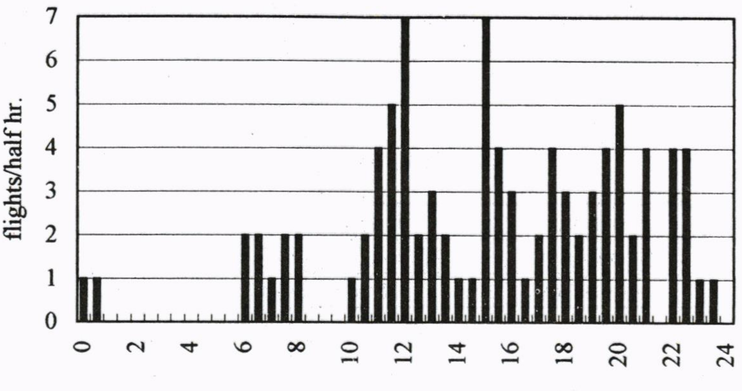


Figure 1. Airplane Arrival Distribution

2.2 On Time Performance Analysis

Figure 2 illustrates the deviation of airplane arrivals compared to their planned schedule. The average deviation is 2.36 minutes per flight. Formula (2) of Table 3 is the deviation model developed by this study.

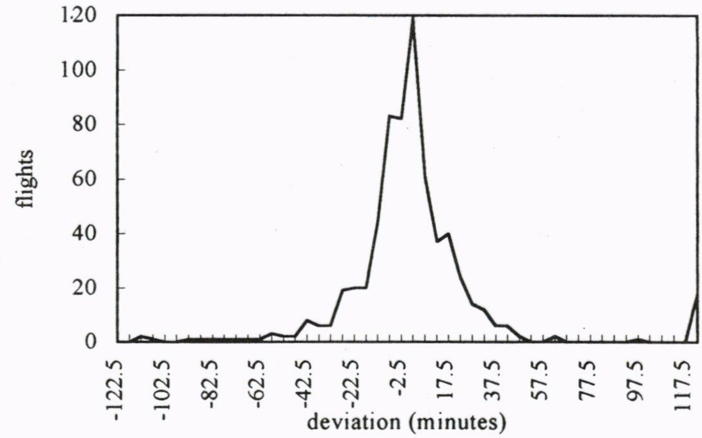


Figure 2. Airplane Arrival Deviation

2.3 Gate Occupancy Time Analysis

Table 2 lists the statistical analysis of gate occupancy times for all studied 647 flights. The times range from as less as 0.3 hour to as high as 37.43 hours. Because the number of passengers onboard an airplane is a major factor which impacts airplane gate occupancy time and available seats of an airplane is a factor of aircraft size, this study classifies airplanes into 4 categories. They are 1. Boeing 747 series airplanes, 2. MD 11, DC 10 size airplane, 3. Boeing 757 midsize airplane, and 4. ATR72 small size airplane. Formulas (3), (4), (5), and (6) of Table 3 present the spline models developed to depict gate occupancy time.

Table 2 Gate Occupancy Time

Attributes	Occupancy Time
Maximum	2,246 min.(37.43 hrs.)
Minimum	18 min.(0.3hr)
Middle	325 min.(5.42hrs.)
Mean	226.08min. (3.77hrs.)
Quantile	60~69min.(101/647)
Standard Deviation	307.07min.(5.12hrs.)

Total number of flights: 647

Table 3 summarizes the application output of SAS (Statistical Analysis System) spline technique to model airplane gate characteristics at C.K.S. airport. The spline models established for gate occupancy characteristics at C.K.S. include (1) flight arrival accumulation model, (2) arrival time deviation model, and (3) gate occupancy time model. Because airplanes are classified in four categories in this study, there are models for each type of aircraft.

Table 3. Flight Gate Use Characteristics

(1) daily flight arrival accumulation model	
$A(t)=0.83+0.64t-0.05t^2+0.54(t-5.3)^2-0.63(t-12.58)^2$	(1)
(2) arrival time deviation model	
$A(t)=271.36+7.59t+0.05t^2+0.12(t+23.71)^2-0.23(t+9.14)^2$	(2)
(3) gate occupancy time model, B747, large size, mid-size, and small size airplane	
$A(t)=5.32-1.17t+0.03t^2-0.05(t-67.86)^2+0.02(t-143.66)^2$	(3)
$A(t)=14.86-2.87t+0.07t^2-0.09(t-52.67)^2+0.03(t-131.48)^2$	(4)
$A(t)=1.16-0.13t+0.01t^2-0.02(t-81.69)^2+0.02(t-109.71)^2$	(5)
$A(t)=0.17-0.16t+0.01t^2-0.01(t-33.46)^2$	(6)

Use formula (1) as an example to explain meaning of the spline models in Table 3:

$A(t)$: number of accumulated arrival flights from time zero to time t

If $A(t)<0$, then $A(t)=0$

If $t>5.3$, then $(t-5.3)>0$, if $t \leqq 5.3$, then $(t-5.3)=0$

If $t>12.58$, then $(t-12.58)>0$, if $t \leqq 12.58$, then $(t-12.58)=0$

3. MODEL DEVELOPMENT

Currently, there are 22 gates in the C.K.S. airport. The 22 gates are evenly divided along the North and South concourses. Each concourse has 11 gates. Gates 1-3 (12-14) and 9-11

(20-22) on North concourse (on South concourse) are gates with space only sufficient to accommodate small size aircraft. Gates 4-8 (15-19) have sufficient space to accommodate large size aircraft such as Boeing 747. They are centered along gate 6 on North concourse or gate 17 on South concourse.

The current practice of C.K.S. gate assignment is that each airline company submits its next day flight plan to airport's flight planning department before 6:00 p.m. each day. Staff of the airport then assign gate to each scheduled arrival airplane. The assignment principle is that Boeing 747 is assigned to gate 6 or gate 17 first, then other airplanes are assigned to gates whichever is closer to gate 6 or gate 17 according to their arrival schedule.

To develop a simulation model for the system, three sub-models as shown in Figure 3 were first developed. They are 1. gate basic characteristics sub-model, 2. airplane arrival/departure sub-model, and 3. gate assignment sub-model. The basic characteristics sub-model stands for the layout of the gates and gate time safe separation requirement. When formula (1) is used to generate an arrival of an aircraft, aircraft type, number of passengers onboard, gate occupancy time, and departure time is determined by the arrival/departure sub-model. Gate-assignment sub-model is used to assign an arriving airplane to a suitable gate according to the assignment algorithm.

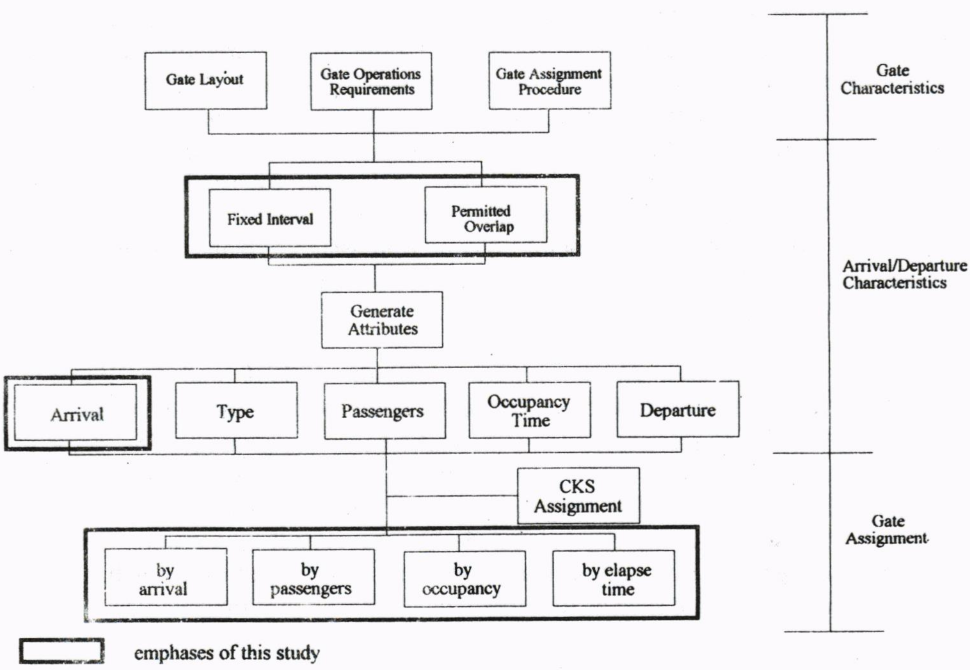


Figure 3. Structure of Gate Assignment Simulation

In order to develop possible gate assignment methods to improve effectiveness of gate operation, four kinds of assignment principles were referred(Gosling 1990, Mangoubi R. *et al* 1985, McCabe L. *et al* 1975, Joao A. *et al* 1990) and their models developed respectively. Definitions of the four assignments and their objectives are explained as follows.

1. by arrival schedule
   This is the first come first serve principle. It is simple and its objective is to assign an arrived airplane to an available gate which has the shortest walking distance to the administration area of the terminal building..
2. by gate occupancy time
   This is to assign airplane with short occupancy time first to the best gate (minimum walking distance). The purpose of such an assignment is to increase turn over rate of the gates which have short walking distance.
3. by number of passengers onboard
   This is to assign airplane with the most onboard passengers first to the best gate (minimum walking distance). The objective of this assignment is to minimize total walking distance.
4. by minimum elapse time between gate use
   This is to assign airplane by arrival schedule. However, an airplane is assigned to a gate which just has an aircraft left. The time between a departing airplane and an arriving airplane is thus minimized. The objective of such an assignment is to minimize the number of gates used and to maximize usage of each gate chosen. Large time span is then created at other gates for aircraft to use.

4. MODEL VERIFICATION

To verify development of the model, this study did two comparisons. The first comparison is to check if the assignment sub-model follows the principle it is required to achieve. Table 4 illustrates comparison result of the assignment sub-model. It is learned that programming of the sub-model can truly represent the actual requirement. The second comparison is to test the simulation model. It is to see if the complete system as Figure 3 is reliable to carry out the desired analysis. Actual gate use data and flight schedules of three days in a week were employed to help verify the system. There were data of a Saturday, a Sunday, and a Monday. The C.K.S. principle was used to assign airplanes to gates. Then simulation assignment followed. Figure 4 shows the result from simulation assignment and from actual assignment by using Monday data.

For the 22 gates, average gate usage from true data was 36.19%, and 36.21% from simulation. The deviation is only 0.05%. To further compare each individual gate, it is seen from Figure 4 that gates 6 and 17 have the highest simulation usage. The shape of usage curve gradually subsides away from the central gates of 6 and 7. The simulated result conforms the described C.K.S. assignment principle and verifies correctness of the system. However, practical usage data revealed that the central gates were not fully utilized. This was explained by situation that there were occasions those gates had to be reserved for special purpose use such as for airline which carried the country's flag.

Table 4. Verification of Gate Assignment Sub-model

Gate	Actual Usage	Simulation	Gate	Actual Usage	Simulation
1	27.43	27.43	12	20.14	20.14
2	37.85	37.85	13	26.04	26.04
3	37.50	37.50	14	40.63	40.63
4	26.04	26.04	15	00.00	00.00
5	56.25	56.25	16	44.79	44.79
6	52.08	52.08	17	37.54	37.54
7	50.14	50.14	18	38.54	38.54
8	30.97	30.97	19	28.82	28.82
9	70.83	70.83	20	34.46	36.46
10	17.01	17.01	21	46.53	46.53
11	35.76	35.76	22	34.72	34.72

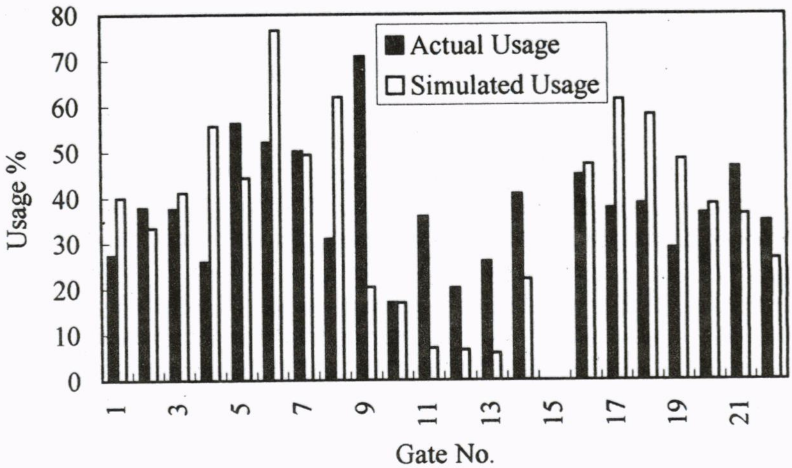


Figure 4. Gate Usage

5. ASSIGNMENT METHODS ANALYSIS

5.1 Fixed versus Overlapped Time Interval

In order to increase gate capacity as well as gate use effectiveness, this study included the factor of airplane gate separation time in analysis. The impact of the fixed time interval and the permitted overlap time is investigated. Fixed interval is gate separation time of an airport which is a requirement of the gate operation and is modeled in airplane arrival/departure sub-model (Figure 3). Overlapped time exists on when gate separation restriction is relaxed. Figure 5 explains the definition of the fixed time interval and the permitted overlap time. Sensitivity analysis of airplane separation time on a gate includes test of the following two groups of combined situations.

1. Combination of the current 30 minutes fixed time interval, and 0, 5, or 10 minutes permitted overlap time.
2. Combination of the 20 minutes fixed time interval, and 0, 5, or 10 minutes permitted overlap time.

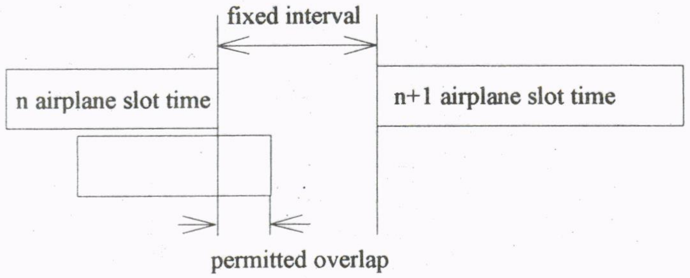


Figure 5. Fixed safe interval versus permitted overlap

To evaluate performance of each assignment method to identify their pros and cons, this study selected 1. total walking distance, 2. total onboard passenger delay, 3. the number of gates used, 4. usage of the two central gates, and 5. average usage of the 10 large size gates as the indexes for system appraisal(Mumayiz 1991, Ashford 1988, Martel N. *et al* 1990, Wang 1992). The first and second indexes have to use formulas (7) and (8) to compute their indexes. Others have to be computed during the system simulation process. After indexes of all simulation runs were completed, they were divided by the smallest index in each group to calculate a relative weight. The relative weights of the five performance items were then summed. Table 5 displays how weight is calculated and summed. Figure 6 illustrates performance review after 150 system simulation runs. For system performance ranking, because the five evaluation indexes selected are all negative utilities, the lower the index the better the system performs. Summation of the relative weight is used to rank performance of the assignment methods which is also the lower the better. In addition to ranking of the assignment methods, the maximum gate capacity simulated for each assignment method is presented in Table 6.

$$MinZ = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=BK(i)}^{EK(i)} P_i D_j X_{ijk} \tag{7}$$

$$MinZ = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=BK(i)}^{EK(i)} P_i T_{ij} X_{ijk} \tag{8}$$

$ST.$

$$\sum_{j=1}^{J} \sum_{K=BK(i)}^{EK(i)} X_{ijk} = 1 \qquad \forall i$$

$$\sum_{i \in N_{jk}} \sum_{l=BK(i)}^{k} X_{ijl} \le 1 \qquad \forall j,k$$

$$X_{ijk} = 0,1 \qquad \forall i,j,k$$

i : flight number *Dj*: gate *j* walking distance *Ek(i)*: flight *i* final departure time
j: gate number *Tij*: delays of flight *i* at gate *j*
k: time slot *Xijk*: =1 if flight *i* is assigned to gate *j* at time slot *k*, =0 if others
I : number of flight *Njk:* flight set which might use gate *J* at time interval *k*
J: number of gate
K: flight departure time *BK(i)* : the earliest departure time which flight *i* could use
*P*i: number of passengers onboard flight i

It is seen from Figures 6.1 and 6.4 that when permitted overlap is zero, assignment by arrival schedule ranks the best. Literature(Lin 1993) also points out that when overlap is not allowed, there will have no flight arriving an airport but have to wait until a gate is available. Therefore, there has no waiting delay, index 2 is zero. In addition, the central gate has a high usage; the total walking distance, index 1, is not much higher than those of other assignment methods. Therefore, the overall performance index ranks the best for assignment by arrival schedule. However, when permitted overlap is allowed, not zero, assignment by arrival schedule causes serious waiting delay. The assignment method then loses its advantage. The best ranked assignment method is then replaced by the passenger onboard assignment principle, such as plots shown on Figures 6.2,6.3,6.5,6.6. The key factor which affects overall performance is total onboard passenger waiting delay. Because, assignment by passengers minimizes total waiting delay and the method also performs above average on other indexes, the method outperforms other methods.

In addition to the analysis above, it is learned from Figures 6.2, 6.3, 6.5, 6.6 that the assignment method by arrival schedule becomes the second worst assignment method when permitted overlap times exist. Simulation output shows that this method easily causes passenger waiting delay when overlap time is permitted.

Table 5. A Sunday Indexes Summation Example

	C.K.S. principle	by arrival schedule	by occupancy time	by passengers onboard	by minimum elapse time
total walking distance	1.04	1.05	1.13	1.00	1.29
total waiting delay	1.00	1.00	1.00	1.00	1.00
no. of gates used	1.00	1.00	1.00	1.00	1.00
usage of the best gate	1.08	1.00	1.52	1.14	3.63
average usage of the large size gates	1.17	1.00	1.30	1.10	1.55
summation	5.29	5.05	5.95	5.24	8.47
ranking	3	1	4	2	5

Note: indexes were obtained by simulation under 30 minutes fixed time interval and no permitted overlap time

When overlap time is permitted, the best assignment method is assignment by passengers onboard. Because when overlap time is permitted, index of waiting delay is crucial which makes the most difference. Assignment by passengers assigns first the airplane with the most passengers, thus its waiting delay is the least. On the contrary, assignment by occupancy time is the method to assign airplane with the shortest occupancy time first, so it is contrary to the method of assignment by passenger. This method is easy to cause delay, and might even has the situation occurred in which an arrived airplane have to wait for a gate on taxiway because all aprons are occupied. The capacity of such an assignment is the lowest among all four methods, which is seen in Table 6.

Table 6. Simulated Service Capacity by Assignment Methods

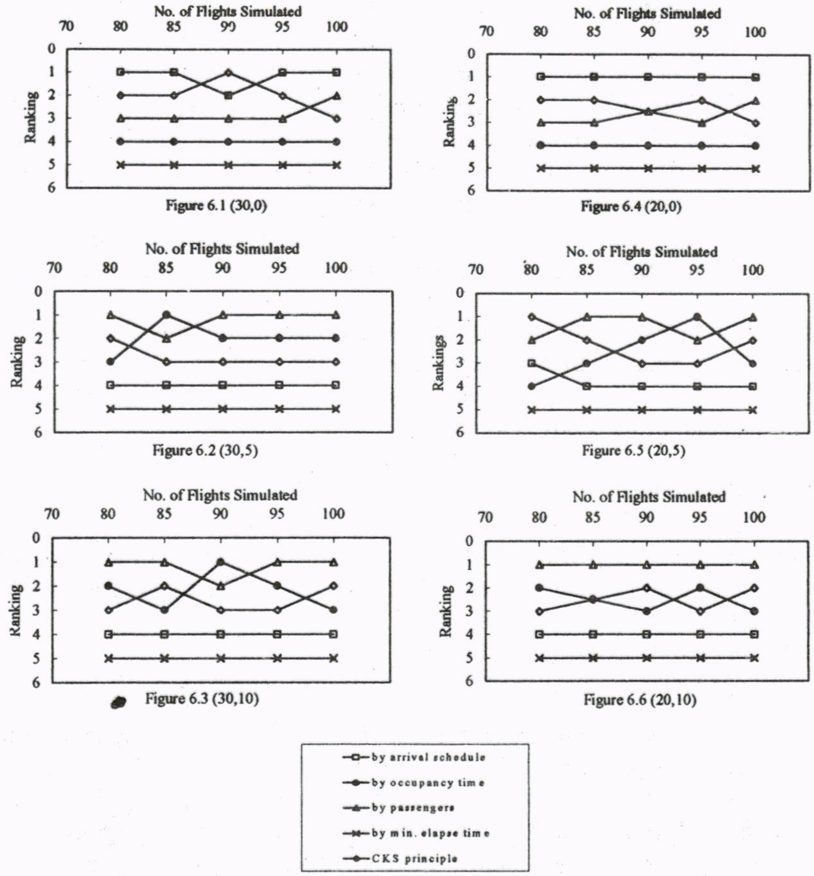
permitted overlap	Assignment Methods			
30 min. fixed interval	by arrival schedule	by occupancy time	by passengers onboard	by minimum elapse time
0 min.	104	104	104	104
5 min.	107	105	107	107
10 min.	110	110	110	110
20 min. fixed interval	by arrival schedule	by occupancy time	by passengers onboard	by minimum elapse time
0 min.	104	104	104	104
5 min.	110	110	110	110
10 min.	113	112	113	113

capacity unit: number of flights according to arrival pattern

Of the four assignment methods, assignment by minimum elapse time has never really displayed its feature to achieve any advantage in performance index. It is because this method tries to increase gate utilization and capacity by assigning airplane to the gate which will minimize waste of available gate time. However, this method in C.K.S.'s frontal gate layout does not fully utilize the central gates 6 and 17. Walking distance is increased and waiting delay easily generated, thus the overall performance is the worst.

This study also found that the simulated capacity of each assignment method is almost the same, as illustrated in Table 6. Capacity increases only when overlap time is permitted. It is because airplane arrival pattern in simulation followed the existing pattern and airplane arrival pattern is influenced by airline fleet management which is less controllable by an airport's operations. Even section 4 of this paper tells that the average rate of gate utilization is only 36.2%, which implies time is available to accommodate more aircraft arrival, once the peak arrival increases, there occurs bottleneck at gate. Gate capability to serve daily arrival aircraft can be increased only if its peak demand can be satisfied. Therefore, in order to increase capacity, airplane arrival pattern has to be changed(Lin 1993, Hwang 1993).

Figure 7 shows the 15 minute gate demand with daily arrival of 105 flights in which gate fixed interval is set to be 30 minutes, no overlap is allowed; the current C.K.S. practice. It is seen that at the time interval between 10:30~10:45 a.m., the gate demand has exceeded the current C.K.S. gate capacity of 22.



Note: (30,0) 30 minutes fixed interval , 0 minute overlap time

Figure 6. Assignment Evaluation Diagram

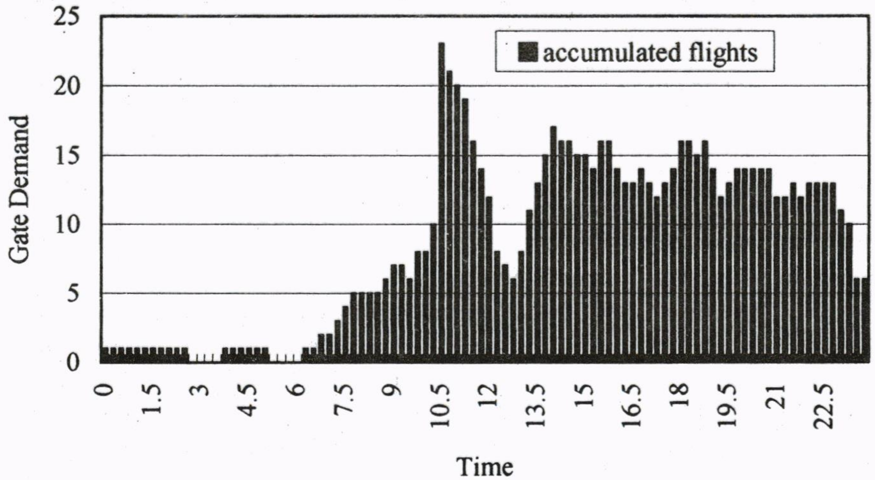


Figure 7. Gate Demand Time Diagram

5.2 Arrival Time Sensitivity Analysis

Most gate assignment studies assume airplane arrive on time(Gosling 1990, Mangoubi R. *et al* 1985, Asian Technical Consultants, Inc., 1992, Mckelvey 1988, Dring H. *et al* 1990), however, there are a lot of interference during arrival, departure, or cruising of an airplane. Although the average deviation of the studied 647 flights from schedule is only 2.36 minutes, it is still uncertain if an airplane can be on time. It is therefore necessary to learn the impact of assignment method on airport gate operations when airplane arrival deviating from schedule. An assignment method must be adaptive to such kind of situation.

Because it is difficult to see the impact of aircraft arrival deviating from its schedule in the previous section, this section of the paper applies the formula (2) spline model to specifically study the performance of each assignment method under the deviation situation. The procedure of the study is as follows:

1. assign each airplane to gate by schedule
2. assign each airplane a deviation time by formula (2)
3. assuming an early arrival will not affect the scheduled departure time of an airplane; however, if an airplane is late, its gate occupancy time will remain the same and its departure time will be delayed accordingly
4. calculate the times and passengers influenced
5. compute the total conflict index (conflict index=waiting passengers x waiting time)

Simulating of the condition set above, the impacts of arrival time and assignments methods on system performance is presented in Table 7. In this study, a conflict index is used to evaluate the system. The index is defined as the product of waiting passengers and waiting time. It is seen from Table 7 that the total conflict is not directly proportional to the number of flight simulated. It only shows a positive relationship. However, the total conflict is significantly affected by assignment methods.

Table 7. Arrival Time Sensitivity Analysis

-30 minutes fixed interval, no overlap

flights simulated	by arrival schedule	by occupancy time	by passenger onboard	by minimum elapse time
80	27,747 (3)	20,383 (2)	14,873 (1)*	46,487 (4)
85	54,726 (3)	19,796 (1)	42,944 (2)	63,605 (4)
90	47,420 (3)	12,394 (1)	45,253 (2)	68,044 (4)
95	66,223 (3)	40,053 (1)	45,593 (2)	89,441 (4)
100	78,462 (3)	32,975 (1)	34,293 (2)	96,524 (4)

-30 minutes fixed interval, 5 minutes overlap

flights simulated	by arrival schedule	by occupancy time	by passenger onboard	by minimum elapse time
80	43,725 (3)	36,235 (2)	21,751 (1)	59,356 (4)
85	54,545 (2)	29,497 (1)	57,682 (3)	86,035 (4)
90	59,110 (2)	16,066 (1)	60,183 (3)	91,795 (4)
95	71,815 (3)	69,478 (2)	50,869 (1)	105,573 (4)
100	96,073 (3)	41,251 (1)	55,798 (2)	149,838 (4)
105	131,275 (3)	36,459 (1)	85,362 (2)	152,051 (4)

-30 minutes fixed interval, 10 minutes overlap

flights simulated	by arrival schedule	by occupancy time	by passenger onboard	by minimum elapse time
80	52,472 (3)	29,367 (1)	38,750 (2)	96,530 (4)
85	86,965 (3)	60,074 (2)	47,584 (1)	141,629 (4)
90	116,091 (3)	70,462 (1)	94,420 (2)	139,271 (4)
95	110,069 (3)	65,082 (1)	70,139 (2)	119,715 (4)
100	143,613 (3)	92,271 (2)	55,894 (1)	160,353 (4)
105	163,850 (3)	58,290 (1)	92,427 (2)	185,142 (4)

Note: the values in the table are the total conflict index (unit: person*minute), and the values in parentheses are the order of ranking

The smaller the conflict index in Table 7 means the lower the conflict and the better the ranking of the assignment. From the order of ranking, it is seen that the method of assignment by passenger onboard or assignment by occupancy time have better capability to adapt to the deviation of airplane schedule. The reason is that the two assignment methods assign airplane to gate starting from the central gate(Lin 1993), therefore, gate slot time is not tightly bundled. Usage of each gate is not high and sufficient time has been left between use of two consecutive airplanes. Therefore, these two kinds of assignments can absorb the impact of airplane early/late arrival from schedule. Nonetheless, once overlap time is permitted, some time slot which was not originally allowed to accommodate an airplane can now be used. When overlap time increases, the total conflict index also increases significantly. Table 7 proves the thinking that a tightly assigned gate has difficulty to adapt to the change of arrival schedule.

5.3 Strategy Analysis

To investigate the direction of gate assignment improvement for the C.K.S. airport, this study prepared the following two scenarios and tested their operation performances.

(i) a 30 minutes fixed interval with 10 minutes permitted overlap time
(ii) a 20 minutes fixed interval with no permitted overlap

Development of the two improvement scenarios is based on the philosophy that currently C.K.S. airport require a 30 minutes fixed interval with no permitted overlap allowed between use of two consecutive airplanes. Therefore, to increase gate capacity, it needs either to decrease fixed interval or to permit overlap. Thus the two scenarios were proposed.

According to description of section 5.1, when overlap is permitted, assignment by passengers onboard outperforms other methods, and when overlap is not allowed, assignment by arrival schedule outperforms other methods. This study thus chose these two methods to conduct simulation for the proposed scenarios. The result is presented in Table 8.

Table 8. Strategy Analysis

by Passengers Onboard			by Arrival Schedule		
flights simulated	Scenario (i)	Scenario (ii)	flights simulated	Scenario (i)	Scenario (ii)
80	4.00	4.26	80	4.00	4.26
85	4.00	4.30	85	4.00	4.25
90	4.11	4.27	90	4.03	4.26
95	4.02	4.14	95	4.10	4.22
100	4.00	4.26	100	4.00	4.36

Note: the values in Table are relative performance indexes, the lower the better

It is seen from Table 8 that scenario (i) a 30 minutes fixed interval with 10 minutes permitted overlap in both assignment methods outperforms scenario (ii) a fixed interval of 20 minutes with no overlap. The direction of improvement for gate operations is then revealed.

6. CONCLUSION AND RECOMMENDATION

This study employed the airplane arrival characteristics from C.K.S. airport to develop spline regression models to describe airplane operation features at gate-apron system. A simulation system was then developed by Slam II simulation language to provide tool for system performance evaluation and improvement scenario development. Four assignment methods in addition to the current C.K.S. practice were tested on walking distance, waiting delay, and gate usage. Other factors such as airplane arrival on-time performance and if overlap time is permitted on fixed interval are also studied. Overall this study has reached the conclusion and recommendation as follows:

(1) overlap time sensitivity analysis

At fixed interval with no overlap time, assignment by arrival schedule outperforms other assignment methods (Table 6 and Figure 6). However, when overlap restriction is relaxed, assignment by passengers onboard outperforms other assignment methods. The key factor is that when assignment with overlap permitted the index of waiting delay causes relative large difference.

(2) capacity sensitivity analysis

At C.K.S. airport, there has current 22 gates. Without change of airplane arrival pattern or occupancy time, peak demand will exceeds the capacity of 22 gates (Figure 7) when daily arrival is as high as 105 flights. Therefore, even though the average daily usage of gate is only 36.2%, the gate can rarely accommodate any more increase of arrival airplane. Possible management improvement for operational practice is to 1. modify the pattern of airplane arrival, 2. reduce airplane gate occupancy time. The may able be achieved by change of service fee structure, namely, peak pricing. Another method is to construct a new terminal building to increase gate number.

(3) on-time performance sensitivity analysis

A good assignment method must be able to adapt to the deviation of airplane arrival. This study testes the adaptability of each assign method. It is found that if the assignment by passengers onboard and assignment by occupancy time are put in a group, the assignment by arrival schedule and assignment by minimum elapse time are put as another group, the former group always outperforms the latter group. The primary reason is that the assignment plan prepared by the former group is not tightly arranged. Therefore, they are better to adapt to the deviation of arrival schedule.

(4) strategy analysis

Two scenarios were proposed and tested by this study: scenario (i) a 30 minutes fixed interval with 10 minutes overlap and scenario (ii) a fixed 20 minutes interval with no overlap. The former always outperforms the latter (Table 8). The former scenario better utilizes the central gate which minimizes walking distance, thus its sum of indexes is better.

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