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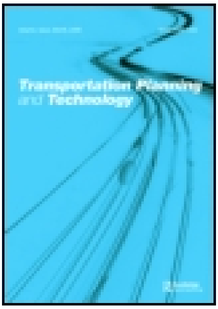

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Development and application of an airport terminal simulation model — a case study of CKS airport

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DEVELOPMENT AND APPLICATION OF AN AIRPORT TERMINAL SIMULATION MODEL – A CASE STUDY OF CKS AIRPORT

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Technology advancement, terminal user behavior and changes of service characteristics of terminal facilities all have great impact on airport terminal operations. Consequently, the adequacy of traditional airport terminal planning concepts and standards have recently been challenged and are worth being explored.

To investigate the associated impact of environmental changes on terminal operations, a simulation model which takes into consideration air travel patterns, facility operational characteristics, flight delays, passenger behavior and needs, etc. is developed and verified. The simulation logic and results show that the model works well for the case of CKS (Chiang Kai-Shek International Airport, Taipei) operations. Also, the exploration demonstrates that passenger arrival patterns, numbers of group passengers, flight delays and load factors all have very significant influences on terminal space requirements. This result strongly suggests that local characteristics should not be neglected in planning terminal operations.

Keywords: Airport terminal; Simulation; Space requirement

1. INTRODUCTION

In general, passenger behavior, flight delays and service characteristics are not taken sufficiently into account in the airport terminal planning process. Terminal space requirement is roughly set by means of standard formulae or procedures. As a result, terminal space is often not adequate for actual operations.[1,2] In reality, passengers may arrive

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much before their flight time due to the inconvenience of the ground access system. Flights may be delayed due to weather conditions or airport congestion. In such cases, passengers may overcrowd the terminal. Therefore, if these related factors are not carefully explored during the planning process, the terminal may be operated in a less than acceptable manner. It will be either not fully utilized or overcrowded. It is for this reason that in this study a variety of factors, along with their impact on terminal operations, are investigated.

An airport terminal is an air transportation facility. Transportation is its very basic and most important function. It provides convenient processing, mode transfer and a comfortable holding area for air passengers.[3] To meet the service requirement, there must be adequate terminal facilities and space. Traditionally, these facilities and space are directly related to the number of passengers and are used only for transportation purposes. However, airports are becoming more than just a place for aircraft to land and take off. In a modern airport, commercial space not directly necessary for air transportation is attracting great attention. Increasingly, airports around the world are shifting to private ownership. With sparkling shopping malls, high-rise hotels and connecting business plazas, some airports have evolved into commercial hubs for surrounding communities, competing against nearby metropolitan centers for travelers' cash once spent mostly downtown. One example is Frankfurt Airport in Germany. Housing a hotel and convention center under one roof, it aims to create an "airport city" with sophisticated urban functions. The other example is Amsterdam Schiphol Airport in the Netherlands. Its terminal includes a hotel, tax-free shopping center, a business center with relevant facilities, etc. Yet another example is Changi Airport in Singapore. It has around 100 shops in terminals 1 and 2. The facility is like a huge shopping center. Aside from the shops, restaurants, hotel and other facilities also contribute to the mini-city atmosphere. In the case of Taiwan's Chiang Kai-Shek International Airport, the plan is that it will also be converted into an "airport city" as part of the government's intention to make Taiwan a regional operations center. As a consequence, these land-side facilities are becoming the major source of income for many major international airports.

More commercial space available in an airport may be a trend. However, there are no hard and fast rules to follow. Utilization of

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this space is very much dependent on the philosophy of the airport management. It completely depends on the airport operator's decision. When it is considered desirable to provide more space for duty-free shopping, recreation, and business offices, an airport terminal requires more space. In other words, the space for ancillary facilities varies with the business goals of the airport operator.

For transportation planners, their major concern is the impact of environmental changes on terminal operations and the associated space requirement. Therefore, the main theme of this paper will focus on passenger traffic characteristics and their impact on terminal operations. Furthermore, inbound and outbound operations in the CKS (Chiang Kai-Shek, Taipei) terminal are separate. They can be analyzed independently. Since outbound operation is much more affected by external factors, in this study we will focus only on the space and facilities needed for processing, circulation and waiting of outbound passengers.

2. FACTORS AFFECTING TERMINAL SPACE REQUIREMENT

Terminal space includes processing, holding, circulation and ancillary units. After reviewing the relevant literature,[1-8] we recognize that most studies do not consider comprehensively factors that affect these terminal space requirements. Empirical and statistical formulae are commonly applied to size individual processing facilities within the terminal building.[2,4] A simple queueing approach with the assumptions of Poisson arrival and exponential service time distribution is frequently adopted.[5-7] However, the arrival and service patterns vary with the time of day. They cannot adequately be described as having a fixed distribution. Besides, some important factors cannot be carefully taken into account in the queueing approach. As a result, the simple queueing approach and statistical formulae may not be appropriate for space requirement decision-making. To plan these space units properly for passengers at a specified 'level of service' (LOS), one should clearly understand the various factors which affect the space required (only for transportation purposes) and how the space is affected.

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These factors include:

(i) *Passenger flow* Given a set of terminal operating conditions, peak occupancy and waiting time in a terminal is simply determined by the peak passenger flow. Thus, the most important element in computing terminal space is peak-hour passenger flow into and out of the terminal. To estimate the number of peak passengers, US-FAA has suggested a ratio of typical peak hour passengers (TPHP) to annual passengers as shown in Table I. However, this may differ significantly from the actual number. The actual number of peak-hour passengers is based on actual flight schedules which are determined by many factors such as market demand, availability of aircraft, etc.

(ii) *Passenger characteristics* Passenger characteristics include passenger arrival patterns and passenger behavior in the terminal. Different passenger characteristics will result in different terminal space occupancy.[1,2] Ashford[10] has pointed out that passengers on different flight routes may have different arrival patterns. Similar results were found in our survey. Table II reveals that passengers with different trip purposes, ground access times and personal characteristics exhibit many differences in their preferred terminal arrival time. Passengers on European/Australian routes arrive at the terminal much earlier than those on other routes. This is because most passengers surveyed on European/Australian routes were traveling as leisure/group passengers. On the contrary, passengers on the Hong Kong route arrive at terminal not so early as their counterparts on other routes. This is because of the very high frequency on the route and a cooperative agreement between China Airlines and Cathay Pacific Airways. Once a flight has been missed, a passenger can get a seat soon on another flight without much difficulty. As to the behavior of group passengers, who share a great proportion of the market, an even greater difference is found. Table III

TABLE I Ratio of TPHP to annual passengers[11]

Annual passengers	*TPHP/Annual passengers* (%)
≥ 20,000,000	0.030
10,000,000–19,999,999	0.035
1,000,000–9,999,999	0.040
500,000–999,999	0.050
100,000–499,999	0.065
< 100,000	0.120

TABLE II Arrival patterns of passengers on different flight routes

Flight route	*Arrival time before flight departure* (min)	
	Mean	*Standard deviation*
Hong Kong	81.5	28.3
Japan	110.6	33.4
North American	103.6	31.8
European/Australian	147.1	28.5

TABLE III Arrival patterns of individual and group passengers

Type of passenger	*Arrival time before flight departure* (min)	
	Mean	*Standard deviation*
Individual	97.4	30.1
Group	162.5	12.9

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shows this difference is statistically highly significant. Group passengers are asked to arrive at the terminal much earlier. They generally arrive at the terminal together by chartered bus. The earlier the passengers arrive at the terminal, the longer they occupy the terminal space. Consequently, to maintain a reasonable level of service when there is a large number of group passengers, providing more space should be considered. This implies that passenger characteristics should be seriously taken into account.

(iii) *Service characteristics* Along with technology advancements and revolutions in airport management, airport operators frequently introduce new facilities and operating strategies to improve terminal service quality and solve capacity deficiency problems. Because of such changes, passengers must adjust their patterns of behavior while using the terminal. For example, common use of terminal equipment reduces waiting time at the check-in counter. It also reduces the time passengers may spend in the check-in lobby. The use of smart cards for ticketing, check-in and security checks will further reduce the processing time and increase the passenger flow rate. If a terminal is further equipped with an efficient people-mover, the time needed to process its air passengers will be significantly reduced. Momberger[12] has pointed out that a passenger can complete the whole process within 45 minutes if new technology is applied in the terminal. Thus, change of operating characteristics should not be ignored.

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(iv) *Flight delays* When flight delays occur, a terminal will be crowded with not only passengers for scheduled flights but also passengers of delayed flights. Those delayed passengers obviously utilize more terminal space than originally envisaged. Jovanovic[13] analyzed Ljubljana Airport flight delays and concluded that the probability of a change in the flight departure sequence is about 9.26%. The number of passengers in the central hall will accordingly increase between 50% and 80%. Our study, employing flight delay data from CKS airport,[14] shows that the number of peak passengers in the check-in area based on actual flight departures is 9.12% *more* than the number based on the flight schedule with no delays taken into account. Since the possibility of flight delays cannot be eliminated, it is better to have this factor considered in determining the amount of terminal space.

(v) *Design standard (LOS)* Planned LOS for future terminal operation is one of the key factors in determining adequate space. The higher the LOS is set, the more space should be allocated. Traditionally, terminal space planned by traffic engineers is based on studies for other modes of transportation. However, those facilities are different from the airport terminal facility.[15] Davis and Braaksma[16] developed a standard for passengers moving from one area to another within the transportation terminal as shown in Table IV. Ashford[17] reviewed standards for a variety of airport terminals. It appeared that standards for different airports were different. The space for each passenger varied from 1 to 3 m^2. Since this has a great influence on the terminal space requirement, an airport authority should consider LOS, cost and its goal very carefully so as to make a more informed decision.

TABLE IV Platoon flow LOS criteria for transportation terminals[16]

LOS	*Speed* (m/s)	*Flow* (ped./min/m)	*Area module* (m^2)
A+	≥ 1.4	≤ 37	≥ 2.3
A	1.3 ~ 1.4	37 ~ 46	1.7 ~ 2.3
B	1.2 ~ 1.3	46 ~ 57	1.3 ~ 1.7
C	1.1 ~ 1.2	57 ~ 68	1.0 ~ 1.3
D	1.0 ~ 1.1	68 ~ 75	0.8 ~ 1.0
E	0.7 ~ 1.0	75 ~ 57	0.7 ~ 0.8
F	≤ 0.7	≤ 57	≤ 0.7

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3. TERMINAL SIMULATION MODEL

A terminal consists of well-organized space units. These are linked on the basis of passenger handling procedures. In order to manage and apply the simulation model, the whole model is divided into four parts as shown in Fig. 1. The first part is from the terminal entrance to the entrance of the emigration procedures area. The second part is from the entrance of the emigration procedures area to the security-check area. The third is from the security-check area to the entrance of the departure lounge. The last part is from the entrance of the departure lounge to the boarding ramp.

Based on the known or simulated flight schedule, aircraft type, load factor and passenger arrival pattern, a variety of passenger-related characteristics are generated. Every minute, passenger activities and the movement in each block of the terminal are scanned and the related statistics are computed.

To be clear, the logic of our simulation model is described as follows. Since every block of the simulation model consists of procedures for processing, holding and circulation, it is worthwhile addressing the concept of passenger handling in these three space units. First, to handle the passengers at the processing facility, service policies governing the number and time of counter opening and closing are set on the basis of a field survey. Given the passenger arrival pattern and the facility service policy, the passengers are processed and move within the terminal during the course of the simulation period. Second,

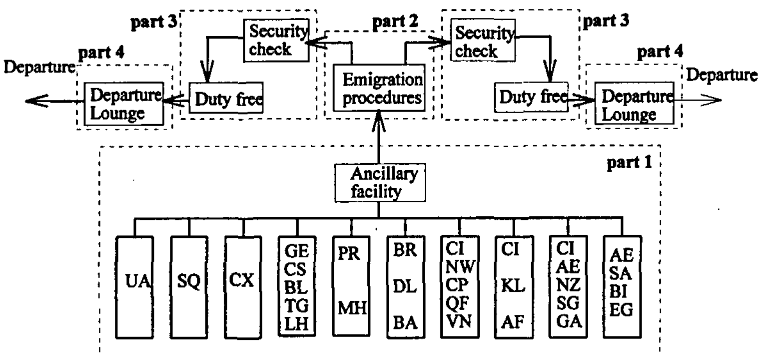

FIGURE 1 The simulation model structure.

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to assess passengers using ancillary facilities such as shops and restaurants, a survey is conducted so as to collect information about how passengers spend slack time. The survey result is then used for the model input to simulate passenger activities in the ancillary facility. With minute-by-minute scanning set in the simulation model, time variation of space occupancy and passenger flow at the relevant area and facility can thus be recorded and analyzed.

4. MODEL VERIFICATION AND VALIDATION

Simulating terminal space requirement involves many complex variables. On any given day, passengers are arriving continuously for check-in, emigration procedure, security check, etc. The occupancy of space in every unit is continuously changing. Uncontrollable factors alter the simulation result. Due to these uncontrollable factors such as flight delay, passenger arrival pattern and passenger characteristics, etc., it is hard to control very accurately the parameters of the model input. Consequently, it is difficult to validate the model output. Nonetheless, the model can be verified by tracing the simulation output. After verifying the correctness of the model logic, we use the data collected from the field to validate the model. By tracing the model output, we find the pattern of open and closed check-in counters well within our expectations. Moreover, compared with the number of passengers computed from flight timetables, the outputs of passenger flow and occupants of associated spaces also have expected results.

Finally, we validate the model via comparison between the real data and the model outputs of passenger arrival patterns both at the terminal entrance and the boarding area. The results are shown in Figs. 2 and 3. Estimates of R^2 of the simple regression equations equal 0.77 and 0.93, respectively. Moreover, if the simulated results fit perfectly to the observed, the coefficients of the regression equation should equal 1. As expected, both t values suggest that under 95% confidence level, the hypothesis that the coefficients are equal to 1 could not be rejected. Furthermore, we adopted Theil's inequality coefficient.

If $U=0$, there is a perfect fit. If $U=1$, the predictive performance of the model is as bad as it possibly could be. The U values of the

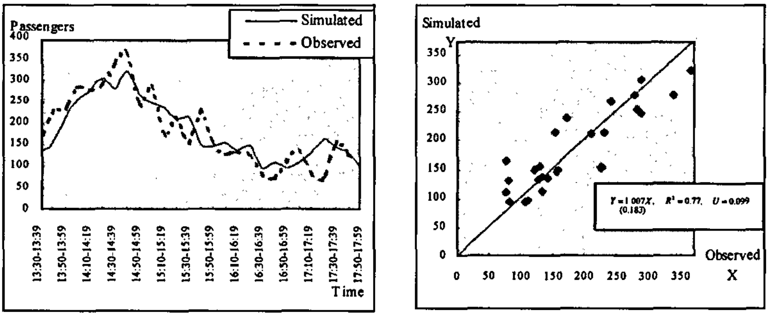

FIGURE 2 Passenger arrival at the terminal entrance.

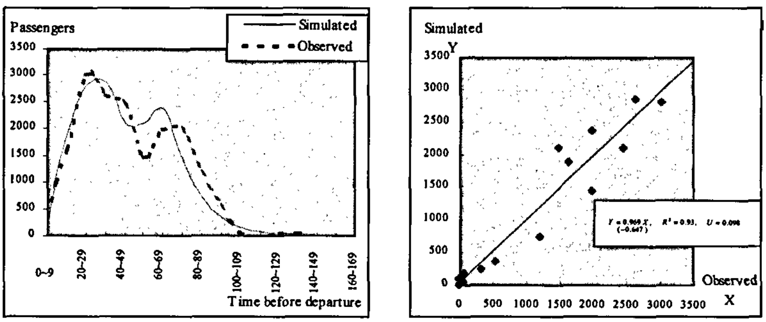

FIGURE 3 Passenger arrival at the departure lounge.

simulated results shown in Figs. 2 and 3 are 0.099 and 0.098, respectively. From these results and statistics, we can see that the simulation model works satisfactorily. In the following section, we will apply it to analyze the impact of various affecting factors.

5. MODEL APPLICATION

Factors to be investigated include annual number of passengers, route distribution, load factor, group passenger and arrival pattern. The basic input of the experiments is listed in Table V, which corresponds to the 1995 survey situation. The flight schedule of the representative case will be applied through the experiments except those cases listed in Table VI. In those cases, the timetables are generated on the

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TABLE V Basic input of the simulation experiments

Item	*Input*
Annual outgoing passengers	6.5 million
Regional flights : intercontinental flights	80% : 20%
Load factor	60%
Arrival pattern of group passengers	260–95 min
Arrival pattern of individual passengers	180–15 min
No. of group passengers : No. of individual passengers	50% : 50%
No. of male : No. of female	70% : 30%

TABLE VI Outputs of flow and occupant for various annual passengers

Annual outbound passengers (million)	0.5	1	5	10	20	30	40
Occupant (pax)							
Check-in area	162	303	1277	2588	5626	7950	10492
Ancillary area	67	174	868	1601	3167	4620	6391
Emigration procedures	19	32	145	318	665	916	1238
Departure lounge	116	204	583	1191	2542	3642	4586
Flow (pax/h)							
Check-in	166	32	1481	2759	5684	8453	11454
Emigration area	227	349	1685	3365	6855	9914	13377
Departure lounge	227	319	1618	3349	6732	9812	13329

same pattern as the existing timetable. The simulation results are summarized in Tables VI–X. Some points drawn from these tables are stated briefly below:

(i) The increases of terminal occupants and passenger flow are approximately proportional both to the increase of annual passengers and to the increase of load factors.

(ii) Differences of peak passenger flow and occupants among cases with different ratios of intercontinental flights may reach as high as 30% or more.

(iii) The proportion of group passengers in a terminal will have a tremendous impact on the space requirement. It, however, has far less impact on the peak passenger flow.

(iv) The passenger arrival pattern also has very significant impacts on the space requirement. Similarly, it has only little impact on the peak passenger flow.

(v) Table VIII shows that since during peak season the load factor can reach as high as 90% or more, the check-in area – which at CKS occupies 2336 m^2 – can be crowded with more than 2500 passengers. This means the space allotted to each passenger

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during the peak period is less than 1 m^2. The terminal obviously is operating at near capacity. Again, this result meets the current terminal situation. To alleviate congestion, a second terminal is under construction and scheduled for operation in 1999.

TABLE VII Outputs of flow and occupant for various route distributions

Region/Inter-continental flights	100:0	90:10	80:20	70:30	60:40	50:50	40:60	30:70	20:80	10:90	0:100
Occupant (pax)											
Check-in area	2215	1828	1767	1838	2025	1868	2171	2170	2069	2457	2419
Ancillary area	1312	1178	997	1082	1133	1242	1213	1334	1355	1507	1533
Emigration procedures	246	230	197	190	209	209	205	243	233	257	280
Departure lounge	904	835	837	790	1090	967	1000	1145	1157	1202	1480
Flow (pax/h)											
Check-in	2193	1816	1743	1971	2090	2071	2149	2149	2226	2524	2503
Emigration area	2589	2088	2128	2151	2408	2421	2666	2627	2472	2582	2981
Departure lounge	2544	2108	2119	2178	2404	2467	2687	2623	2482	2806	2929

TABLE VIII Outputs of flow and occupant for various load factors

Load factor	60%	70%	80%	90%	100%
Occupant (pax)					
Check-in area	1691	1938	2225	2568	2940
Ancillary area	1076	1166	1387	1460	1677
Emigration procedures	201	218	231	257	339
Departure lounge	807	960	1061	1151	1658
Flow (pax/h)					
Check-in	1723	2095	2208	2580	3040
Emigration area	2007	2313	2377	3006	3672
Departure lounge	2094	2346	2317	3017	3659

TABLE IX Outputs of flow and occupant for various ratios of group passenger

Ratio of group passenger	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Occupant (pax)											
Check-in area	653	850	1066	1197	1434	1683	1804	2093	2672	2926	2945
Ancillary area	931	968	997	1008	1019	1111	998	1057	996	837	881
Emigration procedures	195	210	195	189	196	202	197	196	220	190	205
Departure lounge	431	535	717	643	761	790	788	1031	1016	1083	1064
Flow (pax/h)											
Check-in	1822	2029	1976	1748	1749	1731	1718	1749	1749	1752	1765
Emigration area	1985	2215	2151	2014	2033	2048	2011	2211	2124	2127	2148
Departure lounge	2188	2331	2291	2058	1998	1995	1944	2162	2130	2011	2020

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TABLE X Outputs of flow and occupant for various passenger arrival patterns

Time of the first arrival (minutes before departure)	*Group*	260	230	200	170	140
	Non-group	180	150	120	90	60
Occupant (pax)						
Check-in area		1863	1478	1241	889	626
Ancillary area		1006	1069	951	951	888
Emigration procedures		216	209	194	190	198
Departure lounge		886	666	591	468	415
Flow (pax/h)						
Check-in		2058	1786	1884	1760	1708
Emigration area		2514	2074	2363	1995	2084
Departure lounge		2489	2142	2474	2160	2233

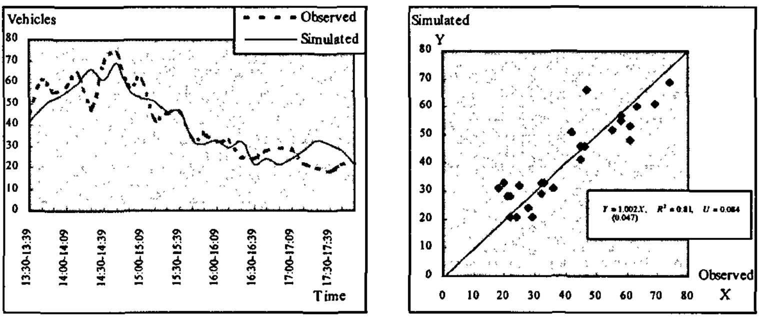

FIGURE 4 Vehicle arrival at the curbside.

In addition, this simulation tool was applied to curb planning. Simulating passenger arrivals and thus transferring them to vehicle arrivals, we then can assess curb utilization demand. To demonstrate applicability of the model, a case study was conducted. The results from the volume count and simulation are shown in Fig. 4. Again, it suggests that the performance of the model is acceptable.

6. CONCLUDING REMARKS

The simulation results demonstrate that the traditional procedures used by traffic engineers may not be in agreement with real operations. It also implies that the transferability of planning standards and procedures should be very carefully examined. Local conditions should be deliberately incorporated, especially for those airports with a large proportion of group passengers.

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During the study process, we found that searching a set of inputs which can represent the airport conditions may be difficult but is nevertheless important. Since the various changes can have significant impacts on terminal operation, current operations may not be appropriate for the model input. Therefore, it is always worth pondering over the input issue when a terminal simulation is to be used.

Setting a planning guidance suitable for most airports is an important task. The key, however, lays in the understanding of the related factors and their impacts. Thus, more simulation runs with careful examination and interpretation are urgently needed.

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