



Dynamic allocation of check-in facilities and dynamic assignment of passengers at air terminals

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ABSTRACT

This study explores the dynamic allocation of check-in facilities and dynamic assignment of passengers at air terminals to achieve the objectives of minimizing total waiting time and better utilization of facilities. Taking into consideration different check-in services required by departing passengers, adjustments to allocations are made according to the maximum allowable wait time and the lowest service counter utilization rate allowed for the initial allocation condition. The developed model was validated for its feasibility and applied at the Taoyuan International Airport, Taiwan. The application results showed that dynamic allocation of check-in facilities can both reduce waiting times and increase service counter utilization rates. Such benefits can be further enhanced by dynamic assignment of passengers.

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1. Introduction

Along with incessant growth in world population, there is a concomitant increase in the number of air passengers. From 2003 through 2008 there was a significant 40% growth in total volume of air passenger (International Civil Aviation Organization, ICAO, 2008). However, global economic changes, such as the 2008 financial tsunami, and the emergence of new types of pandemic diseases have also caused a marked decrease in air travel. Hence, airline operators not only have to handle these demand fluctuations with dynamic assignments of fleets and facilities, but simultaneously seek ways to provide good service, and even enhance passenger satisfaction. Diversified check-in facilities offer many advantages to air passengers, such as enabling them to choose seats that meet their needs, preventing congestion and delay at check-in counters, and reducing check-in times. With better and more efficient check-in services, passengers have more free time for leisure while waiting for departure, which can mean more business opportunities and greater profits for commercial enterprises located at air terminals (Hsu & Chao, 2005). As such, airline operators should optimize check-in facilities both for cost minimization and passenger satisfaction. In view of these issues, this study explores the dynamic allocation of check-in facilities and dynamic assignment of passengers at air terminals.

Between arrival at the airport and boarding the flight, air passengers have to go through passenger and baggage check-in, security check, as well as immigration and customs. Among these routine formalities, security checks, as well as immigration and customs, are carried out on all crew and passengers as standardized procedures in accordance with regulations for national security and flight safety. In contrast, passenger and baggage check-in procedures vary depending on the operations of different airlines and airports. However, restricted timeframes for check-in before departure, limited numbers of available check-in counters, and special facilities provided for privileged passengers, such as first-class passengers or members of certain loyalty programs, may result in delays for other passengers. This not only damages the reputation and image of airports and airlines, but also affects the rights and interests of passengers. Therefore, effective and efficient utilization of resources to meet the check-in needs of air passengers has become an important issue for both airport and airline operators.

Kiosks (automated self-service check-in machines) are designed as one form of airport infrastructure, and act as a (i) time saver for passengers, (ii) cost saver for airlines, and (iii) space saver for airports (International Air Transport Association, IATA, 2006). Self-service technologies have already been extensively implemented in the airline industry and the IATA estimated common-use self-service (CUSS) savings of US\$2.50 per check-in. With a 40% market penetration at every airport, the total annual industry savings add to US\$ 1 billion (Lott, 2005). A passenger self-service survey done by Société Internationale de Télécommunications Aéronautiques and Air Transport World (SITA/ATW) in 2009, however, indicated

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that no more than half of the passengers departing from the airports surveyed used self-service check-in (Karp, 2009). Of passengers who did not use self-service check-in options, many cited the need for checking baggage, which requires the assistance of an agent, as the main deterrent.

The airline industry employs a variety of self-service technologies, including kiosks, and online and mobile check-in technologies. Self-service check-in saves time for passengers and reduces operating costs for airlines (Weiss, 2006). As a result, more airlines plan to increase the number of self-service check-in kiosks and offer web and mobile check-in services (Jenner, 2009). In view of continuous growth in air transportation and increasing demand for self-service check-in, new facilities and strategies have been proposed with the objective of simplifying check-in procedures and minimizing the time required. Beginning in 2006, the SITA has conducted an annual self-service survey for passengers of different nationalities (SITA, 2009). Results of past surveys reveal increasing acceptance of self-service check-in facilities; in particular, online check-in and self-service check-in kiosks. In sum, studies focusing on passengers' needs for check-in services are still lacking. As a result, current facilities and services often fall short of meeting passengers' expectations or enhancing their satisfaction.

Literature on the issue of check-in facilities mainly concerns approaches to achieving more efficient check-in procedures. Research approaches previously employed include the queuing theory, system simulation, integer and dynamic planning, as well as experimental designs. Topics that have been explored include queuing time and space, walking distance, queuing methods, and allocation of facilities. For example, Parlar and Sharafali (2008) employed the queuing optimization approach to dynamic allocation of check-in counters; and Yan, Tang, and Chen (2004) proposed a model and a solution algorithm for assignment of flights to check-in counters. Taking into consideration the time and number of check-in counters to be opened, queuing length, waiting time and baggage-belt loading, Chun (1996) developed a constraint-satisfaction problem (CSP) algorithm to solve the check-in counter scheduling problem.

Following that, Chun and Mak (1999) applied intelligent resource simulation to check-in counter allocation. Yan et al. (2004) established three binary integer planning models and a solution algorithm for airport common-use check-in counter assignments. However, their models did not take into consideration the fluctuations in number of check-in counters available. Using binary integer planning and simulation in combination, Dijk and Sluis (2006) computed and optimized the number of check-in counters and the duration of open time needed for each flight. Bruno and Genovese (2010) proposed some models for determining the optimal number of check-in counters to be opened for departing flights, so as to balance operation costs of the service and passenger waiting time at the terminal. Stolletz (2010) addressed operational models for workforce planning for check-in systems at airports. He characterized different tasks of the hierarchical workforce planning problem with time-dependent demand. Finally, the assignment and reassignment of check-in counters to flights were analyzed with respect to archiving service levels (see Duin & Van der Sluis, 2006; Parlar & Sharafali, 2008; Yan, Tang, & Chen, 2008).

From the overview above, it is evident that past studies focused mainly on analyzing the allocation of counters and staff for passenger check-in and seldom explored different check-in facilities and various types of check-in services required by departing passengers. According to the four types of check-in services, namely ticket purchase, check-in, boarding pass, and checking baggage, this study developed seven combinations of services required by departing passengers. Taking into consideration current check-in facilities, including counter, kiosk, online and barcode check-in, we developed a model for allocation of check-in counters and self-service check-in kiosks at different time points according to

the criteria of maximum waiting time and lowest service counter utilization rate allowed. Applying the model can enable passengers to spend less time on check-in and help airlines save human resources and operation costs.

This study reviews currently available check-in facilities and analyzes the operation strategies of airline operators. A model is formulated for dynamic allocation of check-in facilities and assignment of departing passengers to minimize waiting time for check-in and to reduce operation costs of airlines. The developed model is validated on its feasibility and applied at the Taoyuan International Airport, Taiwan. The results obtained can serve as useful references for airline and airport operators. The rest of the paper is organized as follows: Section 2 details the model formulation; Section 3 validates the developed model, and Section 4 presents its application. Finally, Section 5 contains the conclusion of this study and suggestions for future research.

2. Model formulation

This study explores the operation and planning of check-in facilities with different durations of open times for check-in. A model was developed for dynamic allocation of various check-in facilities and dynamic assignment of passengers with the target of minimizing waiting time for passengers. Let d denote a check-in facility and D denote all check-in facilities provided by an airline. With reference to the literature and operations of different airlines, current check-in facilities include counter check-in, self-service check-in kiosks, online check-in, and barcode check-in. If an airline offers all four check-in facilities, then $D = \{c, k, o, b\}$, where c , k , o , and b denote each of the abovementioned check-in facilities, respectively. Let T denote the total duration of the open time periods of check-in facilities. If an airline opens its check-in facilities for service between 15:00 and 18:00, then $T = 180$ (min). Let N be the total number of passengers arriving for check-in when the facilities are opened for service, where $n = 1, 2, 3, \dots, N$ indicates the order of their arrivals, and the arrival time of the n th passenger for check-in is t^n . For example, for the 10th passenger arriving at 15:30, $t^{10} = 30$. The needs of check-in passengers are divided into four types, namely ticket purchase, check-in, boarding pass, and checking baggage. Table 1 lists the types of services available at different check-in facilities.

According to the four types of check-in services, this study came up with seven different service combinations, as listed in Table 2. As can be seen, counter check-in is the most versatile. Counter check-in offers all service combinations, while barcode check-in can only issue a barcoded boarding pass. Self-service check-in kiosks cannot provide ticket purchase, while online check-in cannot meet the need for checking baggage. Services offered by online and barcode check-in are rather limited and their operation does not involve any physical facility. Hence, the subsequent model formulation and case analysis involve only counter and self-service check-in kiosks.

2.1. Check-in time formulation

When planning dynamic allocation of check-in facilities, model formulation of the total service time for passenger check-in is

Table 1
Different check-in facilities.

Types of services	Counter	Kiosks	Online	Barcode
Ticket purchase	V		V	
Check-in	V	V	V	
Boarding pass	V	V	V	V
Checking baggage	V	V		

Table 2
Combinations of services provided by different check-in facilities.

Types of services	Combinations of services						
	1	2	3	4	5	6	7
Ticket purchase	█						
Check-in		█					
Boarding pass			█	█			
Checking baggage					█	█	
Types of facilities							
Counter	V	V	V	V	V	V	V
Kiosks			V	V	V	V	V
Online		V		V		V	
Barcode						V	

required. In this study, total service time comprises two elements, namely processing time and waiting time. Processing time refers to the total time required for completing the check-in procedure; while waiting time refers to the time spent on queuing at the check-in facility while preceding passengers complete the check-in procedure. The sum of the processing time and waiting time equals total service time for passenger check-in. For passengers with carry-on baggage or who require no baggage check-in, and those with a boarding pass printed online or who have a barcode boarding pass, there will be no waiting time at check-in facilities. Upon arrival at the airport, they can proceed through security, as well as immigration and customs, with their travel documents. The model formulated in this study includes only total service time for passengers at physical check-in facilities, including check-in counters, self-service check-in kiosks, and barcode scanners, and does not take into account any service time at non-physical check-in facilities. For passenger requiring check-in service j at a check-in facility d , the average processing time is P_{dj} . Hence, for the n th passenger arriving for check-in at t^n , the waiting time at the i th counter of d is $W_{di}(t^n)$ and the total service time S_{dj}^n for the n th arriving passenger requiring check-in service j at d can be formulated as

$$S_{dj}^n = P_{dj} + W_{di}(t^n), \quad d \in D. \tag{1}$$

Passenger waiting time refers to the time a passenger stands in a queue at d before being assigned to the i th counter of d for check-in service. Let F_{dji}^n be the time when the n th arriving passenger requiring check-in service j finishes the check-in procedure at the i th counter of d . F_{dji}^n can be formulated as

$$F_{dji}^n = t^n + P_{dj} + W_{di}(t^n), \quad d \in D, \tag{2}$$

where t^n is the arrival time of the n th passenger for check-in. Let I_{dji}^n be the binary variable indicating whether the n th arriving passenger requiring check-in service j is to be assigned to the i th counter of d , if yes, then $I_{dji}^n = 1$; otherwise, $I_{dji}^n = 0$. For the scenario of multiple queuing lines, according to the first-in-first-out (FIFO) service mechanism, the waiting time of the n th arriving passenger at the i th counter of d , $W_{di}(t^n)$, is the maximum completion time of the one between the 1st and $n - 1$ th passenger at the i th counter of d , (i.e. $\text{Max}(F_{dji}^{n-1}I_{dji}^{n-1}, F_{dji}^{n-2}I_{dji}^{n-2}, \dots, F_{dji}^1I_{dji}^1)$), minus the arrival time of the n th passenger for check-in t^n . With the minimum waiting time being 0, $W_{di}(t^n)$ can be formulated as

$$W_{di}(t^n) = \text{Max}[\text{Max}(F_{dji}^{n-1}I_{dji}^{n-1}, F_{dji}^{n-2}I_{dji}^{n-2}, \dots, F_{dji}^1I_{dji}^1) - t^n, 0], \tag{3}$$

$$d \in D, n \in N, j \in J, i \in X_d.$$

At airports around the world, queuing lines at check-in facilities can be either single or multiple. For the scenario of single queuing line, the waiting time of the n th arriving passenger in the queue can be calculated as follows. First, let k be the maximum check-in completion time of all passengers arriving before the n th passenger. $k - 1, k - 2, \dots, X_d, \dots, 1$ would then denote their check-in completion times arranged in descending order, where X_d is the number of check-in counters opened for service. Then let I_{dj}^n be the binary variable indicating whether the n th arriving passenger requiring check-in service j is to be assigned to facility d , if yes, then $I_{dj}^n = 1$; otherwise, $I_{dj}^n = 0$. Hence, the waiting time of the n th passenger at facility d , $W_d(t^n)$, is the sum of all check-in completion times ranked before X_d (i.e., $F_{dj}^k I_{dj}^k + F_{dj}^{k-1} I_{dj}^{k-1} + \dots + F_{dj}^{X_d} I_{dj}^{X_d}$) divided by X_d , minus the arrival time of the n th passenger for check-in t^n . With the minimum waiting time being 0, $W_d(t^n)$ can be formulated as

$$W_d(t^n) = \max \left\{ \frac{F_{dj}^k I_{dj}^k + F_{dj}^{k-1} I_{dj}^{k-1} + \dots + F_{dj}^{X_d} I_{dj}^{X_d}}{X_d} - t^n, 0 \right\}, \tag{4}$$

$$d \in D, \quad n \in N, \quad j \in J,$$

$$F_{dj}^k I_{dj}^k \geq F_{dj}^{k-1} I_{dj}^{k-1} \geq \dots \geq F_{dj}^{X_d} I_{dj}^{X_d} \geq \dots \geq F_{dj}^1 I_{dj}^1$$

2.2. Dynamic passenger assignment model

This study developed the dynamic assignment model for passengers at check-in facilities with reference to the approach developed by Nikolaev, Jacobson, and McLay (2007). In their study, passenger and carry-on baggage-screening operations were modeled as a Sequential Stochastic Assignment Problem (SSAP), the objective of which was to maximize the total security of all passenger-screening assignments over a fixed time period. Unlike Nikolaev et al. (2007), who classified passengers into different categories according to their relative risk levels, our study classified passengers by their service types. The following four assumptions are made.

- (1) The cumulative probability curve of passengers arriving at the airport from the time check-in service is available to the designated departure time is known and can be obtained using an on-site survey.
- (2) The capacity and assignment constraints of different check-in facilities are known.
- (3) According to the type of check-in service required, passengers are assigned to different service facilities.
- (4) All passengers are required to check in once.

The model formulated in this study aims to minimize passenger check-in time and the number of check-in facilities required. The model is composed of two elements. First, under the constraint of limited resources, the model optimizes the number of check-in facilities to be opened for service. Second, it minimizes the total service time for the n th randomly arriving passenger assigned to receive check-in service j at d . In other words, the model's target is minimization of $S_{dji}^n I_{dji}^n A_{dj}$. As mentioned above, S_{dji}^n is the total service time for the n th arriving passenger requiring check-in service j at the i th counter of d . Let $S_{dji}^n I_{dji}^n A_{dj}$ be the product of I_{dji}^n , which denotes whether the n th arriving passenger requiring check-in service j is to be assigned to the i th counter of d and A_{dj} , which denotes whether check-in facility d can provide service combination j . Let A_{dj} be given a value of 1, meaning that check-in facility d can provide service combination j . Otherwise, A_{dj} is given the highest value of 99 so as to prevent the model from assigning passengers to a check-in facility that cannot meet their needs. For instance, counter check-in can provide all seven service combinations listed in Table 2; hence, A_{C1} to A_{C7} are all given a value of 1. On the contrary, self-service kiosk check-in cannot provide ticket purchase service; hence, service combinations 1 and 2 (A_{K1} and A_{K2}) have the maximum value of 99, while service combinations 3–7 (A_{K3} to A_{K7}) that can be provided by self-service check-in kiosks are given a value of 1. The model aims to determine two decision variables. They are the binary variable indicating whether the n th arriving passenger requiring check-in service j is to be assigned to the i th counter of d , I_{dji}^n , if yes, then $I_{dji}^n = 1$; otherwise $I_{dji}^n = 0$, and the number of check-in facilities to be opened for service, X_d . Then the passenger assignment model formulated for different opening time periods can be expressed as follows:

$$\text{Min } \sum_{n=1}^N \left[\sum_{i=1}^{X_d} \sum_{d \in D} S_{dji}^n I_{dji}^n A_{dj} \right], \quad j \in J, \quad (5)$$

$$\text{s.t. } S_{dji}^n = P_{dj} + W_{di}(t^n), \quad d \in D, n \in N, j \in J, i \in X_d, \quad (6)$$

$$\sum_{d \in D} \sum_{j=1}^J \sum_{i=1}^{X_d} I_{dji}^n = 1, \quad n \in N, \quad (7)$$

$$\sum_{n=1}^N \sum_{j=1}^J \sum_{i=1}^{X_d} I_{dji}^n \leq X_d T_d M_d / 60, \quad d \in D, \quad (8)$$

$$\sum_{n=1}^N \sum_{j=1}^J \sum_{i=1}^{X_1} P_{dji} I_{dji}^n \leq X_d T_d, \quad d \in D, \quad (9)$$

$$X_d \leq X_d^{\max}, \quad d \in D, \quad (10)$$

$$I_{dji}^n \in \{0, 1\}, A_{dj} \in \{1, 99\}, X_d \in Z^+,$$

where T_d , M_d , and X_d denote the total duration of the opening time periods, the service capacity per hour, and the number of check-in facilities d assigned, respectively. Eq. (7) indicates that each passenger can check-in only once. Eq. (8) suggests that the capacity of check-in facility d assigned must be greater than or equal to the total number of passengers assigned by the model to use check-in facility d . Eq. (9) holds to ensure that the total processing time of passengers assigned by the model to use check-in facility d must not exceed the total operation time of check-in facilities d allocated for service. Eq. (10) assures that the check-in facilities assigned cannot exceed the maximum check-in facilities made available due to space or human limitations.

3. Model validation

To validate the contribution and value of the developed model in a practical application, a comparison is made between actual selection of check-in facilities by departing passengers and dynamic assignment of passengers according to the model. Data

regarding check-in facilities actually selected by departing passengers at Taoyuan International Airport were collected through an on-site questionnaire survey conducted from April 5–25, 2010. Counter check-in was available for service from 3 h to 40 min before flight take-off; that is, for a duration of 140 min. On average, there were 6 check-in counters and 9 self-service check-in kiosks open for service within that timeframe. The total number of valid survey responses was 197, excluding passengers who arrived outside the servicing hours of counter check-in and responses with incomplete data. Table 3 summarizes the distribution of departing passengers in terms of their arrival times for check-in and the service(s) they required.

As regards dynamic assignment of passengers, the developed model is solved using binary integer programming (BIP), and other variables including passenger waiting time, system waiting time, and service completion time are also solved. When calculating passenger waiting time, information concerning the arrival time of a given passenger and service completion time of the preceding passenger are required. In other words, we need to solve $N!$ (i.e., $N \times N - 1 \times \dots \times 2 \times 1$) variables. Case analysis reveals that computation time is faster when the number of passengers is less than 15. For a scenario with 15 or more passengers, the solution process is time-consuming and may take at least 3 h.

Dynamic assignment of passengers was modeled as a sequential stochastic assignment problem (SSAP), and was shown to be NP-hard by constructing a polynomial Turing reduction from the integer knapsack problem (IKP) (Garey & Johnson, 1979; Nikolaev et al., 2007). In view of the huge computational load and time-consuming calculations, the clustering algorithm (Liao, 2005) is adopted as an auxiliary tool to enhance the solution speed. In this study, all passengers arrive in a random sequence and are served by check-in facilities on a first-come-first-served (FCFS) basis. Hence, the clustering algorithm is applied to the difference in passenger arrival times with Eq. (3) serving as the criterion for clustering. When a passenger arrives at a time point larger than the service completion time point of all preceding passengers, the waiting time will be 0 and the system is in a perfect status. A sequential algorithm is employed mainly to cluster passengers whose arrival times fail to satisfy Eq. (2). When the number of passengers in the cluster exceeds the ideal solution, the results obtained by the sequential algorithm can be substituted into the model to become fixed parameters, thus reducing the number of variables to be solved. According to the solution of Eq. (4), obtained using the input of arrival times and service combinations required by passengers arriving sequentially, the passengers will be assigned to a check-in facility that caters to their needs and with the shortest waiting time incurred. In other words, with the assignment results of the $N - 1$ passenger being known, the model solves the assignment problem of the N passenger. Using both clustering and sequential algorithms, coupled with the LINGO mathematical programming solver, we develop heuristics that can efficiently solve the problems. The deterministic approach to the problem referred the sequential stochastic security design problem (Nikolaev et al., 2007) and stochastic optimization and sequential assignment theory (Derman, Lieberman, & Ross, 1972) in this study. The steps of solution show in Appendix A.

Table 4 presents the comparison between actual selection of check-in facilities by passengers and dynamic assignment. As can be seen, when given the freedom to choose, 92.4% of passengers preferred to check-in at counters, with only 7.6% making use of self-service check-in kiosks despite the shorter average service time (3.5 min vs. 1.8 min) and no waiting time incurred (1.4 min vs. 0 min). In other words, overall waiting time for passengers is due solely to waiting at check-in counters. The average peak time is calculated by dividing the overall service time by the number of facilities opened for service. Overall, the service utilization rate is 18.9%, meaning that during the 140 min when the facilities are

Table 3
Distribution of arrival times for check-in and services required by departing passengers.

Time to take-off	No. of Passengers	Percentage (%)	Service combination	Processing time* (min)	No. of Passengers	Percentage (%)
2.5–3.0 h	56	28.4	1	2.6	6	3.0
2.0–2.5 h	82	41.7	2	1.6	0	0.0
1.5–2.0 h	45	22.8	3	2.1	157	79.7
1.0–1.5 h	10	5.1	4	1.1	6	3.0
<1 h	4	2.0	5	1.5	23	11.7
			6	0.5	2	1.0
			7	1.0	3	1.5

Notation: *: Processing time refers to Park and Ahn (2003).

open for service, they are being utilized for 26.5 min. The ratio of perfect status in the waiting system of check-in counters being 58.6% implies that 41.4% of the time spent by passengers at check-in counters was on waiting.

Under dynamic assignment, 40.1% and 59.9% of passengers are assigned to check-in counters and self-service check-in kiosks, respectively. This is in agreement with the ratio between the two check-in facilities. As mentioned above, there were 6 check-in counters and 9 self-service check-in kiosks operating during the said time duration, making up 40% and 60%, respectively, of the overall check-in facilities. In all respects, dynamic assignment is superior to actual selection of check-in facilities in that it can achieve a reduction in overall service time (656.5 min vs. 423.3 min). Overall waiting time at check-in counters (260.6 min vs. 12.3 min), and across both types of facilities (260.6 min vs. 27.4 min) was reduced. The overall average service time (3.3 min vs. 2.1 min), and average waiting time at check-in counters (1.4 min vs. 0.16 min) and across both types of facilities (1.3 min vs. 0.14 min) was better with dynamic assignment. The longest waiting time (6.9 min vs. 2.1 min) and the number of longest waiting passengers at check-in counters (18 vs. 4) were obtained from passengers' actual selection, as opposed to dynamic selection. Overall, the utilization rate is 19.1% for check-in counters and 18.7% for self-service check-in kiosks. Such low utilization rates reflect the severe idling of the self-service facilities. Despite being low, the rate greatly improved from the 2.1% under actual selection. The ratio of perfect status in the waiting system of check-in counters being 93.5% implies that dynamic assignment incurs less waiting, thus shortening the overall waiting time of passengers as

compared with free selection. In sum, under dynamic assignment, passengers enjoy more efficient check-in services and airline operators also have more efficient utilization of facilities.

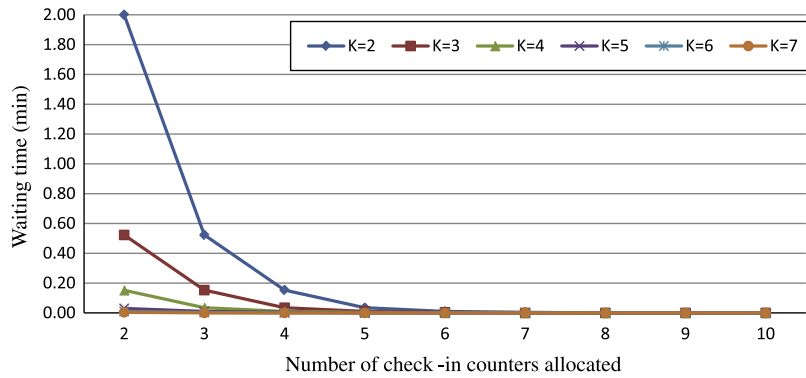
To compensate for changes in passengers arriving for check-in, airline operators can make adjustments in allocation of counters to be opened for check-in service. Such adjustments would not only help reduce the waiting times of passengers during peak hours but could also ameliorate idling of facilities during off-peak hours. Fig. 1 shows the changes in average passenger waiting time and service counter utilization rates under different allocations of check-in facilities. As can be seen, there are 2–10 check-in counters and 2–7 self-service check-in kiosks available for adjustments in allocation. When all 10 check-in counters are open for service, there is no waiting time incurred but the service counter utilization rate is only 23.6%. If the airline prefers to maintain a service counter utilization rate of above 30%, then no more than 7 check-in counters should be opened, and a waiting time of 0.035 min will be incurred.

As seen in the figure, both average waiting time and service counter utilization rates show a decreasing trend with an increase in the number of counters opened. In addition, there is little difference in the trends between check-in counters and self-service kiosks. This would imply the possibility of substituting the two types of check-in facilities, thus allowing more flexibility in allocation, not to mention comparable levels of performance. It should be noted that a further increase in allocation of facilities beyond the threshold will not bring about any improvement in waiting times in the overall check-in system. Worse still, the service counter utilization rate will decrease, resulting in greater inefficiency.

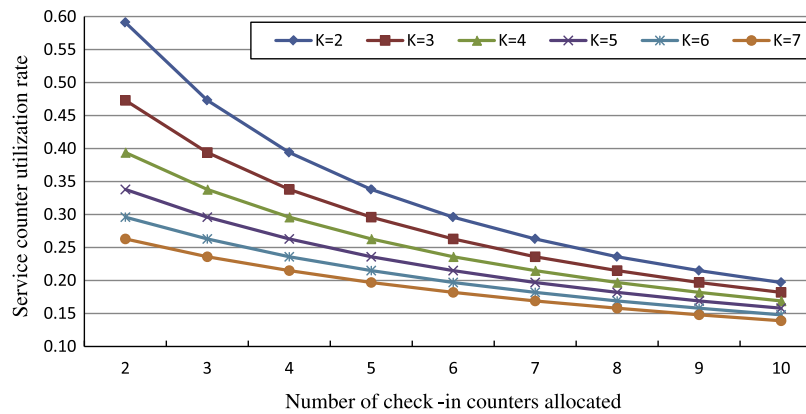
Table 4
Comparison between actual case study and dynamic assignment results.

Comparison indices	Check-in counters			Self-service check-in kiosks			Overall check-in facilities		
	Actual selection	Dynamic assignment	%**	Actual selection	Dynamic assignment	%**	Actual selection	Dynamic assignment	%**
Selection rate (%)	92.4	40.1	56.6	7.6	59.9	–688	100	100	0
Overall service time (min)	629.5	172.6	72.6	27.0	250.7	–829	656.5	423.3	35.5
Overall waiting time (min)	260.6	12.3	95.3	0	15.1	–	260.6	27.4	89.5
Average service time (min)	3.5	2.2	37.1	1.8	2.1	–16.7	3.3	2.1	36.4
Average waiting time (min)	1.4	0.16	88.6	0	0.13	–	1.3	0.14	89.2
Longest waiting time (min)	6.9	2.1	69.6	0	2.1	–	6.9	2.1	69.6
Longest waiting passengers	18	4	77.8	0	6	–	18	10	44.4
Utilization rate (%)	43.9	19.1	56.5	2.1	18.7	–791	18.9	18.9	0
Ratio of perfect status (%)	58.6	92.9	–58.5	100.0	94.0	6.0	60.3	93.5	–55.1

Notation: **: (Actual selection – Dynamic Assignment)/Actual selection * 100%.



(a) Average waiting time



(b) Service counter utilization rate

Fig. 1. Average passenger waiting times and service counter utilization rates under different allocations of check-in facilities.

Table 5
Comparisons of different scenarios.

	Passengers actual selection			Dynamic assignment of passengers				
	Fixed allocation of counters***	Dynamic allocation of counters		Fixed allocation of counters***	Dynamic allocation of counters			
Maximum waiting time allowed (min)	–	2	1.5	1	–	2	1.5	1
No. of adjustments made	–	12	14	18	–	6	6	6
Average waiting time (min)	1.3	0.58	0.37	0.17	0.14	0.46	0.30	0.10
Service counter utilization rate (%)	18.9	44.7	43.8	40.1	18.9	45.9	45.8	45.7

Notation: ***: There are constantly 6 check-in counters and 9 self-service check-in kiosks opened for service.

4. Model application

The developed model was applied to dynamic assignment of check-in facilities for China Airline at the Taoyuan International Airport. The departure lounge of the Taoyuan International Airport is located on Concourse 1F of Terminal 1 and Concourse 3F of Terminal 2. At Terminal 1, China Airline has nine self-service check-in kiosks for passengers to choose seats, print boarding passes, and drop baggage. Departing flights of China Airline have an average passenger load factor of 77%, with an average of 198 passengers on each flight. In this study, economy-class seats account for 85% of total seat capacity; that is, 168 seats. Actual data concerning arrival time of departing passengers for check-in and proportion of passengers using different service combinations are obtained via on-site questionnaire survey.

From the perspective of airline operators, dynamic allocation of facilities and assignment of passengers not only can reduce operation costs but also enhance passenger satisfaction in terms

of shorter waiting times. Nevertheless, in actual operation, due consideration has to be given to passengers' preferences and willingness to use the facilities allocated and comply with the assignment. As a result, optimal assignment of passengers may sometimes be infeasible. While respecting passengers' wishes, airline staff can only suggest but cannot force them to use facilities that would incur the least waiting time. Hence, this study explores the application of the developed model to dynamic allocation of facilities with and without dynamic assignment of passengers.

4.1. Dynamic allocation of facilities without dynamic assignment of passengers

To begin with, a minimum of 2 check-in counters and 9 self-service check-in kiosks were allocated for service. Adjustments to such allocations were made according to two criteria. One was the maximum waiting time allowed, which was set to be 2, 1.5 and 1 min; and the other was the lowest service counter

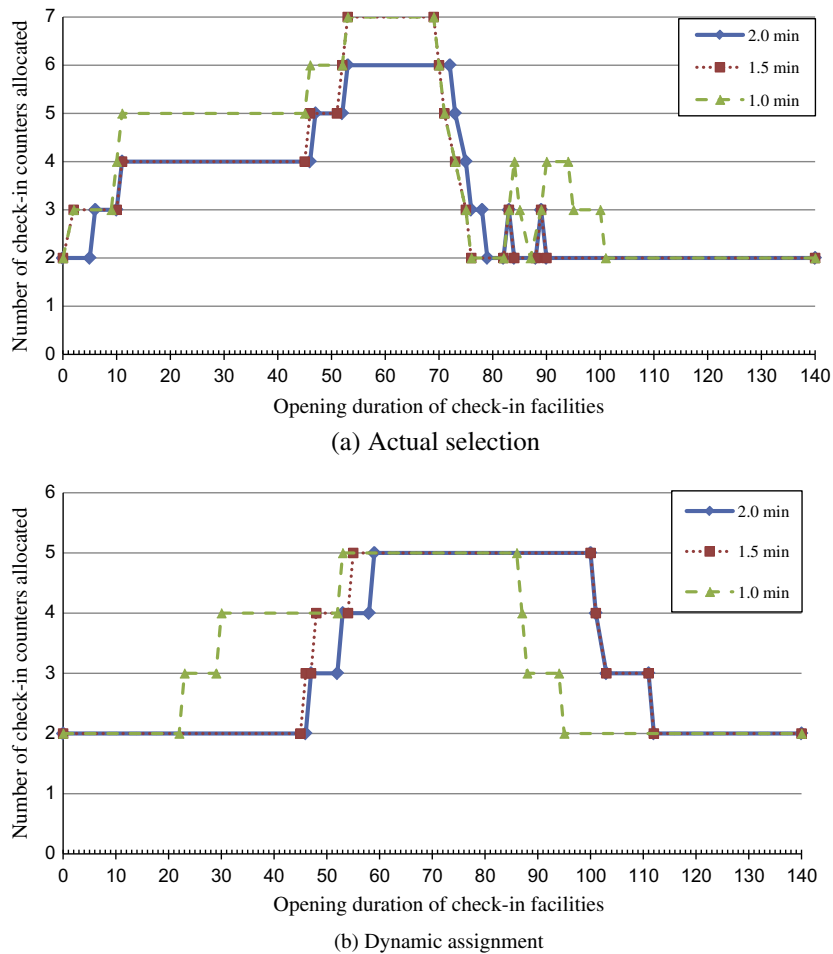


Fig. 2. Number of check-in counters allocated for different maximum waiting times.

utilization rate allowed, which was derived by the model as 59.1% for the initial allocation condition. Each adjustment involved either an increase or decrease of one counter. Table 5 compares the numbers of adjustments made, the average waiting time incurred, and the service counter utilization rate for different scenarios; that is, with and without dynamic allocation of check-in counters, as well as with and without dynamic assignment of passengers.

As can be seen, with dynamic allocation of check-in facilities, the average waiting time incurred was reduced from the 1.3 min to 0.17 min and the service counter utilization rate was maintained above 40%. In other words, while allowing passengers to freely choose the check-in facilities according to their preference, airline operators can use dynamic allocation of facilities to reduce passenger waiting time. To achieve a maximum 1-min waiting time involves 18 adjustments in the allocation of check-in counters. Fig. 2a shows the variations in the number of check-in counters in operation for different maximum waiting times.

As can be seen, frequent adjustments were made under the varying arrival of passengers for check-in. The erratic arrival of passengers changes both the waiting time required for check-in as well as the service counter utilization rate, thus necessitating adjustments. As seen in the figure, a maximum of 7 check-in counters are opened for service at the peak hours of passengers arriving for check-in. Information revealed in Fig. 2a can provide useful references for airline operators to decide on the optimal allocation of service counters to facilitate check-in of departing passengers with minimum waiting time incurred.

4.2. Dynamic allocation of check-in counters with dynamic assignment of passengers

In the scenario when both the allocation of facilities and assignment of passengers follow the dynamic model, Table 5 shows that the lowest average waiting time of 0.1 can be achieved with a service counter utilization rate maintained above 45%, a large increase from the original 18.9%. In addition, as shown in Fig. 2b, a maximum of only 5 check-in counters, instead of 7, are needed to meet the need for check-in services. Moreover, only 6 adjustments are made in allocations throughout the 140-min period, a large reduction compared with the scenario without dynamic assignment of passengers. Adjustments for increases in service counters are mainly made between 30 and 60 min after check-in service becomes available. On the other hand, adjustments for decreases in service counters are mainly carried out between 87 and 112 min. Those two time periods indicate the peak and off-peak hours of passengers arriving for check-in.

It is interesting to note that, regardless of the maximum waiting time allowed, the number of adjustments made for the three cases are the same. However, the average waiting time incurred still varies depending on the maximum waiting time allowed. As seen in Table 5, for the maximum waiting time of 2, 1.5 and 1 min allowed, the average waiting time incurred was 0.46, 0.3 and 0.1 min, respectively. In addition, the shorter the maximum waiting time allowed, the earlier the adjustment in service counter allocation needs to be made. Prompt and early adjustment has the advantage of reducing the waiting time incurred during

subsequent peak hours, thus contributing to the lowest average waiting time.

5. Conclusions and suggestions

This study explored the operation and planning of check-in facilities from the standpoint of airline companies. A model was developed for dynamic allocation of facilities and dynamic assignment of passengers with the target of minimizing waiting time for passengers. The feasibility of the developed model is validated by case analysis by comparing actual data from free selection of check-in facilities by passengers and dynamic assignment of passengers to check-in facilities. Results of the comparisons evidenced the superiority of dynamic assignment in terms of shorter waiting times and better utilization of facilities.

Furthermore, dynamic allocation of facilities is also more efficient than fixed allocation in achieving shorter waiting times and better utilization of services. In particular, under dynamic allocation, the shorter the maximum waiting time allowed, the earlier the adjustment for an increase in facilities provided. Prompt and early adjustment contributes to the prevention of congestion at subsequent peak hours, thus effectively reducing waiting times. However, under actual selection, the shorter the maximum waiting time allowed, the more frequently adjustments need to be made. Yet, the number of adjustments required can be reduced with dynamic assignment of passengers, thus avoiding repeated changes in facility allocation, which, in turn, saves human resources and operation costs. Hence, airline operators with the goal of reducing long-term operation costs can consider opening more self-service check-in kiosks during peak hours to decrease both waiting times and the number of adjustments required for dynamic check-in counter allocation when passengers are given the freedom to choose the facilities they prefer.

Two criteria, namely waiting time and service counter utilization rate, are adopted as indicators for needed adjustments for allocation of facilities. To airline operators, service counter utilization rates should be considered together with the human resources, space, and costs involved. Hence, it is suggested that cost difference be included as an index for required adjustments. As mentioned above, among passengers who do not opt for self-service check-in, many cite the need for baggage check-in, which cannot be handled at the kiosks. Hence, airline operators should try to meet such needs and install kiosks that can provide baggage drop service for self-check-in passengers, which would enhance the utilization rate of self-service check-in kiosks. Airlines can motivate more departing passengers to opt for kiosks, online, and barcode check-in facilities by providing additional benefits or seat-selection privileges. In this way, not only can passengers enjoy more rapid check-in with less waiting, but airlines can also reduce operation costs and space due to fewer check-in counters being required.

Some airports have exclusive checking baggage for self-service check-in passengers. Future studies can discuss the variations in application results for such scenarios. In addition, whether dynamic allocation and the developed assignment model can be applied to air cargo services and other industries to achieve higher efficiency and better utilization of facilities also merits further investigation.

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Appendix A. The steps of the solution algorithm developed for dynamic assignment of passengers and allocation of facilities

Step 1: Input the values of parameters related to the solution, namely T_d , N , P_{dj} , M_d and X_d^{\max} .

Step 2: Input the arrival time of the n th passenger for check-in, t^n and, from the cumulative probability curve of passengers arriving at the check-in counter, randomly generate the service combination j of the n th arriving passenger requiring check-in service.

Step 3: Determine whether check-in facility d can provide service combination j . If yes, then $A_{dj} = 1$; otherwise $A_{dj} = 99$.

Step 4: Calculate the waiting time of the n th arriving passenger at the i th counter of d , $W_{di}(t^n)$, using Eq. (3) or Eq. (4).

Step 5: Obtain the number of check-in facilities d assigned, and, X_{di} , based on the maximum allowable waiting time and the lowest service counter utilization rate allowed.

Step 6: According to Eqs. (5)–(10), determine the n th arriving passenger requiring check-in service j to be assigned to the i th counter of d , $I_{dji}^n = 1$.

Step 7: Repeat Steps 2–6 until the assignment of N passengers is completed.

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