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# DEMAND DISTRIBUTION AND OPERATING STRATEGIES OF AIRPORT REMOTE AND TERMINAL PARKING FACILITIES

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Analytical approaches are used to explore factors affecting how travelers choose between remote and terminal parking facilities, to analyze the cost components of the parking process, and to formulate models for estimating the demand levels for remote and terminal parking. The demand distribution model is formulated by assuming that travelers choose the parking facility with the minimum total parking cost with respect to their parking duration and other characteristics. On the basis of this model, a parking duration control model is then formulated to maximize the operator's revenue while maintaining the levels of services and balancing the utilization of parking facilities. The model shows that parking revenues will be reduced if the operator imposes parking duration control to maintain the level of terminal parking service and increase utilization of remote parking.

*Keywords:* Airports; parking demand; remote parking; terminal parking; parking location choice; parking duration control

## 1. INTRODUCTION

The continued growth of air traffic and heavy reliance on private automobiles for airport access has greatly contributed to an increase in parking demand at major airports around the world (LaMagna *et al.*, 1979). As there are usually a limited number of parking spaces around central terminal areas, provision of remote parking facilities in peripheral areas has been the trend in recent decades (Mundy, 1982; Fan, 1990). For instance, in 1990, remote parking accounted for 48.84% of total parking in Singapore's Changi Airport (Fan,

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1990). Generally, close-in terminal parking offers high parking fees but low access time, while remote parking offers low parking fee but high access time. These different service characteristics affect the travelers' choice between terminal and remote parking facilities. Parking operating strategies play a major role in the management of the two types of parking facilities in airports. Inappropriate parking operating strategies may result in imbalance of parking demand distribution that degrades the level of service and makes parking spaces idle.

Most previous literature concerned with airport parking has focused on analyzing terminal curb parking using engineering approaches (e.g., Parizi and Braaksma, 1993; Fan, 1990; Mandle *et al.*, 1982). Some studies analyzed parking space allocation or parking location choice but most have focused on metropolitan areas (e.g., Ellis and Rassam, 1970; Bates, 1972; Goot, 1982; Goyal and Gomes, 1984; Gur and Beimborn, 1984; Hunt and Teply, 1993). In these studies, linear programming, logit or gravity models were used. Few studies have been aimed at developing analytical models to explore issues regarding the demand distribution and operating strategies between terminal and remote parking facilities.

This paper attempts to use an analytical approach to explore factors affecting air travelers' parking decisions and the trade-off considered in the choice between remote and terminal parking facilities, to analyze the cost components of the parking process, and to formulate models for estimating the demand levels on remote and terminal parking facilities. The demand distribution model is formulated by assuming that travelers choose a parking facility to minimize their total parking costs with respect to parking duration and other socio-economic characteristics. Departing from the logit model approach in recent literature (Tambi, 1991), this paper introduces the concept of "critical parking duration" as a way of determining the optimal choice and the demand distribution between remote and terminal parking facilities. On the basis of this concept, a model for parking duration regulation is then formulated to maximize the operator's revenue while maintaining service levels and balancing the utilization of these two types of parking facility. In addition, this paper analyzes how parking demand distribution and optimal regulated parking duration are affected by changes in policy and socioeconomic factors such as access time, parking fee, and travelers' time value.

Section 2 describes parking costs, the concept of critical parking duration, parking demand, and stall demand. Two models, one for the parking demand distribution and the other for parking duration regulation strategies, are described, respectively, in Section 3 and Section 4. Section 5 presents conclusions.

## 2. PARKING DEMAND AND STALL DEMAND

In this section, we estimate the parking demand and the stall demand on remote and central terminal parking facilities by assuming that total airport public parking demand, and parking duration distribution of travelers are exogenously given. Because traveler and visitor car parks are usually combined whereas employees generally park in separate areas, this paper incorporates visitor parking into traveler parking as total airport public parking demand but does not consider employee parking demand. We first analyze the cost components involved in an air traveler's parking process.

### Airport Parking Cost

We classify airport travelers into two market segments. Let  $i$  denote traveler type; then there are two types of travelers, business ( $i = B$ ) and non-business ( $i = NB$ ). Each has a different time value that has a varied effect on their choices between remote and terminal parking. An airport traveler's parking cost includes the parking fee, access cost between the parking facility and the terminal building, and the time cost of searching for an available stall. Because self-driven travelers may wish to drop their baggage at the curb before parking their cars, "curbside" check-in of luggage becomes common in major airports. This paper does not consider luggage carrying as a factor affecting travelers' choice between remote and terminal parking facilities.

For simplicity, we assume that the parking fee per unit time of facility  $k$  is a uniform unit-parking fee  $F_k$ . " $k$ " denotes the parking facility category; e.g.,  $k = C$  stands for a terminal parking facility and  $k = R$  stands for a remote parking facility. The parking fee for a traveler  $i$  with parking duration  $t_{ij}$ , for parking facility  $k$ ,  $PC_k(t_{ij})$ , is calculated as:

$$PC_k(t_{ij}) = F_k \cdot t_{ij} \quad (1)$$

We assume that terminal parking facilities are located within walking distance of the terminal, while remote parking facilities are located at distance  $d_R$ , which is beyond walking distance and served by shuttle buses with fixed headway and uniform arrival of passengers. The access cost for a traveler  $i$  who chooses remote parking,  $T_{Ri}$ , and central terminal parking,  $WC_{Ci}$ , are expressed, respectively, as follows:

$$T_{Ri} = 2f_t + 2 \cdot v_i \left( \frac{h}{2} + \frac{d_R}{V_b} \right), \quad (2)$$

$$WC_{Ci} = 2 \cdot v_i \cdot \frac{d_C}{V_P}, \quad (3)$$

where  $V_b$ ,  $h$ , and  $f_t$ , are, respectively, the average speed, headway, and fare of shuttle bus,  $V_p$  is the average walking speed of traveler type  $i$ , and  $v_i$  is the time value of traveler type  $i$ .

Searching time is defined as the average amount of time an airport traveler would have to search for a parking space at a given facility, or wait for one to become available. Gur and Beimborn (1984) have formulated a searching-time function that varies with the volume of parkers, average parking duration, and the capacity of the given off-street parking facility. This paper follows their searching-time cost function but introduce a stall utilization factor,  $u_k$  to symbolize the ratio of parking stall demand to capacity at parking facility  $k$ , and a parameter  $\sigma$  to represent the effect of techniques used in the parking facility, to obtain the average searching time cost to the traveler  $i$  at the parking facility  $k$ ,  $SWC_{ki}$ ,

$$SWC_{ki} = 0.5 \cdot \sigma \cdot u_k^\kappa \cdot \mu_{ik}^\iota \cdot v_i, \quad (4)$$

where  $\mu_{ik}$  is the average parking duration at facility  $k$ , and  $v_i$  is the time value of traveler  $i$ . The parameters  $\kappa$  and  $\iota$  represent, respectively, the effects of utilization of parking facility,  $u_k$ , and average parking duration,  $\mu_{ik}$ , on the average searching time cost,  $SWC_{ki}$ . The average searching time cost as shown in Eq. (4), increases with average parking duration of travelers,  $\mu_{ik}$ , utilization of parking facility,  $u_k$ , so that the values of  $\kappa$  and  $\iota$  would be positive. If a parking facility provides mechanical devices or automatic instructions for travelers, then  $\sigma$  is small and searching time decreases; otherwise,  $\sigma$  is large and searching time increases.

### Traveler Parking Choice

A traveler's total parking cost plays a major role in his or her choice among different parking facilities. The total parking cost for traveler  $i$  with parking duration  $t_{ij}$  is the summation of the cost components described above. We assume any traveler  $i$  aims to minimize total parking cost when choosing between terminal and remote parking facilities. Specifically, if

$$PC_C(t_{ij}) + WC_{Ci} + SWC_{Ci} \leq PC_R(t_{ij}) + T_{Ri} + SWC_{Ri}, \quad (5)$$

then the terminal parking facility  $C$  is least expensive and traveler  $i$  would choose  $C$ , otherwise,  $i$  would choose the remote parking facility,  $R$ .

Because a direct relationship exists between parking fee and parking duration [e.g.,  $PC_k(t_{ij}) = F_k \cdot t_{ij}$ ], the optimal parking facility for traveler  $i$  depends on whether  $t_{ij}$  is greater than or less than a "critical parking duration", denoted

by  $t_i^*$ . Critical parking duration is the value of  $t_{ij}$  which satisfies the following:

$$PC_C(t_i^*) + WC_{Ci} + SWC_{Ci} = PC_R(t_i^*) + T_{Ri} + SWC_{Ri}, \quad (6)$$

where  $PC_C(t_i^*) = F_C \cdot t_i^*$ ,  $PC_R(t_i^*) = F_R \cdot t_i^*$ . From Eq. (6) the critical parking duration,  $t_i^*$  can be expressed as a function of differences in access costs, searching time costs, and unit parking fees between terminal parking and remote parking. That is

$$t_i^* = \frac{[(T_{Ri} - WC_{Ci}) + (SW_{Ri} - SW_{Ci})]}{F_C - F_R}. \quad (7)$$

The critical parking duration is also the longest parking duration of travelers who choose terminal parking, and the shortest parking duration of travelers who choose remote parking. Airport travelers whose parking duration is shorter than the critical parking duration will choose terminal parking, but those whose parking duration is longer than the critical parking duration will choose remote parking. The critical parking duration for business travelers,  $t_B^*$ , is higher than that for non-business travelers,  $t_{NB}^*$ , in light of their higher time value.

### Parking Demand

The parking demand on a parking facility is expressed as the number of parkings in the parking facility during a certain time interval. Let  $f(t_{ij})$  represent parking duration distribution, i.e. a distribution describing the relationship between parkings with a certain duration  $t_{ij}$ , and the total amount of parking during a given time interval. Then, based on the concept of the critical parking duration, parking demands on terminal parking and remote parking,  $D_C$  and  $D_R$ , respectively, are obtained by:

$$D_C = \sum_{i=B,NB} D_i \cdot \int_{t_{il}}^{t_i^*} f(t_{ij}) dt_{ij}, \quad (8)$$

$$D_R = \sum_{i=B,NB} D_i \cdot \int_{t_i^*}^{t_{iu}} f(t_{ij}) dt_{ij}, \quad (9)$$

where  $t_{il}$  and  $t_{iu}$  are, respectively, the lower and upper bounds of parking duration distribution for traveler  $i$ , and  $D_i$  is the total parking demand for traveler  $i$ , where  $D_i = D \cdot P_i$ , i.e. the total parking demand multiplied by the proportion of type  $i$  travelers.

Parking demands on the two type of parking facilities are functions of the critical parking duration,  $t_i^*$ , as shown in Eq. (8) and Eq. (9). When the parking

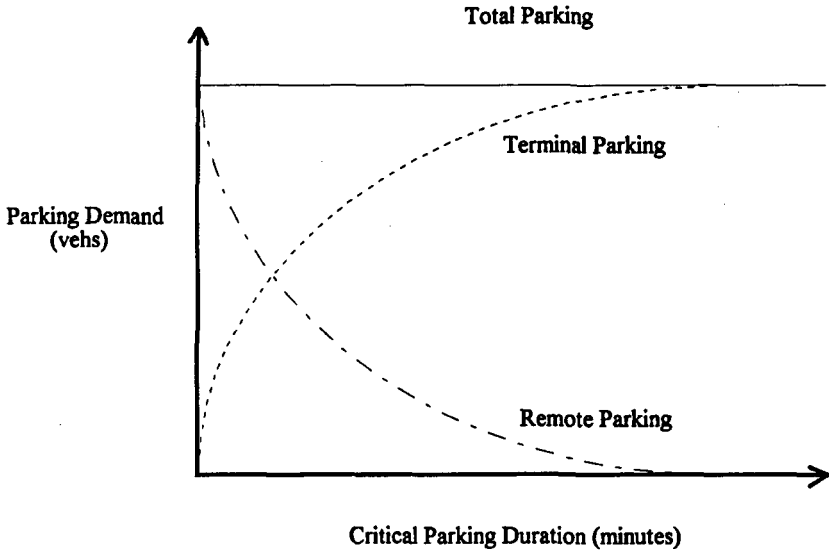


FIGURE 1 Terminal and remote parking demand vs. critical parking duration.

duration distribution,  $f(t_{ij})$ , is known, then a longer critical parking duration means a larger accumulated probability below the critical parking duration, and parking demand on the terminal parking facility will increase. On the other hand, a shorter critical parking duration means a larger accumulated probability above the critical parking duration, and the parking demand on the remote parking facility will increase. The relationships among the critical parking duration, terminal parking demand, and remote parking demand are illustrated in Figure 1.

### Stall Demand

The number of parking stalls needed can be calculated by assuming that the parking facility's supply (stall-hours) equals travellers' parking demand (vehicle-hours). Assume that  $D_i$  travelers park their vehicles at a parking facility during observation period  $T$ , and that the duration distribution is  $f(t_{ij})$ . Hence, there are  $D_i \cdot f(t_{ij})$  travelers with a parking duration  $t_{ij}$  forming the total parking time demand  $D_i \cdot f(t_{ij}) \cdot t_{ij}$ . The number of parking stalls  $SD(t_{ij})$  needed by these travelers can be calculated from the quotient

$$SD(t_{ij}) = \frac{D_i \cdot f(t_{ij}) \cdot t_{ij}}{T}, \quad (10)$$

which expresses the relationship between total parking time demand and parking time supply ( $T$ ) offered by one parking stall (Lautso, 1981). Then, from Eqs. (8), (9) and (10), the parking stall demand on terminal parking and remote parking,  $SD_C$ ,  $SD_R$ , can be formulated as follows:

$$SD_C = \sum_{i=B,NB} \frac{D_i}{T} \cdot \int_{t_{il}}^{t_i^*} f(t_{ij}) \cdot t_{ij} dt_{ij}, \tag{11}$$

$$SD_R = \sum_{i=B,NB} \frac{D_i}{T} \cdot \int_{t_i^*}^{t_{iu}} f(t_{ij}) \cdot t_{ij} dt_{ij}. \tag{12}$$

The utilization factor for parking facility  $k$ ,  $u_k$ , defined in Eq. (4) can thus be expressed by

$$u_k = SD_k/S_k, \tag{13}$$

where  $S_k$  is the capacity of parking facility  $k$ . For the same parking demand, the stall demand for a parking facility would be less if average parking duration of vehicles in this facility is shorter. Here, we use index  $g_k$ , the ratio of stall demand ratio to parking demand ratio for parking facility  $k$ , to represent the relative number of stalls needed for individual parking facility  $k$  as compared to the total number of stalls needed.

$$g_k = \frac{SD_k/SD}{D_k/D}. \tag{14}$$

### 3. PARKING DEMAND DISTRIBUTION MODEL

In choosing a parking facility, especially when searching time is considered, an airport traveler is usually confronted with high degrees of uncertainty, due to inadequacy in information. We assume in the model that the traveler chooses the parking facility that minimizes total parking cost, and that this includes only the parking fee and access cost. The concept of critical parking duration introduced in Section 2 is used to determine the traveler's parking choice and aggregate parking demand. A nonlinear programming model is formulated here to determine the critical parking duration of business and non-business travelers,  $t_B^*$ ,  $t_{NB}^*$ , and the equilibrium parking and stall demands on remote and terminal parking facilities,  $D_R$ ,  $SD_R$ ,  $D_C$ , and  $SD_C$ . The nonlinear programming model is as follows:

$$\text{Min } TC^{ij} \tag{15}$$

$$\text{St. } \sum_i D_i = D \tag{16}$$



$$\sum_i D_i = \sum_k D_k \quad (17)$$

$$D_i = D \cdot P_i \quad (18)$$

$$D_R = \sum_i D_i \cdot \int_{t_i^*}^{t_{iu}} f(t_{ij}) dt_{ij} \quad (19)$$

$$D_C = \sum_i D_i \cdot \int_{t_{il}}^{t_i^*} f(t_{ij}) dt_{ij} \quad (20)$$

$$SD_R = \sum_i \frac{1}{T} \cdot D_i \cdot \int_{t_i^*}^{t_{iu}} f(t_{ij}) \cdot t_{ij} dt_{ij} \quad (21)$$

$$SD_C = \sum_i \frac{1}{T} \cdot D_i \cdot \int_{t_{il}}^{t_i^*} f(t_{ij}) \cdot t_{ij} dt_{ij} \quad (22)$$

$$F_C > F_R \quad (23)$$

$$d_C < d_R \quad (24)$$

$$D_i, D_k, t_i^*, t_{iu}, t_{il} \geq 0; i = B, NB; k = C, R$$

$$D, F_C, F_R, d_C, d_R > 0.$$

In the formulation above, Eq. (15) represents the objective function of the traveler  $i$  minimizing the sum of access cost and parking fee with respect to his parking duration  $t_{ij}$ ,  $TC^{ij}$ . The constraints include equalities among total parking demand, parking demands of different types of travelers, and demands for different types of parking facilities, i.e. Eqs. (16) and (17); and disparities in services between terminal and remote parking facilities, i.e. Eqs. (23) and (24). This nonlinear programming problem may be solved by means of a variety of algorithms. We solved the problem using GINO, a computer modeling program based on a generalized reduced gradient algorithm.

A hypothetical example is illustrated here to observe the behavior and results of the model. A set of parameter values, shown in Table I, is chosen as the input values for the parking distribution model. The parking duration distribution of business and non-business travelers,  $f(t_{Bj})$ ,  $f(t_{NBj})$ , are assumed to be distributed with normal distributions. The base parameter values are assumed on basis of previous studies and only for demonstration purpose. Estimates based on actual data should be used in future application of the model in specific airport. The results are summarized in Table II. The critical parking duration of business travelers is shown to be higher than that of non-business travelers in light of their higher time value. This phenomenon suggests that business and short parking-duration travelers are likely to choose

TABLE I Base parameter values for parking distribution model

Parameter	Value	Unit
$D$	4000000	vehs
$T$	4380	hrs
$P_B$	0.5	
$P_{NB}$	0.5	
$v_B$	0.2	US\$/minute
$v_{NB}$	0.15	US\$/minute
$h$	10	minutes
$F_C$	1.45	US\$/hr
$F_R$	0.9	US\$/hr
$V_p$	80	m/minute
$V_b$	500	m/minute
$f_t$	0.6	US\$
$f(t_{Bj})$	$N(8, 2.6^2)$	(hr, hr <sup>2</sup> )
$f(t_{NBj})$	$N(4, 1.25^2)$	(hr, hr <sup>2</sup> )
$d_C$	180	m
$d_R$	3000	m
$S_C$	2849	stalls
$S_R$	4000	stalls
$\kappa$	2	
$\sigma$	1.5	
$\iota$	0.5	

the more expensive but closer central parking. Meanwhile, the value of  $g_k$  for the remote parking facility is shown to be larger than that of the terminal parking facility. That is, in response to the longer parking duration and lower turnover rate, the remote parking facility should provide more parking stalls than the terminal parking facility for the same demand level.

For the same stall-utilization factor, the searching time in the remote parking facility is normally higher than that in the terminal parking facility, due to longer parking duration. However, as shown in Table II, the comparatively higher searching time for the terminal parking facility implies that there is an unbalanced distribution of parking demand because of incomplete information; that is, the terminal parking facility is over-occupied while the remote parking facility is under-utilized. The result agrees with the findings of Fan

TABLE II Model results for parking demand distribution

Facility Type	Parking Demand (vehs)	Stall Demand (stalls)	Searching Time (minutes)	Revenues (US\$)	$g_k$
Terminal Parking	3144266	3455	10.7	21945404	0.8
Remote Parking	855734	2024	4.7	7978716	1.8

(1990) which suggested convenience is more important than monetary cost by showing that at Singapore's Changi Airport, the closer car park is always full while the cheaper car park is usually half-empty even though it is only a short distance away.

In response to these findings, a parking duration control model is formulated in Section 4 to optimize parking facility duration control strategy and explore the impact of the strategy. The parking demand distribution model was tested to determine the effects of various parameters and policies on model behavior. Sensitivity analyses were performed based on the sample data shown in Table I by varying the value of one or two parameters while holding the others constant.

Air travelers' time values are usually high, especially in airports located in areas with high income and large proportion of business travelers. The critical parking duration which is the shift point of traveler's choice decreases with the increase in travel time value. This phenomenon suggests that high time-value travelers are willing to pay high parking fees to reduce access time. Figure 2 shows that with an increase in the time value of the traveler, the parking demand on the terminal facility increases while that on the remote facility decreases. Improvements that reduce the access-time difference between the

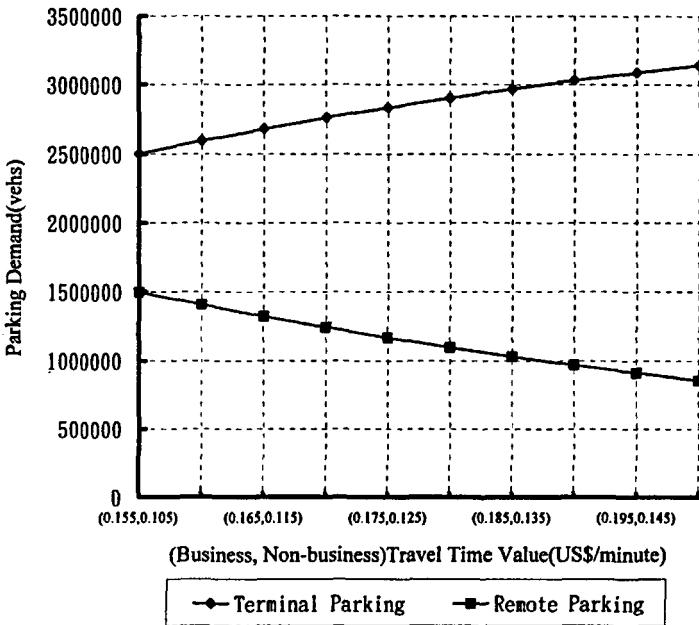


FIGURE 2 Parking demand distribution vs. traveler time value.

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remote parking facility and central terminal building may raise the utilization of the remote facility.

Inconvenience accounts for the low utilization of remote parking facilities in airports. The results of changes in the access time of the remote parking facility is shown in Figure 3. As the access time of the remote parking facility decreases, the critical parking duration of traveler also decreases; that is, the parking demand shifts from the terminal parking facility to the remote parking facility as indicated by the opposite change directions of parking demand on the two types of facilities shown in Figure 3. Therefore, at airports confronted with idle remote parking facilities and terminal parking facility crowding problems, operators could alleviate the imbalance problem by improving transportation of travelers from the remote facilities to the central terminal building.

The utilization imbalance of various parking facilities could be improved by raising the parking fees at the over-used facility. As the unit parking fee for the central terminal parking facility goes up, the critical parking duration decreases; thereby, the parking demand shifts from the terminal parking facility to the remote parking facility as indicated by Figure 4. Pricing policies could be applied to alleviate the imbalance problem without major investments. However, in the case that travelers place a high value on their time, the

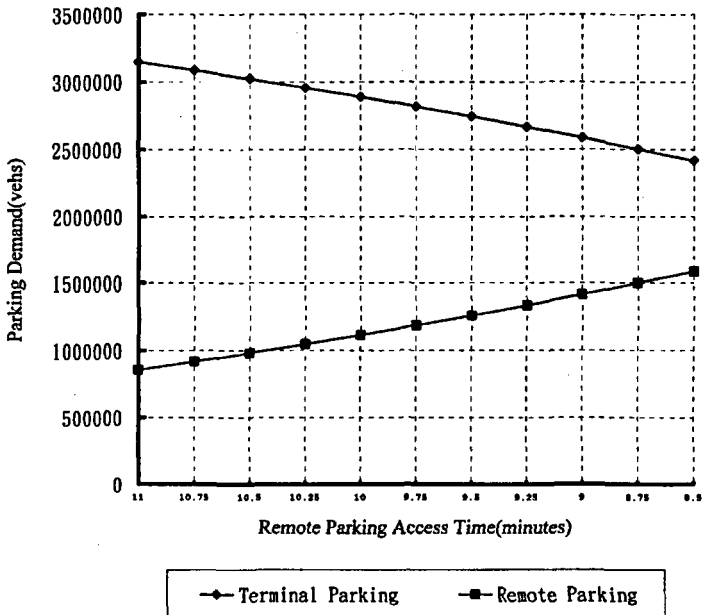


FIGURE 3 Parking demand distribution vs. remote parking access time.

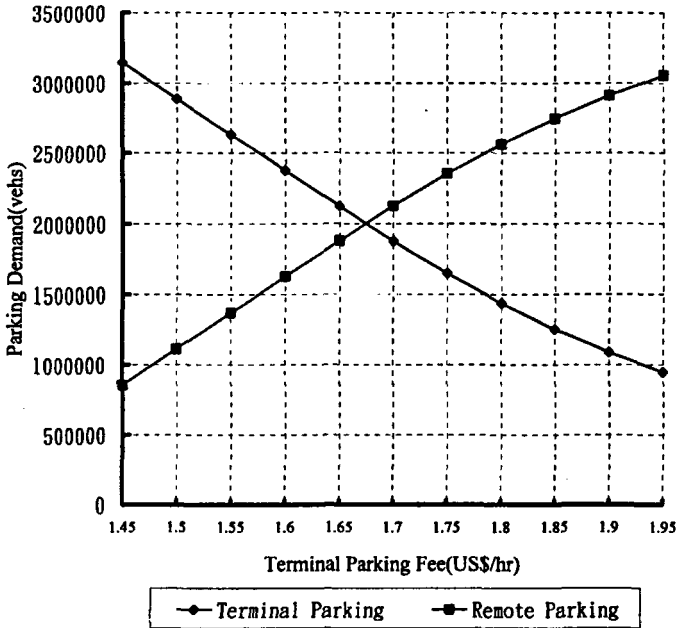


FIGURE 4 Parking demand distribution vs. terminal parking fee.

advantage of this policy could diminish. Other operating strategies such as parking duration control will be explored in the next section.

#### 4. THE PARKING DURATION CONTROL MODEL

Parking operating strategies play a major role in alleviating the problem of utilization imbalance between remote and terminal parking facility without major investments. Parking duration control, like parking pricing, is one of these strategies; therefore, a model aimed at such a regulation is formulated here by maximizing the operating revenues while balancing the utilization and maintaining the service levels of parking facilities.

This paper uses the “critical parking duration” approach to determine travelers’ parking choices, and obtain parking demand distribution. This approach has the advantage of simplicity in predicting the aggregate parking demand as compared to the aggregation problem in the logit model (Ben-Akiva and Lerman, 1985). The model also provides a basis on which to set up a regulation parking duration. Operators may apply parking duration restrictions so as to regulate travelers’ use of different parking facilities. Travelers whose parking

durations are shorter than the regulated parking duration ( $t_r^*$ ), are allowed to park in the central terminal parking facility; otherwise, they must park in the remote facility. Regulated parking duration,  $t_r^*$ , and critical parking duration,  $t_i^*$ , are similar in that both are the shift points in parking choice and vary travelers' parking decisions, e.g., compulsory versus voluntary. From Eqs. (8) and (9), total revenue, without parking duration control, PC, can be obtained from:

$$TPC = FC \cdot \sum_i D_i \cdot \int_{t_{il}}^{t_i^*} f(t_{ij}) \cdot t_{ij} dt_{ij} + F_R \cdot \sum_i D_i \cdot \int_{t_i^*}^{t_{iu}} f(t_{ij}) \cdot t_{ij} dt_{ij} \quad (25)$$

Similarly, the total revenue with parking duration control,  $TPC_r$ , can be calculated by replacing  $t_i^*$  with  $t_r^*$ , and obtained from:

$$TPC_r = FC \cdot \sum_i D_i \cdot \int_{t_{il}}^{t_r^*} f(t_{ij}) \cdot dt_{ij} + F_R \cdot \sum_i D_i \cdot \int_{t_r^*}^{t_{iu}} f(t_{ij}) \cdot t_{ij} dt_{ij} \quad (26)$$

The revenue increment with parking duration control,  $OR$ , is the difference between  $TPC_r$  and  $TPC$ , i.e.  $TPC_r - TPC$ . The optimal regulated parking duration,  $t_r^*$ , is assumed to be set up such that it maximizes the revenue increment subject to balancing utilization levels for two types of parking facilities. The formulation of this nonlinear optimization problem is as follows:

$$\text{Max } OR \quad (27)$$

$$\text{St. } \sum_i D_i = D \quad (28)$$

$$\sum_i D_i = \sum_k D_k \quad (29)$$

$$D_i = D \cdot P_i \quad (30)$$

$$u_k^l \leq u_k \leq u_k^u \quad (31)$$

$$F_C > F_R \quad (32)$$

$$d_C < d_R \quad (33)$$

$$D_i, D_k, P_i \geq 0; D, F_C, F_R, d_C, d_R, u_k^l, u_k^u, u_k > 0$$

$$i = B, NB; k = C, R.$$

Eq. (27) represents the objective function that maximizes the revenue increment with parking duration regulation, where the decision variable is regulated

TABLE III Model results for parking duration control

	<i>Stall Utilization</i>	<i>Searching Time (minutes)</i>	<i>Revenue (US\$)</i>
Terminal Parking with control	0.8	6.5	14476646
Terminal Parking w/o control	1.21	10.7	21945404
Remote Parking with control	0.8	9.2	12614495
Remote Parking w/o control	0.51	4.7	7978716

parking duration  $t_r^*$ . Eqs. (30) and (31) specify, utilization intervals  $[u_k^l, u_k^u]$ , which the operator is supposed to maintain for each type of parking facility. Other constraints are similar to those in the parking demand distribution model. The nonlinear optimization model can also be solved by GINO. The input data of the hypothetical example illustrated in Section 3 is used again by specifying only  $[u_k^l, u_k^u]$  values as  $[0.8, 0.9]$  so as to evaluate output changes solely as a consequence of applying parking duration control. Table III shows results for two scenarios, one with parking duration control and the other

TABLE IV Model results for parking duration control with different pricing strategies

	<i>Parking Fee Rate (US\$/minute)</i> <i>(Terminal parking, Remote parking)</i>		
	<i>(1.5, 0.85)</i>	<i>(1.6, 0.75)</i>	<i>(1.7, 0.65)</i>
Total Revenue Increase (US\$)	-839110	3632138	7646898
<i>Optimal Control Duration(hrs)</i>			
Business Traveler	6.3	6.3	6.3
Non-business Traveler	6.3	6.3	6.3
<i>Critical Duration(hrs)</i>			
Business Traveler	7.22	5.52	4.47
Non-business Traveler	5.88	4.49	3.64
<i>Stall Utilitization</i>			
Terminal Parking with control	0.8	0.8	0.8
Terminal Parking w/o control	0.9	0.46	0.22
Remote Parking with control	0.8	0.8	0.8
Remote Parking w/o control	0.73	1.04	1.22
<i>Searching Time(minutes)</i>			
Terminal Parking with control	6.5	6.5	6.5
Terminal Parking w/o control	7.2	2.8	0.9
Remote Parking with control	9.2	9.2	9.2
Remote Parking w/o control	7.6	11.2	13.2
<i>Revenue(US\$)</i>			
Terminal Parking with control	14975879	15974271	16972664
Terminal Parking w/o control	16912286	9137305	4591972
Remote Parking with control	11913669	10512061	9110452
Remote Parking w/o control	10816372	13716888	13844246

without control. Without parking duration control, the terminal parking facility is over-utilized and searching time is high due to an insignificant discrepancy in unit parking fees between terminal and remote parking facilities. However, parking revenues will be reduced if the operator applies the parking duration control to balance the utilization and service levels between these two types of parking facilities. Table IV shows the results of parking duration controls applied in scenarios with a variety of pricing combinations. The optimal regulated parking duration is shown to hold in spite of different pricing strategies. However, as the difference in unit parking fee between two types of facilities expands, the remote parking facility becomes over-occupied. In these cases, the parking revenues will increase if the operator applies parking duration control to increase the utilization of the central terminal parking while maintaining the service levels of the two facilities.

## 5. CONCLUSIONS

This paper has analyzed the components of airport parking cost, explored travelers' choices between terminal and remote parking facilities, and formulated a model for estimating demand on two types of facility. Travelers were assumed to choose the parking facility that minimizes their parking fees and access costs. Instead of utilizing the conventional logit model, this paper introduced the concept of "critical parking duration" as a way to determine the optimal choice and aggregate parking demand on the two types of facility. The approach is simple and can be used logically to develop a model for parking duration control. The results show that business and short parking-duration travelers tend to choose the terminal parking while non-business and long-duration travelers tend to choose the remote parking. For the same demand level, the remote parking facility should provide more parking stalls than the terminal parking facility, due to longer average parking duration. Reductions in access time and parking fees for a parking facility will stimulate parking demand for this facility.

Finally, in regard to parking duration regulation, parking revenues will be reduced when the terminal parking facility is crowded and the operator applies parking duration control to increase use of remote parking while maintaining use and service levels of terminal parking. On the other hand, the parking revenues increase when the remote parking facility is overutilized and the operator applies parking duration control to balance usage between these two different parking facilities.



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