Abstract: This study attempts to optimize sizes and locations of the airport parking facilities considering demand-supply interaction and travelers’ socioeconomic characteristics. This study formulates both travelers’ parking and operators’ supply costs functions. This study further develops a mathematical programming model to determine optimum sizes and locations of the remote and terminal parking facilities. Results show the demand on terminal parking increases with an increase in travelers’ values of time. Results imply when the airport locates in a region with higher income residences, the remote parking facility should locate at a closer distance with higher parking fee while terminal parking supplies a considerable amount of stalls. As the land acquiring cost is less related to terminal access distance, a closer remote parking facility will not cause a higher operating cost. Remote parkers will benefit from both a relatively low parking fee and a short access time, thereby resulting in an increased demand.

Key Words: Terminal parking, Remote parking, Airport

1. INTRODUCTION

Airports have experienced a large traffic flowing in and out of airport parking areas, because of the continued growth of air traffic and heavily being relied on private automobiles. To alleviate the serious shortage of parking spaces around central terminal areas, the airport also operates remote parking facilities with shuttle buses in peripheral areas. A distant remote parking facility is advantageous to the operator due to the abundant area with low acquiring cost. However, travelers are less likely to park as the parking facility locates far from the airport terminal building, yielding an insufficient demand and a low utilization of the parking facility. The above process involves a trade-off between travelers’ demand and operators’ costs.

The total traveler demand on airport parking can be satisfied by both terminal and remote
parking. Generally, close-in terminal parking offers high parking fees but short access time, while remote parking provides low parking fee but long access time. These different service characteristics affect the travelers’ choices between terminal and remote parking, which further determines the utilizations of the parking facilities, thus their performances of providing the service. In addition, traveler demand on parking facilities is also characterized by their socioeconomic characteristics. Even when served by the same supply attributes, travelers with different characteristics perceive parking alternatives differently, which may further influence demand on the parking facility. It is important for the operator to investigate how traveler demand is affected by the parking fee and locations of parking facilities and their impacts on the total operating cost.

Previous studies have focused on analyzing terminal curb parking using engineering approaches (e.g. Parizi and Braaksma, 1993). Other studies analyzed parking space allocation or parking location choice but most have focused on metropolitan areas (e.g. Gur and Beimborn, 1984; Hunt and Teply, 1993). In these studies, linear programming, logit or gravity models were used. Hensher and King (2001) employed stated preference survey method to investigate the role of parking pricing and supply by time of the day in whether to drive or park in the central business district (CBD). Bonsall and Palmer (2004) reported on models developed from data collected using the parking choice simulator. This study also discussed the incorporation of these choice models into a network assignment model and concluded that much of the power of the choice models is lost if the network model is not able to support the use of information about travelers’ socioeconomic characteristics. Previous studies dealt with the size and location of different types of parking facilities mostly used manual approach, and moreover adopted the perspective of architecture design and/or operations research. However, there are few studies aiming to examine how the operating cost of parking facilities is affected by traveler demand and their impacts on the size and locations of the parking facility, which are important issues for the operator.

Hsu and Lin (1997) 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 facilities. Apart from the conventional logit model, the study 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 results showed that business and short parking duration travelers tend to choose the terminal parking, while non-business and long duration travelers prefer choosing the remote parking. Furthermore, reductions in access time and parking fees for a parking facility will stimulate parking demand for the facility. Though traveler choices on parking facilities have been explored, the interaction of traveler demand and operating cost related to different locations and sizes of terminal and remote parking facilities has seldom been investigated. In this study, optimal traveler parking choice model is formulated following Hsu and Lin (1997).

The terminal and remote parking facilities in this study are assumed to be the public infrastructure operated by the airport operator, where the former is located within walking distance of the terminal, while the latter is located at a distance beyond walking distance and served by shuttle buses. This study explores how to optimize the locations and sizes of the terminal and remote parking facilities in terms of their distance to the airport terminal building and the total stalls supplied by considering close demand-supply interaction. In addition, this study analyzes how the optimal sizes and locations of parking facilities are affected by the land acquiring cost and travelers’ values of time. Section 2 formulates a travelers’ parking choice model and aggregates the parking demand and stall demand on
terminal and remote parking. Section 3 formulates the total supply cost of terminal and remote parking. The optimal problem is also discussed in Section 3. In Section 4, a case study and numerical example are presented to demonstrate the application of the model. Finally, Section 5 presents the summary of the study.

2. PARKING DEMAND AND STALL DEMAND

This study assumes that total airport public parking demand is exogenously given. Travelers choose the optimal parking facility by minimizing their total parking costs with respect to parking duration and socioeconomic characteristics. The parking cost incorporates parking fee, access cost to the airport terminal building and searching cost for an available stall. Among these costs, an increased parking fee is usually resulted from an increased parking duration, especially for a terminal parking facility. The access cost includes the fare of shuttle buses, waiting time for a shuttle bus and travel time from the remote parking facility to the airport terminal building, where the last two time components are converted into cost by travelers’ values of time. In most airport remote parking, shuttle buses are free and there is no fare. The searching cost of an available parking stall depends on the utilization and mechanical parking device of the parking facility. Let $i$ denote traveler type and $v_i$ be the value of time of travel type $i$. For the sake of simplification, the airport travelers are classified as two types of travelers, i.e. business ($i=B$) and non-business ($i=NB$), where business travelers are characterized as with higher value of time than non-business travelers, $v_B \geq v_{NB}$.

Let $k$ denote the parking facility category, e.g., $k=C$ stands for the terminal parking facility and $k=R$ represents the remote parking facility. Following Hsu and Lin (1997), the parking fee and the average searching cost of traveler type $i$ who chooses parking facility $k$, $P_{ki}$ and $S_{ki}$ can be formulated, respectively, as follows

$$P_{ki} = f_k \cdot t_i$$

$$S_{ki} = 0.5 \cdot \sigma \cdot u_k \cdot \bar{t}_k \cdot v_i$$

where $F_k$ and $t_i$ in Eq. (1) represent the average hourly parking rate of facility $k$ and total parking duration of traveler type $i$; and $\sigma$, $u_k$ and $\bar{t}_k$ in Eq. (2) represent the parameters representing the effect of techniques used in the parking facility, utilization and average parking duration in parking facility $k$, respectively. Moreover, $\kappa$ and $\iota$ are parameters representing, respectively, the effects of utilization of parking facility, $u_k$, and the average parking duration, $\bar{t}_k$, on the average searching cost, $S_{ki}$. Note that the two parameters $\kappa$ and $\iota$ are positive values meaning that the searching cost is exponentially increased as more travelers park at the facility combined with long parking duration. The access cost of traveler type $i$ choosing remote parking and choosing terminal parking, $A_{Ri}$ and $A_{Ci}$, can be expressed, respectively, as

$$A_{Ri} = 2f + 2 \cdot v_i \left( \frac{h}{2} + \frac{d_R}{V_R} \right)$$

$$A_{Ci} = 2 \cdot v_i \cdot \frac{d_C}{V}$$

where $d_R$ and $d_C$ are the distances from remote and terminal parking facilities to the terminal building, respectively, while $V_R$ and $V$ represent the average speed of shuttle bus
and the average walking speed, respectively. Moreover, \( f \) and \( h \) express fare and headway of shuttle buses, which are determined by the operator. Note that variables \( d_r \) and \( d_c \) are the decision variables in the study. As shown in Eqs. (3) and (4), the access cost of travelers who choose remote parking is higher than those choosing terminal parking, due to not only the remote parking facility is distant but also there exists extra waiting time and/or charge for the shuttle buses. This study assumes that travelers choose the optimal parking facility so as to minimize the total parking cost. That is, the choice of parking at terminal parking facility depends on whether or not \( P_{ci} + S_{ci} + A_{ci} \leq P_{ri} + S_{ri} + A_{ri} \). Furthermore, as shown in Eq. (1), there is a direct relationship between total parking fee and parking duration. Other thing being equal, the optimal parking facility for traveler type \( i \) depends on whether \( t_i \) is greater than or less than a “critical parking duration”, denoted by \( t_i^* \). The critical parking duration is defined as the parking duration, which results in an indifference choice between remote parking and terminal parking. That is, the critical parking duration is the value of \( t_i \) which satisfies the following equation

\[
P_{ci}(t_i^*) + S_{ci} + A_{ci} = P_{ri}(t_i^*) + S_{ri} + A_{ri}
\]

From Eqs. (1) and (5), the critical parking duration, \( t_i^* \) can be further obtained as

\[
t_i^* = \frac{[S_{ri} - S_{ci} + (A_{ri} - A_{ci})]}{f_c - f_R}
\]

Eq. (6) shows the critical parking duration is the result of differences in access costs, searching costs and average hourly parking rate between remote and terminal parking. Airport travelers whose parking duration is shorter than the critical parking duration will choose terminal parking, while those whose parking duration is longer than the critical parking duration will choose remote parking. Moreover, the critical parking duration for business travelers, \( t_i^*_{B} \), is higher than that for non-business travelers, \( t_i^*_{NB} \), according to their values of time. Let \( f(t_i) \) be the parking duration distribution of travelers type \( i \). Based on the concept of the critical parking duration, the terminal parking demand, \( D_c \), and the remote parking demand, \( D_r \), can be, respectively, expressed as

\[
D_C = \sum_{i=B, NB} D_i \cdot \int_{t_i^*}^{t_i^*} f(t_i) dt_i
\]

\[
D_R = \sum_{i=B, NB} D_i \cdot \int_{t_i}^{t_i^*} f(t_i) dt_i
\]

where \( t_u \) and \( t_l \) represent the lower and upper bounds of parking duration distribution of traveler type \( i \) and \( D_i \) is the total parking demand of traveler type \( i \), respectively. The total parking demand of traveler type \( i \) can be estimated by the total parking demand, \( D \), and the proportion of the traveler type \( i \) to total parking demand, \( p_i \), such as \( D_i = D \cdot p_i \). Note that parking demand is measured as vehicles. Eq. (6) suggests an infinite critical parking duration if there are indifferent parking rates between remote and terminal parking, which further results in exclusively demand on terminal parking as shown in Eq. (7).

The stall time demand is defined as the total stall hours demanded on the parking facility during an observation period. The expected stall hours demanded by traveler type \( i \) with parking duration \( t_i \) can be expressed as \( D_i f(t_i) t_i \). The average number of parking stall demanded by these travelers, \( L(t_i) \) can be further calculated as

\[
L(t_i) = \frac{D_i f(t_i) t_i}{T}
\]
where $T$ represents the observation period. Considering all travelers with different parking duration, the expected parking stall demand on terminal parking, $L_C$, and on remote parking, $L_R$, can be formulated as follows

$$L_C = \sum_{i=0, NB} \frac{D_i}{T} \int_{t_i}^{t_i'} f(t_i) u_i dt_i$$

$$L_R = \sum_{i=0, NB} \frac{D_i}{T} \int_{t_i}^{t_i'} f(t_i) u_i dt_i$$

The utilization in Eq. (2) can then be expressed as

$$u^*_k = \frac{L_k}{Y_k}$$

where $Y_k$ is the number of stall supplied, i.e. the size of the parking facility, which is the decision variable in the study. In practice, the operator may determine an ideal utilization, $u^*_k$, then the optimal capacity of parking facility can be obtained.

3. PARKING SUPPLY AND STALL SUPPLY

The costs of providing the parking service are further discussed in the section. The total supply cost of providing the parking service can be classified as three categories, i.e. land acquiring and construction costs for the facility, the operating costs of the parking facility and shuttle buses. The extent of land acquiring cost involves the concept of opportunity cost, which arises from the scarcity of physical resources, at which choices of the resources can be made among a set of possibilities. In general, lands that have high opportunity cost tend to have high monetary cost, and lands which opportunity costs are low have low monetary cost. Since the available area at airport surroundings is limited, the competition among different types of public facilities and commercial activities in getting access to the area becomes increasingly fierce as the access distance approaching to the airport terminal building. That is to say, the land acquiring cost is negatively related to the distance to the airport terminal building, which can be illustrated as Figure 1.

![Figure 1 The relationship between the land acquiring cost and the distance to the airport](image)

Moreover, the extent to which the access distance influences the land acquiring cost should be different between the airport neighboring district and area outside the district. According to Kowalski and Parakevopoulos (1990), the land acquiring cost per unit area for parking facility $k$, $l_k$ can be formulated as
\[ l_k = \alpha_k \cdot e^{\beta_k d_k} \]  

where \( \alpha_k \) represents the base acquiring cost per unit area and \( \beta_k \) is the non-positive parameter representing the effects of the access distance on the land acquiring cost, respectively. Note that the base acquiring cost for the area surrounding the airport terminal building is higher than that for area outside the airport district, thus \( \alpha_c > \alpha_R \) and the impacts of the access distance on land acquiring cost of terminal parking are heavier than that of remote parking, thus \( \beta_c > \beta_R \). The required area of the parking facility can be estimated by the number of stall supplied, \( Y_k \), the average area per unit stall, \( a \) and floor space index \( c \). Then, the total land acquiring cost of parking facility \( k \), \( L_k \) can be formulated as

\[ L_k = l_k \cdot (aY_k) \cdot \frac{1}{c} \]

The related cost of operating the stalls involves stall construction cost and stall maintenance cost, where the former is classified as lumpsum cost, while the later is overheads. Economies of scale exist, since the average construction cost per unit stall and average maintenance cost per unit stall decrease with an increasing total number of stalls. Let \( \eta \) and \( \phi \) represent the base unit-stall construction cost and base unit-stall maintenance cost, respectively. The average construction cost per unit stall, \( c(Y_k) \) and the average maintenance cost per unit stall, \( m(Y_k) \) can be expressed as the functions of the number of stalls supplied and formulated as follows

\[ c(Y_k) = \eta \cdot e^{\gamma Y_k} \]
\[ m(Y_k) = \phi \cdot e^{\lambda Y_k} \]

where \( \gamma \) and \( \lambda \) are non-positive parameters representing the effects of economies of scale on the average construction and maintenance costs, respectively. The total construction cost, \( C(Y_k) \) and total maintenance cost, \( M(Y_k) \) can be further estimated as

\[ C(Y_k) = c(Y_k) \cdot Y_k \]
\[ M(Y_k) = m(Y_k) \cdot Y_k \]

Travelers who choose remote parking have to pay a price, i.e. fare of the shuttle bus, for transferring from the remote parking facility to the airport terminal building. The fare of the shuttle bus should reflect the cost of providing the service. The total operating cost of the shuttle bus is positively related to the frequency of shuttle buses and the access distance from the parking facility to the airport terminal building, \( d_k \). A distant remote parking facility combined with frequent shuttle bus may result in high operating cost. Assume that total capacities of the shuttle buses during the observation period must meet total parking demand on remote parking, which yields

\[ D_R = F \cdot Q \cdot l \]

where \( F \), \( Q \) and \( l \) are the number of shuttle buses dispatched during the observation period, the capacity and the average load factor of the shuttle bus, respectively. The average headway in Eq. (3) can be expressed as \( h = \frac{T}{F} \). This study assumes an identical shuttle bus where travel distance is the most influential factor affecting the cost of dispatching one shuttle bus. The average operating cost per unit shuttle bus, \( c_v \) is formulated as

\[ c_v = x \cdot d_R^\tau \]

where \( x \) represents the base unit-shuttle bus operating cost and \( \tau \) is the non-negative parameter representing the effect of travel distance on the operating cost, respectively.
total operating cost of the shuttle buses, \( C_v \) can then be formulated as

\[
C_v = c_v \cdot F
\]  

(21)

The operator may pass on the operating cost of the shuttle buses through either a part of parking fee or the fare of shuttle buses. Assume that the fare or fee as related to shuttle buses is priced according to the average operating cost of the shuttle buses. That is, the total revenue from operating the shuttle bus must cover the cost of providing the service, which yields

\[
C_v = f \cdot D_R
\]  

(22)

where \( f \) is the fare or fee of the shuttle buses in Eq. (3). From Eqs. (19) and (20), the fare or fee of the shuttle buses can be represented as

\[
f = \frac{x}{Q \cdot I} d_k^t
\]  

(23)

Where \( \frac{x}{Q \cdot I} \) is the base value of fare or fee of the shuttle buses.

The parking fee of remote parking and terminal parking are further discussed. In the study, the airport provides a public-pay parking facility for those individuals traveling from/to the airport. The parking fee is determined at which the balance of the total supply cost of operating the parking facility and the total revenue from the parking fee exists. A costly parking facility usually accompanies a high parking fee. In addition, the average hourly parking rate is also affected by the parking demand and yearly operation time. An increased parking rate is usually resulted from an insufficient parking demand, i.e. a low utilization, thereby yielding an increased average operating cost. This study denotes \( O \) as total operation hours of parking facilities in one operating year. The total revenue of parking facility \( k \) in one operating year can be estimated by the average hourly parking rate, \( f_k \), total operation hours, \( O \), the number of stall supplied, \( Y_k \), and average utilization, \( u_k \) as

\[
f_k \cdot O \cdot Y_k \cdot u_k
\]  

Since total revenue must cover total supply cost of the parking facility, the average hourly parking rate of parking facility \( k \) can be represented as follows

\[
f_k = \left[ L_k \cdot I + M_k (Y_k) + C_k (Y_k) \cdot \sigma \right] Y_k u_k / O
\]  

(24)

Where \( I \) and \( \sigma \) are average interest rate and recovery rate, respectively. Note \( \sigma = \frac{(1+I)^X}{(1+I)-1} \), where \( X \) represents the lifespan of the parking facility. As Eq. (24) shows, there exists a lower average hourly parking rate of remote parking resulting from a lower average total supply cost, as compared with that of terminal parking. However, as shown in Eq. (3), an increased access cost of the travelers incurs because of the distant parking facility far from the airport, especially for those with high values of time. Moreover, a profit margin may be realized by determining a higher average hourly parking rate than that as Eq. (24) suggested. Let \( q \) represent a reasonable rate of return, \( q \geq 0 \), such that the revenue is \( q \) times larger than the cost. Then, the average hourly parking rate is rewritten as

\[
f_k = \left[ L_k \cdot I + M_k (Y_k) + C_k (Y_k) \cdot \sigma \right] (1 + q) / Y_k u_k / O
\]  

(25)

Since the parking facility of the airport is classified as public infrastructure, the operator may aim to enhance the utilization of the facilities, while to maintain a least total cost of providing the service. Influences on total demand of terminal parking and remote parking include not only the parking fee, access cost to the airport terminal building and searching cost for an available stall, but also travelers’ perception towards the above supply attributes. Travelers with high value of time prefer parking at the terminal parking facility due to these travelers
are more concerned with the access time to the airport than the parking fee. Although the terminal parking facility can attract more travelers to park, the limited area around the airport hinders the operator from providing enough parking capacities. To maximize the service level for travelers and maintain a reasonable total cost of operating the parking facilities, the operator must carefully investigate how the parking demand is influenced by different service levels and determine the optimal size and location of the remote and terminal parking facilities.

This study formulates a mathematical programming model for determining the sizes and locations of both remote and terminal parking facilities by considering the relationship between the parking demand and the total cost of operating the facilities. This study assumes the operator is seeking to minimize the average total cost per unit stall-time of the travelers. The total cost of the individual traveler includes parking fee, access cost to the airport terminal building and the searching cost for an available stall, which are formulated, respectively, as Eqs. (1)-(4). The above cost items of all travelers can be estimated by summing up the costs of all types of travelers who choose either remote or terminal parking. Then, the total parking fee, \( P \), total access cost to the airport terminal building, \( A \) and total searching cost for an available stall, \( S \) can be, respectively, formulated as follows

\[
P = \sum_{i} F_C \cdot D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \cdot t \, dt_i + \sum_{i} F_R \cdot D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \cdot t \, dt_i 
\]

\[
A = \sum_{i} A_C \cdot D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \, dt_i + \sum_{i} A_R \cdot D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \, dt_i 
\]

\[
S = \sum_{i} S_C \cdot D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \, dt_i + \sum_{i} S_R \cdot D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \, dt_i 
\]

The total parking cost of all travelers can be expressed as \( P + A + S \). The total demand of stall time is further expressed as

\[
O = \sum_{i} D_i \cdot \int_{t_{i}}^{t_{i}} f(t_i) \cdot t \, dt_i 
\]

Then, the average total cost per unit stall-time, \( \pi \), can be calculated based on the total cost of the travelers and the total stall time, which yields

\[
\pi = \frac{P + A + S}{O} 
\]

The nonlinear programming model is formulated as follows.

Min \( \pi = \frac{P + A + S}{O} \) \hspace{1cm} (31)

s.t. (26)—(29)

\[
d_R, \quad d_C, \quad Y_R, \quad Y_C \geq 0 
\]

Eq. (31) represents the objective function that minimizes the average total cost per unit stall-time of the travelers. Eq. (32) constrains decisions variables, the distances from remote and terminal parking facilities to the terminal building, \( d_R \) and \( d_C \), and the number of stalls supplied by remote and terminal parking, \( Y_R \) and \( Y_C \), to be non-negative. Moreover, the critical parking duration for business and non-business travelers, \( T_B^\ast \) and \( T_{NB}^\ast \), the parking demand of remote parking and terminal parking, \( D_R \) and \( D_C \) and the stall demand of remote parking and terminal parking, \( L_R \) and \( L_C \) can be also obtained from the model.
4. CASE STUDY

A hypothetical example is illustrated in this section to demonstrate the application of the proposed model. Assume there are four million vehicles visiting the objective airport during the observed six months, where the number of business and non-business travelers are approximately the same, i.e. \( p_B = p_{NB} = 0.5 \) and the values of time for the two types of travelers are 0.2 and 0.15 US$/min, respectively. The initial values of base demand and supply parameters are assumed on basis of Hsu and Lin (1997) and shown as Tables 1 and 2. The model is programmed using GINO, a computer modeling program based on a generalized reduced gradient algorithm. Table 3 summarizes the initial solution results.

<table>
<thead>
<tr>
<th>Table 1 The initial values of base demand parameters</th>
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<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>( D_{NB} )</td>
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<td>( D_B )</td>
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<td>( V )</td>
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<td>( V_R )</td>
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<tr>
<td>( f(t_B) )</td>
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<td>( f(t_{NB}) )</td>
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<tr>
<th>Table 2 The initial values of base supply parameters</th>
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<tr>
<td>Parameter</td>
</tr>
<tr>
<td>( \sigma )</td>
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<td>( \kappa )</td>
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<tr>
<td>( \iota )</td>
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<tr>
<td>( \alpha_C )</td>
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<td>( d_{FR} )</td>
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<table>
<thead>
<tr>
<th>Table 3 Results and the optimal objective function value</th>
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<tbody>
<tr>
<td>Terminal parking</td>
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<tr>
<td>Distance to the airport (m)</td>
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<tr>
<td>Stall supply (stall)</td>
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<tr>
<td>Parking demand (veh)</td>
</tr>
<tr>
<td>Average hourly parking rate (US$/hr)</td>
</tr>
<tr>
<td>Average access time to the airport terminal building (min)</td>
</tr>
<tr>
<td>Average searching time for an available stall</td>
</tr>
</tbody>
</table>
As shown in Table 3, the remote parking facility locates far beyond the airport terminal area, resulting in an increased access time to the airport as compared with the terminal parking facility. Due to the low land acquiring cost, the number of stalls supplied at the remote parking facility are more than that at the terminal parking facility. Since the total cost of operating the remote parking facility is decreased, the operator could determine a relatively low parking fee so as to attract the demand and enhance the utilization of the facility. The results show the critical parking duration of business travelers is higher than that of non-business travelers in light of their value of time. The result also implies that the demand from business travelers on terminal parking exceeds that from non-business travelers. The phenomenon suggests that business and short parking-duration travelers are likely to choose more expensive but closer terminal parking. The results from the study also agree with the fact that the terminal parking facility is operated mostly for the use of travelers with short parking duration. Sensitivity analyses are further performed based on the data shown in Table 1 by varying the value of one or two parameters while holding the others constant.

The average walking speed will be improved if there is pedestrian-only sidewalk or people mover provided at the terminal parking facility. The increased walking speed leads to a decreased access time to the airport terminal building for travelers who choose terminal parking, as shown in Eq. (4). This study further examines how the optimal locations and sizes of remote and terminal parking facilities are influenced by the average walking speed. Figure 2 shows the optimal locations of the remote and terminal parking facilities, i.e. their distance to the airport terminal building, under varying average traveler walking speed. The numbers of stalls supplied on these parking facilities are shown in Figure 3.

As shown in Figure 2, the optimal distance for the remote parking facility from the airport terminal building is decreasing as traveler walking speed increases. The results imply that as travelers’ average walking speed increases due to there is automated people mover, the remote
parking facility should locate more closely to the terminal building, or else the remote parking will not compete with the terminal parking due to the excess access time.

Furthermore, more travelers are attracted by the convenient terminal parking, thereby yielding an increasing parking demand. Consequently, there will be an increase in the stall supply of terminal parking, resulting in a decreased number of stalls on remote parking, as shown in Figure 3. Nevertheless, in reality there is usually limitation in satisfying the demand of terminal parking, resulting from providing pedestrian-only sidewalk or people mover, since the available surrounding area for terminal parking is always constrained.

In this study, the land acquiring cost reflects the difficulty in searching an available area for constructing the parking facility. For a region of land scarcity, the acquiring cost will be considerably high even if the parking facility locates far away. The non-positive value of parameter $\beta_R$ in Eq. (13) represents the effects of the distance on the land acquiring cost with respect to remote parking, $k=R$ and terminal parking, $k=C$. Under an equal distance from the facility to the terminal building, an increased parameter $|\beta_c|$ leads to a decreased land acquiring cost, i.e. the area can be acquired without much effort and cost. Otherwise, the area is not accessible and the acquiring cost is high with a decreased $|\beta_R|$. Other things being equal, the varying difference in $|\beta_R|$ and $|\beta_C|$ will result in diverse sizes and locations for remote and terminal parking facilities. Figures 4 and 5 show the optimal sizes and locations of the remote and terminal parking facilities under varying values of parameter $|\beta_C|$, respectively.

The impact of the access distance on the cost of acquiring the land is higher with a lower $|\beta_R|$. As Figure 4 shows, the optimal location of terminal parking facility remains the same despite the lower values of $|\beta_C|$. The result can be explained as that though a decreased land acquiring cost can be achieved by a distant terminal parking facility, the increased access cost may result in an inferior objective function value, i.e. increased average total cost per unit stall-time of the travelers. Furthermore, the insufficient and costly resources keep the operator from operating large-scale parking facility around the airport. And to satisfy total travelers’ parking demand, there ought to be an increase in stalls supplied by remote parking, while a decrease on terminal parking. This study further examines how the location and sizes of terminal and remote parking facilities are affected by the accessibility of land beyond the airport region. Figures 6 and 7 show the optimal sizes and locations of the remote and
terminal parking facilities under the varying values of parameter $|\beta_R|$. 

As the resources become accessible, the parking facility can be located approaching the airport terminal building, without much cost increasing. As shown in Figure 6, the remote parking facility is closer to the airport terminal building as the value of parameter $|\beta_R|$ increases. Since the impact of distance on the land acquiring cost is less influential, the total operating cost is not increased with a closer parking facility. Travelers who choose remote parking will benefit from both a relative low parking fee and a decreased access time, resulting in an increased demand on remote parking while a decreased demand on terminal parking, as shown in Figure 7.

In this study, travelers’ values of time significantly influence parking demand on remote parking and terminal parking, which further determines the optimal sizes and locations of the parking facilities. Travelers’ values of time reflect travelers’ perceptions towards access time to the terminal building, searching time for an available stall, etc. Specifically, travelers with different values of time have different levels of concern with time and parking charges. This study captures the impacts of values of time of travelers on the optimal sizes and locations of the parking facilities by classifying total travelers into business and non-business types. The overall access cost and searching time cost will be higher as most travelers emphasize more on time than monetary cost, resulting in a deceased demand on remote parking and an increased demand on terminal parking. Figures 8 and 9 show the optimal sizes and locations of terminal and remote parking facilities under various combinations of business and non-business travelers’ values of time, where the first and second number in the parenthesis represent the values of time for business and non-business travelers, respectively.
Travelers with higher value of time are less price-sensitive and may be willing to pay a higher parking fee to access the airport faster. As shown in Figure 8, the location of remote parking facility ought to be less distant from the airport as average values of time for all travelers increase. Additionally, the operator can determine a relatively high parking fee for remote parking so as to compensate the high cost of operating the facility. However, travelers’ intention to park at the terminal parking facility is still high for high-income ones. As shown in Figure 9, the demand on terminal parking increases with increasing travelers’ value of time. In case that the airport locates in a region where there are more high-income residences, the finding suggests that the remote parking facility may locate at a closer distance with higher parking fee. And, the terminal parking should supply a considerable amount of stalls.

5. CONCLUSIONS

Past studies have investigated the sizes and locations of different types of parking facilities using manual approach or/and adopted the perspective of architecture design and/or operations research. However, there are few studies aiming to examine how the operating cost of parking facilities is affected by traveler demand and their impacts on the sizes and locations of the parking facilities. This study explores how to optimize the locations and sizes of the terminal and remote parking facilities in terms of their distance to the airport terminal building and the total stalls supplied by considering travelers’ socioeconomic characteristics and close demand-supply interaction. In addition, this study analyzes how the optimal sizes and locations of parking facilities are affected by the land acquiring cost and travelers’ values of time.

The result suggests that business and short parking-duration travelers are likely to choose the more expensive but closer central parking, which agrees with the fact that the terminal parking facility is operated mostly for the use of travelers with short parking duration. The results also imply that as traveler-walking speed increases due to there is automated people mover, the remote parking facility should locate more closely to the airport, or else the remote parking will not compete with the terminal parking due to the excess access time. Furthermore, more travelers are attracted by the convenient terminal parking, thereby yielding an increasing parking demand. Nevertheless, in reality, there is usually limitation in satisfying the demand of terminal parking, resulting from providing pedestrian-only sidewalk or people mover, since the available surrounding area for terminal parking is always constrained.
The results show the demand on terminal parking increases with increasing travelers’ values of time. In case that the airport locates in a region where there are more high-income residences, the finding suggests that the remote parking facility should locate at a closer distance with higher parking fee while terminal parking should supply a considerable amount of stalls. The results also show that as the distance from the terminal building has less effect on the land acquiring cost, a closer remote parking facility will not result in an increased operating cost. The travelers who choose remote parking will benefit from both a relative low parking fee and a short access time, resulting in an increased demand on remote parking while a decreased demand on terminal parking. In practice, travelers’ optimal parking is affected by the travel budget. Even though time-sensitive business travelers may choose remote parking due to limited total travel budget. Future studies may apply the model to investigate how the optimal sizes and locations of airport parking facilities are affected travelers’ budget. Such studies would need to examine the impacts of travelers’ value of time, travel budget and parking fee on the parking demand.

REFERENCES