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OPTIMIZATION OF AIRPORT PARKING FACILITIES SIZE, LOCATION AND CONNECTION

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ABSTRACT

In this paper, a decision making tool for the optimization of size and location of airport parking facilities is presented. The model is developed by considering travellers' socioeconomic characteristics, demand variability and infrastructure costs. After a review of the literature focused on parking space allocation, parking location choice and influence of operating costs, a mathematical model is applied for determining the optimum size, location, connection and fees of an airport parking facility.

Keywords: airport, parking facilities, optimization model.

INTRODUCTION

Airports have been characterized by a dramatic traffic expansion in and out of their parking areas, because of the constant growth of air transportation and the high percentage of private car utilization. The provision of car parking space and facilities is a key element of airport development and planning, because the convenience and flexibility of the private car implies that it is by far the most used and the easiest method for accessing airports both for passengers and visitors both for employees (Ashford *et al*., 1997). Consequently, airports should consider large parking capacity into their medium-long term planning.

Parking facilities, their main characteristics and location are important aspects of airport business. Indeed, they make up a considerable part of the total revenue at most airports. A survey performed by the Airport Council International (ACI, 1998) revealed that almost 50% of total revenues, during the '90s, at North American airports were generated by non-aeronautical sources, including parking. In the UK the revenues from commercial sources represent the 40% (Humphreys, 1999) of airport revenues and the ATRS global report (ATRS, 2003 in Oum and Yu, 2004) showed that the non-aeronautical revenues, for a sample of 16 large European airports are almost the 42% of the total amount of revenues.

In particular, some authors (Ashford *et al*., 1997; Maise, 1997) highlighted that in the largest airport (hub airports) the revenues generated from parking facilities are almost the 20% of the total. In Europe, airports raise around 13% of their income from car parking revenue (source: ACI, in Humphreys and Francis, 2002). The BAA annual report shows that in 2007 the net income from car parking facilities was about 33% of the total net retail income, with a growth rate of 5, 5%.

To mitigate the serious shortage of parking spaces around central terminal areas, and to reduce airport environmental impacts (Postorino and Mantecchini, 2014), airport operators often build remote parking facilities in peripheral areas provided with rapid connection transit systems (usually shuttle buses). A distant parking facility is advantageous for the airport operator because of the abundant areas with potentially low acquiring cost and because this solution can reduce the congestion near terminals. Nevertheless, travellers are less willing to use parking facilities located far from airport terminals, yielding an insufficient demand and a low utilization of the parking itself. The above process clearly involves a trade-off mechanism between travellers' demand and operating costs.

Previous studies analyzed the parking space allocation or the parking location choice focusing on metropolitan areas (e.g. Gur and Beimborn, 1984; Hunt and Teply, 1993; Hess and Polak, 2004). In these studies, linear programming, Logit, mixed Logit or gravity models were used. Hensher and King (2001) adopted a stated preference survey method to evaluate the role of parking pricing and supply 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. Previous studies which dealt with the size and location of different types of parking facilities usually adopted a simply approach, and moreover adopted the perspective of operational research and optimization techniques. However, in literature there are relatively few studies aiming at examining how the parking facilities operating costs are affected by travellers' demand and their impacts on the size and locations of the parking facility, which are important issues for the operator. The remote parking facilities considered in this study are operated by the airport operator, and are connected to the airport terminal by shuttle buses. This study explores how to optimize the size of the parking facilities and the total stalls supplied by considering in detail demand-supply interaction. Moreover, this study analyzes how the optimal characteristics of parking facilities are affected by the construction and operating costs and by the travellers' values of time.

The paper is organized as follows. After a short introduction, the section 2 explores the parking demand, stall demand, on terminal and remote parking. Section 3 formulates the total supply cost of parking facility. The optimal problem is discussed in Section 4. In Section 5, a case study with the numerical example is presented to

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demonstrate the application of the model. Finally, Section 6 presents the main conclusions of the study and explores further developments.

PARKING DEMAND ANALYSIS

In this paper, we work under the assumption that the total airport parking demand is exogenously given. The demand for airport parking space can be assumed dependant both on the average characteristics of the travellers both on the dispersion of the catchment area and the consequent availability of alternative transport modes, which can connect the airports with different locations. Travellers tend to minimize their total parking costs with respect to parking duration and socioeconomic characteristics. The parking cost includes: the parking fee, the access cost to airport terminal and the generalized searching cost for an available free stall. Among these costs, generally speaking, an increased parking fee is usually resulted from an increased parking duration but an higher hourly rate is typically associated at shorter durations, for instance this is the typical case for the business trips of 2 days. The access cost includes the waiting time for a shuttle bus, the fare of shuttle buses and the travel time from remote parking facilities and to the airport terminal. The last two time components can be converted into costs by considering travellers' value of time. In some airport remote parking, internal shuttle buses or other transit systems for airport remote parking facilities are free of charges (actually, the connection fee is included in parking rate) while the searching cost of an available parking stall is strictly related with the utilization factor of the parking facility.

Let *v* be the value of time of travellers. Following Hsu and Lin (1997), with some adjustments, we can formulate the parking fee *F* and the average searching cost *S* of travellers as follows:

$$F = ft$$
$$S = 0{,}5u^{\vartheta}t^{\beta}v$$

where *f* is the average hourly parking fee, *t* is the average parking duration (we suppose that f(*t*) has a normal distribution), *u* is the utilization ratio of the parking and *θ*, *β* are calibration parameters.
The access cost *A* of travellers can be expressed as:

$$A = 2p + 2v\left(\frac{\phi}{2} + \frac{d}{V}\right)$$

where *p* is the fare of the shuttle bus, *Φ* is the headway of bus service, *d* is the distance from the terminal and *V* is the commercial speed of shuttle bus.

The stall time demand is defined as the total stall hours demanded on the parking facility during an observation period (for example one year). Let *D* the total parking demand and f(*t*) the parking duration distribution, the expected stall hours demanded by a traveller with parking duration *t* is *D*f(*t*)*t*. The average number of stall demanded by travellers can be written as:

$$L(t) = \frac{Df(t)t}{T}$$

where *T* is the analysis period (i.e. one year). Then, the expected value of parking stall demand can be expressed as follows:

$$L = \frac{D}{T}\int f(t)tdt$$

Furthermore, being *B* the number of stall supplied (the capacity of the parking facility), the parking utilization factor u can be easily obtained as:

$$u = \frac{L}{B}$$

The parking facility demand is considered as an exogenous variable even if it is a paramount factor influencing the planning and management of parking facilities. The demand evaluation is among the main source of inaccuracy of the model and it is dependant on the uncertainty in air traffic demand forecast. This aspect will be analyzed hereafter.

PARKING SUPPLY ANALYSIS

The total supply cost to provide the parking service can be divided in three categories: land acquiring and construction costs for the facility, operating costs and costs for the connection with airport terminals (i.e. shuttle bus or transit system).

The complexity of the land acquiring cost evaluation involves the concept of opportunity cost, which arises from the scarcity of resources and the potential value, considering that the choice of the resources can be made among a set of possibilities. Generally speaking, lands that have an high opportunity cost tend to have higher monetary cost, and lands whose opportunity costs are low have lower monetary cost. Since in airport surroundings the availability of land for parking facilities is usually limited, the competition among different types of facilities and commercial activities becomes increasingly strong as the access distance approaches to the airport terminal. Moreover, traffic congestion in road network near terminals is usually high. Consequently, airport operators often locate new parking facilities in remote positions from the terminal, in peripheral areas, with a lower acquiring cost and lower congestion and accessibility problems.

The required area for the parking facility can be estimated by the number of stalls supplied, *B*, the average area per unit stall, *a*, and the floor index ratio, *γ*. The latter

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is an index related with the number of floors of the parking facility. Obviously, the higher the number of floors, the lower the land required, but the higher the construction cost. Named *c* the unit cost of land acquiring, the total land acquiring cost C_T is given by:

$$C_T = c(aB)\frac{1}{\gamma}$$

Parking operating costs involve the stall construction costs and the stall maintenance costs, where the former is classified as lump sum cost, the latter as overheads. Considering the existence of economies of scale, the average construction cost per unit of stall and the average maintenance cost per unit of stall decrease when the total number of stalls increases. Let *n* and *m* be the base unit construction cost and the base unit maintenance cost of a stall, the average construction cost $N(B)$ and the average maintenance cost $M(B)$ can be expressed as follows, adopting an exponential law:

$$N(B) = n \cdot e^{\alpha B} B$$
$$M(B) = m \cdot e^{\varepsilon B} B$$

Where α and ε are non-positive parameters representing the effect of economies of scale on the average construction and maintenance costs, respectively. The travelers that choose remote parking facilities have to pay a connection price (i.e. fare of the shuttle bus or transit system) from the remote parking facility to the airport terminal. The fare of the connection system should reflect the providing cost of the service and the total operating cost of the shuttle bus is related to the frequency of the service, φ and to the access distance, *d*. The capacity of the connection service satisfies the total parking demand, thanks to a total number of *Z* vehicles (shuttle buses), with a capacity *Q* and a predefined load factor.

Given an average operating cost per shuttle bus, *r*, the total operating cost of the shuttle bus service can be expressed as *rZ*. Assuming that the total revenue from shuttle bus operation must cover the cost for providing the service, being *z* the service fare, we can write:

$$z = \frac{r}{Q}$$

The parking fee is determined by balancing the total supply cost and the maintenance operative cost during the entire useful life of the infrastructure with the expected total revenues generated by the parking in the same time lapse. A costly parking facility in general gives a higher parking fee. In addition, the average hourly parking rate is also affected by parking demand and duration.

However, in the case of a low utilization of the parking facility the operator can raise the fees in order to meet the costs and the budget scheduled, consequently the users are subjected to a higher parking costs. The accuracy of the evaluation and forecasting process of parking demand is a crucial element of the analysis. Denoting with *H* the total operation hours of parking facilities in one year, being *f* the average parking fee, the total annual revenue generated by a parking facility with *B* stall and with average utilization factor *u* is given by *fHBu*. Since total revenue must balance the total supply cost of the parking facility, the average parking fee can be represented as:

$$f = \frac{C_T i + N(B)\sigma + M(B)}{(Bu)/H}$$

Where *i* is the average interest rate and *σ* is the average capital recovery rate, the latter calculated for a given lifespan of the facility. A profit margin may be realized from the parking, by determining a higher average hourly parking rate. Let *q* represent a reasonable rate of return, $q>0$, such that the revenue is *q* times higher than the cost:

$$f(q) = \frac{[C_T i + N(B)\sigma + M(B)] \cdot (1+q)}{(Bu)/H}$$

Influences on total demand of parking include not only the parking fee, access cost to the airport terminal and searching cost for an available stall, but also travelers' perception towards the above described supply characteristics. Travelers with high value of time (business travelers) usually prefer parking facilities located near the terminals, because they are more concerned with the access time to the airport than the parking fee. To maximize the service level for travelers and to maintain a reasonable total cost, airport operators must carefully investigate how the parking demand is influenced by different service levels and determine the optimal size and location of parking facilities.

THE OPTIMIZATION MODEL

This study is focused on the formulation of a mathematical programming model for determining the size and the main operating parameters of an airport parking facility, by considering the relationship between the parking demand and the total costs. This study assumes that the operator is seeking to minimize the average travelers total cost per unit of stall-time. The total cost of the individual traveler includes the parking fee, the access cost to the airport terminal and the searching cost for an available stall, which have been previously formulated. Then, the total parking fee, the total access cost to the airport terminal, and the total searching cost for an

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available stall can be, respectively, formulated for all travelers as follows:

$$\overline{F} = FD\int f(t)tdt$$
$$\overline{A} = AD\int f(t)dt$$
$$\overline{S} = SD\int f(t)dt$$

The total parking cost of all travellers can be expressed as (*F*+*A*+*S*). Furthermore, the total demand of stall-time is expressed as:

$$\overline{D} = D\int f(t)tdt$$

Then, the average total cost per unit-stall time, *Ω*, can be easily calculated basing on the travellers total cost and the total stall time:

$$\Omega = \frac{\overline{F} + \overline{A} + \overline{S}}{\overline{D}}$$

The objective function and the program can be conceptually formulated as follows:

$$\text{Min}\ \Omega = \frac{\overline{F} + \overline{A} + \overline{S}}{\overline{D}}$$

The project variables are:

- number of supplied stall, *B*;
- parking fee, *f*;
- shuttle bus fee, *z*;
- operating parameters of connection service (nr. of buses *Z* and service frequency *φ*).

CASE STUDY

This paragraph introduces a practical application of the proposed model and above presented. The analysis is performed taking a large regional airport (with above 4.000.000 pax/year) as an example and considering the need of expanding parking facilities. Most of regional airports are surrounded by dwellings which make it difficult to build parking nearby the existing terminals.

In the case study examined the parking proposed is located 3 km far from the main terminal. The connection between the parking and the terminal is provided by a shuttle bus service. The demand for parking facility is taken as an exogenous datum, since the evaluation of the relationship between air traffic demands and parking facility demand goes beyond the scope of this paper, however demand forecast is among the most important aspects of the all process. The case study is based on the hypothesis of building a remote parking facility in a remote area around 3 kilometers far from the main building. The facility considered is a three floors building and it is supposed to be aimed at accommodating leisure passenger cars. The expected demand has been estimated in 400.000 vehicles/year. The program has been developed by utilizing specific software for solving linear and nonlinear optimization programming. The values of the parameters contained in the proposed model have been chosen on the one hand considering real values corresponding to practices adopted in a sample of Italian regional airports, on the other hand they have been hypothesized following current practices. These values are reported in Tables 1 and 2.

Table-1. Initial values of demand parameters.

Parameter	Value	Unit
D	400.000	vehicles/year
V	6,9	m/sec
f(*t*)	Normal (72, 242)	

Table-2. Initial values of supply parameters.

Parameter	Value	Unit
V	6,9	m/sec
Θ	2	
B	0,5	
D	3.000	m
A	24	m^2
C	1.400	€/ m^2
Y	3	
A	-0,0001	
E	-0,0001	
N	9.000	€/stall
M	700	€/stall
R	12	€/trip
I	2%	
Σ	5%	
lifespan	15	years
Q	20%	m/sec
V	6,9	m/sec

The results of the application of the model, considering the input data in Table-1 and Table-2, are provided in Table-3 hereafter.

Table-3. Results of the optimization program.

Variable	Value	Unit
Stall supply	2240	stall
Average parking fee	0,47	€/h
Average searching cost	8,13	€
Headway of shuttle bus	2	minutes
Capacity of shuttle bus	60	passengers
Fare of shuttle bus	0,4	€
Average utilization factor	0,81	
Stall supply	2240	stall

The program provides the values of the main variables as the output. In detail the use of the proposed solution presents a reserve of capacity of the 19% (utilization factor = 0.81). This results in the possibility of accommodating future traffic demand growth.

Uncertainty regarding air traffic demand forecasts in a particular airport, and consequently the private vehicle parking demand, is a constraining element for the infrastructural choice adopted to accommodate this demand.

In Table-4 a series of brief economic indicators (cash-flow) of the project are evaluated and proposed. These indicators are calculated considering an average lifespan of the project of 15 years and a constant vehicle parking demand rate (evaluated as a percentage of air transport demand at the airport).

Table-4. Main economic indicators.

Parameter	Value	Unit
Demand	16.000.000	vehicles/h/year
Capacity	19.622.400	stall/h/year
Actualized revenues	7.515.605	€/year
Land and building costs	5.325.067	€/year
Operating costs	1.432.868	€/year
Cash flow	257.669	€/year

CONCLUSIONS

Parking facilities not only represent commodities for accommodating private vehicles for airports' passengers, but are more and more considered as among the major sources of non-aviation revenues for airport operators. This implies that airport operators seek to maximize the revenues stemming from such facilities.

This paper presents a comprehensive methodology for assessing the main parameters related with airports parking infrastructure planning, design and management. The methodology presented is based on mathematical programming and suggests an analytical approach with the aim of maximizing revenues and minimizing the uncertainty during the entire useful life of the infrastructure.

The results of the case study demonstrate the effectiveness of the proposed model. In particular, starting from the initial demand and supply values (Tables 1 and 2), the cash flow of the project (Table-4) confirms the economic sustainability of the main operating parameters obtained from the optimization program (Table-3). Due to parking demand uncertainty, the number of stall supplied is greater than the initial stall-hour demand. This represents a capacity reserve, useful to accommodate possible future parking demand growth.

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