AIRPORT PASSENGER HANDLING AT THE INTERFACE

A Problem of Modal Choice

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This paper[1] is concerned with a particular problem in airport design which governs the allocation of passengers between different means of transfer from terminal to aircraft (or aircraft to terminal). The essential analytical point is common to many transport planning situations: the choice between a facility that involves high fixed but low operating costs and one with the opposite characteristics, the advantage of the former being low unit costs when operated at full capacity. Here we are concerned with the choice between *finger piers* and *articulated passenger vehicles.* The finger piers are more capital-intensive and "fixed" in the sense of having to be installed for a long period and thus not adjustable to seasonal variations in traffic, while the articulated vehicles incur high operating costs in labour and fuel but are brought into operation only when required.

This aspect of airport planning is discussed in the overall context by Horonjeff [5], and some of the practical points in decisions of this type are described in Kuckuck [6]. In contrast to the specific numerical solutions explored in de Neufville [2], this paper derives a general solution to the problem of allocating passenger transfers, although data from [2] is used to illustrate the results. In fact, the form of solution presented here could be simply applied to the choice between modes of different capital-intensity in similar transport planning situations where peaking is present. Possibly it could be applied even more widely—to problems such as those discussed in Turvey [7].

AN ANALYTICAL MODEL

The object of the exercise is to choose the least-cost means of transferring passengers between terminal and aircraft. The essential difference between the piers and the APVs is that the piers have a cost function almost entirely composed of the fixed cost of construction, while that of the APVs contains a large proportion of variable costs; but when the piers operate at full capacity their unit cost is lower than that for an APV. Generally, therefore, we would expect that, where there is a peaked flow of traffic over a period, an optimal allocation of passengers between the two modes would involve the use of APVs at the peak and piers for the base traffic—the problem being to choose the exact combination that will minimise costs.

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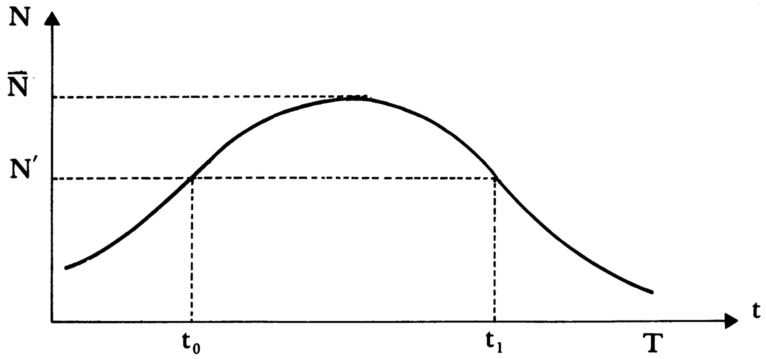

Diagram 1

In formal terms, let us suppose a given traffic pattern over time such that the passenger flow is N_t at any one point in time *(t)* over the period as a whole *(T)*. In fact, the contribution of transfer costs to total trip cost is too small for the solution chosen to affect demand significantly. We have an aggregate of passengers for the whole period:

$$\hat{N} = \int_0^T N_t \cdot \mathrm{d}t \tag{1}$$

and a maximum at the peak of:

$$\bar{N} \geqslant N_t \text{ for all } t$$

Let us define a certain traffic flow (N') which is to be handled by the piers alone, the remainder being handled by APVs. These definitions are shown in Diagram 1, the points in time (t_0, t_1) being defined as those where

$$N_t = N' \tag{2}$$

Let us suppose cost functions such that capacity is infinitely divisible and annual capital charges are the product of this and the unit capital cost *(k)* of capacity sufficient to serve one passenger per hour To this must be added the operating costs, which are the product of the passenger flow at any one point in time and the unit handling cost *(v)*. For piers, the operating costs may be taken as negligible, and capacity depends upon the decision variable (N'):

$$C_p = k_p \cdot N' \tag{3}$$

and for the APVs a slightly more complex:

$$C_a = k_a(\bar{N} - N') + v_a \int_{t_0}^{t_1} (N_t - N')\mathrm{d}t \tag{4}$$

We can now formulate the general properties of the cost functions as

$$k_p > k_a$$

$$k_p < k_a + v_a \cdot T$$

and define the total cost function *(X)* which is to be minimised as:

$$X = C_p + C_a$$
$$= k_p \cdot N' + k_a(\bar{N} - N') + v_a \int_{t_0}^{t_1} (N_t - N')\mathrm{d}t \qquad (5)$$

A necessary condition for the minimum, assuming no corners in the vicinity of the solution, is

$$\frac{\mathrm{d}X}{\mathrm{d}N'} = 0$$

Differentiating the function, which is quite simple because the terms in dt/dN' and dt_0/dN' each cancel out, gives from (5):

$$\frac{\mathrm{d}X}{\mathrm{d}N'} = k_p - k_a - v_a(t_1 - t_0)$$

or

$$k_p = k_a + v_a(t_1 - t_0)$$

In other words, at the optimum, the cost of expanding pier capacity by one passenger per hour is just equal to the capital cost of putting on one more unit of APV capacity and operating it for the relevant period—so that we are indifferent to the mode used by the marginal passenger. In fact, this *is* the minimum, because by differentiating (7) again, we get:

$$\frac{\mathrm{d}^2X}{\mathrm{d}N'^2} = - v_a \left\{ \frac{\mathrm{d}t_1}{\mathrm{d}N'} - \frac{\mathrm{d}t_0}{\mathrm{d}N'} \right\} > 0$$

The solution ($\tilde{N}'$) at the optimum can now be found easily. In principle, it is derived from the traffic function (N_t) for the root values satisfying equation (7). In practice, once the traffic curve has been plotted, the critical value of N' can be found by inspection—using (7):

$$t_1 - t_0 = (k_p - k_a)/v_a$$

We now have the optimal capacity for piers ($\tilde{N}'$) and thus that for APVs ($\tilde{N}$-$\tilde{N}'$). It should be noted that this solution is independent of the traffic level near the peak ($\bar{N}$), but the form does depend upon the constancy of the marginal cost parameters.

We can generalise the result to allow for any traffic pattern over time, as the only real requirement is that the sum of the periods in which traffic exceeds the critical flow ($N_t > \tilde{N}'$) should equal the "threshold" value. For the form in Diagram 2, the solution is:

$$(t_1 - t_0) + (t_3 - t_2) = \frac{k_p - k_a}{v_a}$$

This we can then generalise to give the threshold value *(Z)*:

$$\sum_j (t_{2j+1} - t_{2j}) = \frac{k_p - k_a}{v_a} = Z$$

It will have been noted that we have assumed in this analysis that capacity is divisible—in other words, that a "tenth of a pier" or "half an APV" can be installed. This is clearly not so, but to find an integral solution would be an extremely

TABLE 1

Basic Data

Construction Costs	*Finger Piers*			*Articulated Passenger Vehicles*								
	Fixed Costs $ *per a/c per hr*			*Fixed Costs* *per a/c per hr*				*per APV per hr*		*Variable Costs*		
$ *per sq. ft.*	*Building*	*Air Bridges*	*Tugs*	*Apron Service Building*	*Crew Buses*	*Crew Stairs*	*Additional Terminal Building*	*APV Ramp and Roadway*	*APV*	*Crew Buses*	*Crew Stairs*	*APV*
				$	$	$	$	$	$	$	$	$
100	900,000	135,000	65,000	7,715	15,000	45,000	140,000	85,000	115,000	30,000 Per a/c	60,000 Per a/c	50,200 Per APV
75	675,000	135,000	65,000	7,715	15,000	45,000	105,000	85,000	115,000	30,000 Per a/c	60,000 Per a/c	50,200 Per APV
Lifespan	yrs 20	yrs 10	yrs 10	yrs 20	yrs 5	yrs 8	yrs 20	yrs 20	yrs 20			

Type of aircraft	*Boeing 747*	*DC10/ L1011*	*Boeing 707/DC8*	*Boeing 727*	*Boeing 737/DC9*	*Average no. of APVs per a/c required for each a/c in the mix*
	%	%	%	%	%	
Mix I	10	0	35	30	25	1.20
Mix II	15	15	25	25	20	1.45
Mix III	20	40	10	10	20	1.80

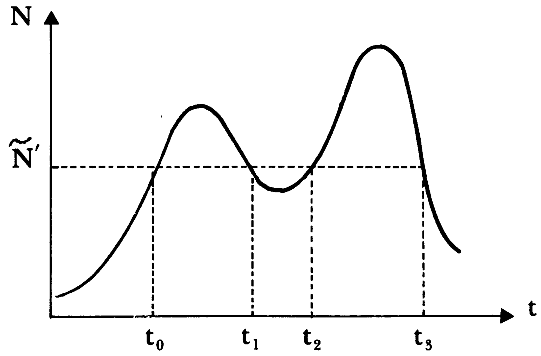

Diagram 2

long process, if vast numbers of possible combinations of piers and APVs were to be simulated over the expected traffic pattern to find the minimum cost combination. Our "continuous" solution provides a rapid and reliable way to establish the "neighbourhood" of the correct integral solution. In effect, what is done is to explore the nearest integral values for the number of piers (the number of APVs being the complement to this) and to choose that which minimises the cost function *(X)*. This procedure is very rapid, and essential when a large number of annual solutions have to be found in a dynamic planning process: a similar methodology has been applied to runway expansion by FitzGerald and Aneuryn-Evans [3].

AN ILLUSTRATIVE EXAMPLE

A particular problem in airport planning is the tendency to employ capital-intensive "structural" solutions rather than more flexible ones involving a greater current cost element. This may arise from the general practice of state subsidies being given for investment costs; but, even if full economic cost is applied, the natural preference of designers for permanent monuments can lead to unwieldy and costly solutions.

To illustrate the use of this model, we shall examine the relationship between the threshold period *(Z)* and the main capital cost parameters: construction and interest rates. To the extent that these, and the current cost parameters for APVs, are common to all airports, a general solution can be derived—although, of course, a specific pattern of traffic would have to be used to calculate the actual capacities required. The imputation of general cost data would also allow us to examine the sensitivity of the solution to reasonable parameter variations.

De Neufville [2] presents a cost-effectiveness analysis of airport terminal design which includes standardised data that is ideal for our purpose. In fact, de Neufville does tackle modal application, but only in numerical form and without capturing the peaking problem. His standardised unit costs (for U.S. airports in 1970) are shown in Table 1. We have assumed that each pier has one gate, and have also added variants of the "aircraft mix" which affects the number of APVs

TABLE 2

Variations in the Solution

Construction Cost $ per sq. ft.	a/c Mix	Discount Rate %	k_p $ per a/c per hr	k_a $ per a/c per hr	v_a $ per a/c per hr	Z %
100	I	10	138,255	61,218	150,240	51
		15	183,642	80,923	150,240	68
	II	10	138,255	71,202	162,790	41
		15	183,642	94,504	162,790	55
	III	10	138,255	85,179	180,360	29
		15	183,642	113,516	180,360	39
75	I	10	111,828	56,285	150,240	37
		15	147,694	74,213	150,240	49
	II	10	111,828	65,241	162,790	29
		15	147,694	86,396	162,790	38
	III	10	111,828	77,780	180,360	19
		15	147,694	103,451	180,360	25

required to serve a single aircraft in the same time as a pier—these too are shown in Table 1. This data is then elaborated (see Abdelmoneim [1] for more details) to produce the variables that interest us, for a range of construction costs, discount rates and aircraft mixes—the results being shown in Table 2. The fixed cost parameters (k_p, k_a) are converted to annual values by applying the usual amortisation formula containing the discount rate. It should also be noted that the variable cost parameter (v_a) is expressed in units such as to represent the cost of operating an APV throughout the total period *(T)*, the hourly cost being the dividend of these (ie v_a/T).

The results show that a mixed strategy is generally optimal (i.e., the ratio *Z* is neither zero nor one); this confirms the suggestions in de Neufville [2] and Kuckuck [6]. As might be expected, higher construction costs and higher discount rates favour the use of APVs because of their higher component of operating cost, while mixes with more of the larger aircraft favour the use of piers because of their high throughput rates. Other things being equal, we may suppose that aircraft size will increase over time and that wage rates will rise faster than the cost of capital. In that case (to use the jargon of the airport planners) the "structural concept will become more attractive".

Finally, for illustrative purposes alone, Abdelmoneim [1] has applied the model with these cost parameters (and thus the results in Table 2) to the traffic pattern at Gatwick Airport for 1973-4. The output of the exercise has no policy implications whatsoever, of course, but does illustrate the important effect of the discount rate and the aircraft mix on the optimal pier capacity (N'). For example, the results for

TABLE 3

An Applied Example

A/C Mix	*Discount Rate %*	*Z %*	*% of total passengers handled by piers*	*% of total passengers handled by APVs*	*Pier capacity % of maximum flow*
I	10	51	56	44	13
	15	68	35	65	7
II	10	41	67	33	17
	15	55	51	49	11
III	10	29	77	23	22
	15	39	69	31	18

a construction cost of $100 per square foot are as follows. For "Mix III" and a 10 per cent discount rate, the piers should be designed to handle the passenger flow which is exceeded for only 29 per cent of the time. This turns out to be 3364 passengers per hour, equivalent to 22 per cent of the maximum flow. APVs would meet the remaining 78 per cent of the maximum flow but would only handle 23 per cent of annual traffic.

These explorations immediately underline the need for models of this kind in airport planning. They are needed for two reasons. First, the correct balance of APVs and finger piers is highly sensitive to the capital cost element, which may vary sharply from one case to another and (more important) over time, so that a rapid means of recalculating the optimal allocation would clearly be useful. Second, probability functions could easily be introduced to these models for use in flexible forecasting. This is valuable, even though the uncertainty about future peak traffic levels is mitigated by the fact that for a considerable proportion of the cycle the volume of traffic is well below the peak, so that the pier capacity can be planned with some confidence even though piers take time to install, while APVs or even buses can be brought in rapidly as fluctuations warrant.

CONCLUDING REMARKS

While it is easy to point out the failings of an analytical model as simple as that just presented, it does provide the theoretical basis upon which it is possible to erect further constructs covering economies of scale, indivisibilities and congestion, without being forced into the "particularism" of numerical solution. Further, it does have implications for other situations where capital-intensive facilities are proposed in substitution for labour-intensive operations when demand varies widely over the year.

REFERENCES

[1] Adelmoneim, A. A.: *Airport Planning: Optimal Techniques for Passenger Handling at the Interface.* M.Sc. Dissertation, Department of Land Economy, Cambridge, 1976.

[2] de Neufville, R. *et al.*: *Optimal Use of Vehicular Systems in the Design of Airport Terminals.* Civil Engineering Systems Laboratory, Massachusetts Institute of Technology, 1971.

[3] FitzGerald, E.V.K., and Aneuryn-Evans, G. B.: "The Economics of Airport Development and Control." *Journal of Transport Economics and Policy,* Vol 7, No 3, September 1973.

[4] Horner & Shifrin Inc.: *Terminal Area Comparative Study on Lambert-St. Luis (Missouri) Municipal Airport.* Chapter IV. New York 1969.

[5] Horonjeff, R.: *Planning and Design of Airports.* McGraw-Hill, New York, 1962.

[6] Kuckuck, H. H.: "Mobile Lounge or Fixed Gates?" *Airport Forum,* No 1, 1975

[7] Turvey, R.: *Optimal Pricing and Investment in Electricity Supply,* Allen & Unwin, London, 1968.