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Airport Terminal Building Planning: A Theoretical Approach

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1.00 INTRODUCTION

IN THE PLANNING of transport facilities a fundamental question of resource allocation always arises: should we design the facilities according to peak demand, thereby creating the problem of underutilization of capacity during off peak periods or should we cater to average demand, hence facing congestion during peak periods? Let us illustrate this question by a hypothetical distribution of hourly passenger volume for the design year, represented by the following diagram.[1]

PASSENGER DISTRIBUTION AND THE CHOICE OF PLANNING STANDARD

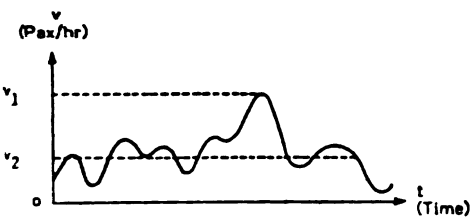

FIGURE 1

In this diagram v_1 and v_2 represent respectively the peak and average hourly volumes of passengers using a certain airport. If this airport is designed to meet the demand denoted by v_1, an underutilization of resource will result since v_1 occurs only once in the whole year. On the other hand, if the airport is designed to meet v_2, congestion will take place whenever the hourly volume of passengers exceeds v_2.

Several authors have looked into this problem. Horonjeff [4], for example, recognized the need for using a 'typical peak-hour' passenger volume in airport planning. Although Horonjeff did not define what constitutes this measure, he indicated that this design hourly passenger volume is usually in the range of 0.03 to 0.05 of the annual volume. Beinhaker and Elek [2] proposed the use of the hourly passenger volume which is exceeded not more than 15 times in the year. In this case, these authors contended, only a small proportion of the passengers (much less than 5%) will be subject to conditions less favourable than the conditions in the design peak hour.

In the U.S., one of the methods generally adopted in airport planning is to determine the peak month for passenger traffic and use the average day of that month as the design day [5]. An analysis of the peak periods during that day is essential in order to minimize the effects of critical peaks on airport facilities.

Similar problems of choosing a design criterion are also encountered in highway planning [3]. In fact, a highway designed to give an acceptable level of service on the basis of the average hourly traffic volume would be less than adequate on many occasions when higher demand existed. On the other hand, a highway designed to provide a high demand of service for the maximum recorded hourly volume would have substantial excess capacity during all but one hour of the year. The selection of an appropriate design criterion is, therefore, a trade-off between the service provided and cost. In the U.S., the 30th highest hourly traffic volume is frequently used in highway planning.

Recently, the 90th percentile of the annual deplaning passengers distribution has been used as an interim design standard in planning of terminal buildings of major airports in Canada. Essentially, this is the hourly passenger volume which is exceeded by only a small number of hourly passenger volume observations under consideration, the total of which represents 10% of the total passenger volume involved. The 90th percentile criterion implies that less than 10% of passengers would experience a level of service lower than that corresponding to the design volume.

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The method of basing design criteria upon a particular "peak" period traffic has been challenged on the grounds that the total benefit and cost of alternative design options over all times of airport operation are ignored and that this leads to distorted evaluations [5]. It should be recognized that where safety is of prime importance (for instance, in the provision of runway capacity and facilities in aid of air navigation), cost-benefit analysis is impracticable mainly because the costs of accidents are appalling and at the same time virtually unquantifiable. In the design of airport terminal buildings, however, the consequences of congestion, on the one hand, and underutilization during off-peak periods, on the other hand, are estimable albeit with difficulty. These costs and benefits can be expressed in terms of passenger convenience/inconvenience as well as capital and operation and maintenance costs. Trade-offs between these costs and benefits can then be used to determine optimum design criteria for air terminal buildings. This is the subject of discussion of this paper.

2.00 A THEORETICAL APPROACH

Let us consider an airport designed at a standard $\bar{v}$ and having the following annual distribution of hourly passenger volume v(t) during the design year for which there are T observations.

PLANNING STANDARD AND PASSENGER CONVENIENCE/INCONVENIENCE

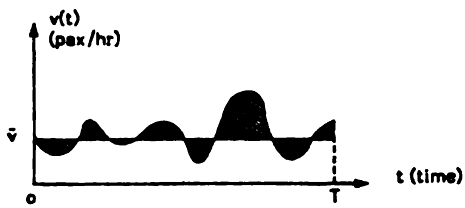

FIGURE 2

It can be seen that when v exceeds $\bar{v}$, the design or planning standard, passengers will experience inconvenience due to congestion and when v is below $\bar{v}$, passengers will derive some convenience due to the underutilization of facilities.

Let the proportional deviation of the hourly passenger volume from the planning standard be denoted by w:

$$w(t) = [v(t) - \bar{v}]/\bar{v}$$

and let f [w(t)] be the function representing passenger convenience or inconvenience per passenger per unit of time (expressed in monetary terms for example) at time t:[2]

passenger convenience is represented by $f[w(t)] > o$,

passenger inconvenience is represented by $f[w(t)] < o$,

We call f[w(t)] the passenger-convenience density function.

Assuming that passenger inconvenience increases rapidly as passenger volume rises further and further from the planning standard, while passenger convenience increases slowly as passenger volume falls from it, we can postulate that f[w(t)] has the following form:

PASSENGER-CONVENIENCE DENSITY FUNCTION

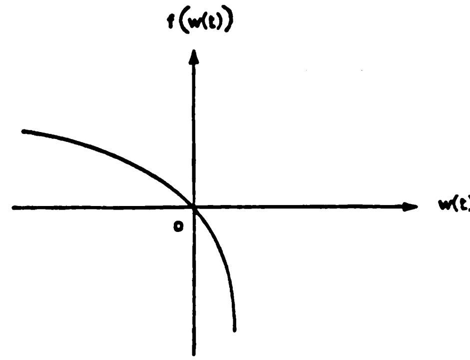

FIGURE 3

If both functions f[w(t)] and w(t) are plotted on the same graph, we have the following curves. (See Figure 4).

Let Z be the net convenience accruing to passengers during the design year due to deviations from the planning standard, we have:

$$Z = \int_{t=o}^{t=T} f[w(t)]\, v(t)\, dt = g(\bar{v})$$

It can be proved that $Z = g(\bar{v})$ has concave form as a consequence of the assumptions underlying f[w(t)]. If $\bar{v}$, the planning standard, is set very low, construction and operation and maintenance costs will be low but passengers will experience inconvenience due to congestion. On the other hand, if $\bar{v}$ is set very high, construction and operation and maintenance costs will be high but passengers will experience extra convenience since facilities will not be fully used. There is, consequently, a trade-off between these costs and passenger convenience. Assuming that airport cost, which consists of capital and operation and maintenance costs, C, is a linear function of the planning standard, i.e., $C = k\bar{v}$ where k is a factor of proportionality, we can represent this trade-off as follows. (See Figure 5).

RELATIONSHIP BETWEEN PASSENGER-CONVENIENCE DENSITY FUNCTION AND DEVIATION FROM PLANNING STANDARD

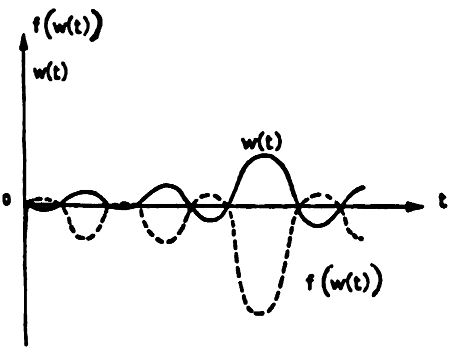

FIGURE 4

NET PASSENGER CONVENIENCE AND AIRPORT COST FUNCTIONS

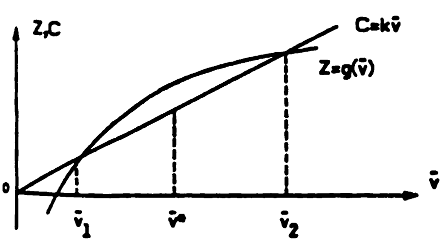

FIGURE 5

It can be seen from Figure 5 that there exists an optimum value of $\bar{v}$ for which the net benefit accruing to passengers and airport owners as a group is maximum. The optimum value of $\bar{v}$, denoted by $\bar{v}^*$, is the planning standard that should be used if the net benefit is to be maximized.

2.01 OPTIMUM PLANNING STANDARD

The existence of an optimum planning standard can be proved in a systematic way. Let Y be the net benefit accrued to passengers and airport owners as a whole, we have:

$$Y = Z\text{-}C$$

i.e., $$Y(\bar{v}) = g(\bar{v})\text{-}(k\bar{v}$$

It should be noted that in this formulation of net benefit, it is assumed the passenger distribution of the design year is given. Therefore, revenue accrued to the airport as well as operating and maintenance expenditures during the same year can also be considered as given, i.e., these terms do not change with the planning standard $\bar{v}$.

The maximization of net benefit $Y(\bar{v})$ requires that:

i/ $$\frac{dY}{d\bar{v}} = o, \text{ i.e., } g'(\bar{v}) = k$$

ii/ $$\frac{d^2Y}{d\bar{v}^2} < o, \text{ i.e., } g''(\bar{v}) < o$$

The first order condition, $\frac{dY}{d\bar{v}} = o$, requires the existence of a solution to the equation $g'(\bar{v}) = k$.

The second order condition, $\frac{d^2Y}{d\bar{v}^2} < o$, is automatically satisfied by the concavity of $g(\bar{v})$.

So far we have discussed the trade-off within the design year between passenger convenience and airport cost in the determination of an optimum planning standard. Let us see how the arguments presented above can be applied to the whole life of airports. We consider two separate cases: the construction of new airports and the expansion of existing airports.

2.02 CONSTRUCTION OF NEW AIRPORT

Let us assume in the case of construction of a new airport, that it takes a time period t_1 to build airport facilities which can be used until the time period t_3 with the same capacity. Let us also assume that the demand for airport facilities, represented by the annual passenger volume, increases steadily from t_1 to t_3 and that at t_2, airport facilities exactly meet this demand. The whole process can be represented by the following diagrams.

RELATIONSHIP BETWEEN DEMAND AND CAPACITY OF A NEW AIRPORT

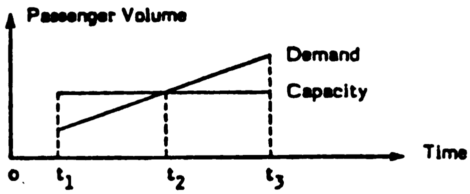

FIGURE 6

In this case the net passenger convenience Z and airport cost can be evaluated as follows, assuming that the whole capital cost is incurred during the year in which the airport becomes ready to use.

$$Z = g(\bar{v}) = \int_{t_1}^{t_3} e^{-rt} f[w(t)]\, v(t)\, dt$$

and

$$C = ke^{-st_1}\bar{v}$$

where r and s are the discount rates applied on net passenger convenience and airport cost.

Once Z and C are evaluated, the net benefit function $Y(\bar{v})$ can be established for the determination of the optimum planning standard.

2.03 EXPANSION OF AN EXISTING AIRPORT

In the case of expansion of an existing airport, let us make the following assumptions:

(a) present facilities will be able to meet demand until t_1;

(b) expanded facilities will be available from t_2 to t_4. These facilities will exactly meet demand at t_3.

We can represent this situation as shown in Figure 7.

The net passenger convenience Z and airport cost C can be evaluated here as follows, assuming that the whole expansion cost is incurred during the year in which new facilities become ready to use.

$$Z = g(\bar{v}) = \int_{t_2}^{t_4} e^{-rt} f[w(t)]\, v(t)\, dt$$

$$C = ke^{-st_2}\bar{v}$$

Once Z and C are established, the determination of the optimum planning standard is carried out as shown above.

In summary, the sequential steps to be taken in the determination of the

RELATIONSHIP BETWEEN DEMAND AND CAPACITY OF AN EXPANDED AIRPORT

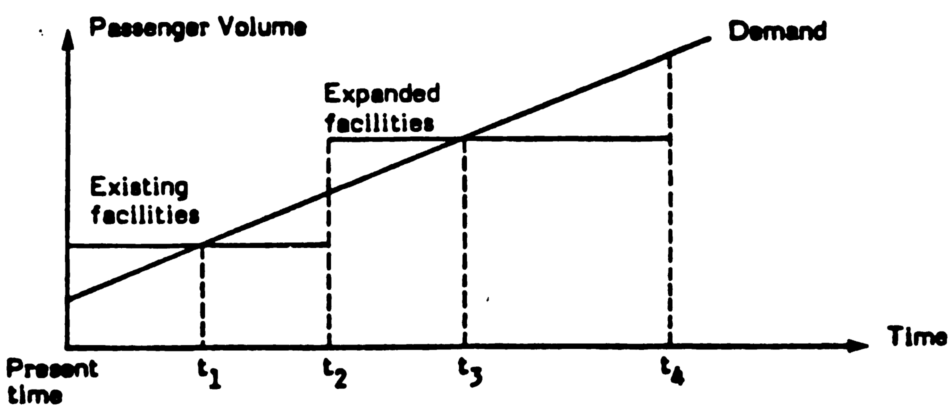

FIGURE 7

optimum planning standard can be defined as follows:

(a) forecasting a typical distribution of passenger volume;
(b) conducting an attitudinal survey to obtain the form of the passenger convenience density function in terms of deviation from the planning standard;
(c) estimating an airport cost function (C) in terms of planning standard;
(d) obtaining the net passenger convenience (Z) as a function of planning standard;
(e) finding the value of planning standard for which the net benefit (Z-C) is maximum. This is the optimum planning standard.

3.00 CONCLUSION

We have shown in this paper that from a conceptual point of view the cost-benefit approach can be used to determine the optimum planning standard for airport terminal buildings. This approach is based on the assumption that it is possible to quantify air passenger convenience/inconvenience. Conceivably, this can be achieved by the use of an attitudinal survey. Since public views on convenience/inconvenience are likely to change over time, it is necessary to keep them as up to date as possible in the airport planning process.

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FOOTNOTES

1 For simplicity of presentation a continuous function is used here instead of a discrete function.

2 It is assumed that passengers in all traffic sectors (domestic, transborder, and international) have the same convenience density function.

