ESTABLISHING AN APPROPRIATE LANDING FEE SCHEDULE AT VANCOUVER INTERNATIONAL AIRPORT

by

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ABSTRACT

The last twenty years has seen a tremendous increase in aviation activity within Canada. Air links have been established and improved and safety standards upgraded to the point where the air can now be regarded as the optimum environment in which to travel. Because of its tremendous popularity, flying has also placed demands on the public purse. Every year more money is allocated to the aviation sector. Until recently, this outflow of funds continued virtually unchecked. With an increasing awareness of ecological balance and the impending depletion of non-renewable resources, public opinion has begun to question the viability of increased aviation investment.

In consideration of these factors, this work has investigated the economic theory upon which rational pricing is based. Given the current level of investment, the first chapter examines the relationship between the present level of demand for aviation services, and the appropriate level of price to be assessed against this demand. Demand is also used to formulate a decision framework for future investment in airports.

Succeeding chapters introduce research conducted in the United States which attempts to relate the economic theory presented above to a practical pricing schedule.

The final chapter incorporates all of the work described above. Using the Airborne Instrument Laboratory, Airport Capacity Handbook, the practical capacity of Vancouver International Airport (movements per hour) is calculated. Consideration is given to

prevailing weather patterns as well as the configuration and characteristics of the runways to arrive at the annual capacity of the airport. This capacity figure is then used to determine how appropriate the current levels of landing fees are at Vancouver International Airport. Ratios of processing time are determined for Air Carrier and General Aviation aircraft. These ratios, which reflect the time required for an aircraft of one class to land relative to the time required for an aircraft of the other class to land, are calculated for various mixes of the aircraft population. Using these ratios and weighting them with the frequency with which each ratio could be expected to occur, a schedule of opportunity cost (General Aviation - Air Carrier) is prepared. By applying the latter schedule to the current level of landing fees, an alternate schedule of landing fees at Vancouver International Airport has been calculated.

By observing how the level of charges at Vancouver International Airport has been, to some degree, responsible for the pattern of investment there, it is evident that considerable improvement in the allocation of resources can be effected by revising this schedule. Application of the resultant fee schedule will not guarantee an improvement in the economy but utilization of the principles inherent in its derivation, will certainly clarify the direction change must take.

TABLE OF CONTENTS

LIST OF TABLES

L I S T   O F   F I G U R E S

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To my wife Glenis, for her infinite patience and unflagging determination.

Introduction

The Ministry of Transport (Pacific Region) intends to expand the capacity of Vancouver International Airport by constructing an additional runway parallel to the 08-26 facility. Little thought has been devoted to the question of economic justification for the expansion. The schedule of landing fees at Vancouver International Airport encourages use by general aviation and air carrier aircraft. These fees discriminate between aircraft type but not time of use. Particular aircraft can land at any time for the same price. Consequently, the airport is utilized the most during the hours most convenient to business travel--between 7:00 a.m. and 9:00 a.m., and 6:00 p.m. and 8:00 p.m. Expansion of the airport is sought to accommodate the traffic which utilizes the runways at the peak hours. During the off-peak hours the runways are used much less. It is the writer's hypothesis that the system of landing fees currently employed by the Ministry of Transport is, to a large degree, responsible for the level and pattern of traffic using the airport. This schedule of fees provides no incentive for utilization of facilities at off-peak times, nor does it ration capacity in an economically efficient manner. It is felt that if the level of landing fees was equated to the cost of providing the service, the demand for service would drop. Only users who placed a value on landing equal to the higher fees would be accommodated, and additional investment in the airport could be delayed or even avoided.

The idea of equating cost and price to ensure efficiency is not new. Under perfectly competitive conditions marginal cost and price are equivalent. The application of this concept to welfare economics, primarily the pricing of services, has attracted renewed attention in recent years. Peak load pricing under constraints, and in the general case, is the topic in this instance. P.O. Steiner, J. Hirshleifer and O.E. Williamson have incorporated marginal cost theory into a theory for pricing a commodity under varying conditions of demand. The commodity was a service and, by virtue of its nature, was not storeable. Steiner was instrumental in devising a geometrical solution to the pricing problem. Unfortunately his technique was tenable only under very restricted conditions. Hirshleifer modified Steiner's technique to comply with his own notion of discriminatory pricing. Williamson's work modified Steiner's approach and allowed marginal cost pricing theory to be applied to very general situations.

During the last ten years, the concepts explored by the above authors have been examined in the light of pricing the services of airports. J. Yance, A. Carlin & R. Parks, M.E. Levine, and J. Wardford examined the pricing schemes used at major American airports and concluded that the rules adhered to by policy-makers in establishing prices did not conform to economic efficiency criteria. Carlin & Park developed a pricing scheme based on the marginal delay costs that aircraft impose on each other when operating within a congested system. Michael E. Levine investigated the dilemma of excess demand at major airpost. (U.S.)

Levine recommended a practical approximation to marginal cost pricing but qualified his suggestions with recognition of the difficulty of ascertaining this figure. He further suggested that marginal costs of operating and expanding facilities be averaged over some period of time to avoid disruption due to highly variable prices. J. Yance has addressed the problem from a different standpoint. Like the others, Yance questions the validity of weight based landing fees. He feels that a more significant variable is the length of time that a movement takes. Landing fees would, in his view, better reflect the cost of a movement, if they were proportional to the relative time demands of aircraft using an airport at a given time.

The present work incorporates the Yance technique of assessing landing charges. An analysis has been made of the traffic densities at Vancouver International Airport to determine if the airport is currently operating at capacity. The Airborne Instruments Laboratory (AIL) criterion for capacity operation was adopted: an airport is considered to be at capacity if the average delay experienced by departing aircraft is equal to four minutes. Using the Yance model, the time demands of air carrier aircraft relative to general aviation aircraft has been calculated This calculation has been repeated for various configurations of aircraft mix, weather conditions and season. Given the relative demands of these two classifications, a revised schedule of landing fees has been calculated.

The revised schedule is compared with the schedules at airports in three metropolitan (U.S.) areas where increases in the minimum level of landing fees precipitated a significant reduction in traffic.

Based on the results of the above work, recommendations for future policy have also been made.

Chapter I

Before discussing the theory of peak load pricing it may be worthwhile stating the objectives of this paper and the studies being reviewed.

By adopting a scheme of pricing, one attempts to improve efficiency in the allocation of resources in one sector of the economy. The sector in question is aviation-related activity emanating from Vancouver International Airport. No attempt will be made to prescribe techniques which recover the full costs of providing service or which enable the airport to accommodate all demands. The sole aim of the application of peak load pricing theory to traffic at the airport is to maximize consumer welfare by improving the allocation of resources currently employed there.

The social welfare function to be maximized is defined in terms of the so called Marshallian "surplus" criterion. This definition disregards the distribution of income for all individuals. Additionally, all of the work reviewed assumes that the optimum conditions of production and exchange are satisfied elsewhere in the economy. This simplifying assumption should not detract from the value of these studies since it obviates the requirement of "second-best" approaches and permits a partial analysis of this problem.

The problem of peak load pricing has been addressed many times since the last world war. Of the solutions presented in the literature, five predominate: Marcel Boiteux; Hendrik Houthakker; Peter Steiner; Jack Hirshleifer and Oliver Williamson.

Three of these studies will be elucidated in this presentation. Peter O. Steiner[1] presented an approach to peak load pricing in an article published in the Quarterly Journal of Economics, November 1967. Steiner's work, though dependent on some very restrictive assumptions, provides a good point to begin the review.

Steiner begins by assuming that only two kinds of costs are incurred in providing capacity: "b" - the operating costs per unit of capacity per period (assumed constant), and "B" - the cost of providing a unit of capacity (assumed independent of the amount of capacity required). If there is excess capacity the marginal cost of a unit of output is equal to "b". If new capacity is required, the marginal cost becomes "b+B". This assumption is retained throughout Steiner's paper and all work subsequent to it. A more limiting qualification can be found in the second assumption: "...the product is to be produced in two time periods of equal length." A further assumption is also made: the demand for output in each period is independent of demand in other periods and these independent demands are not identical: the demand in one period being everywhere above the demand in the other period. The number of limitations to the analysis is reduced in a later, more general approach, but the elements essential to the simplified analysis are retained: each demand curve is a declining function of the

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[1] Steiner P.O. Peaks Loads and Efficient Pricing, Quarterly Journal of Economics, 1957.

quantity of product in that period alone and the demand for output (service) in one period is independent of demand in the other period. Steiner's object is to "determine the prices that will lead buyers to purchase these quantities." He recognizes that the amount of capacity required is equal to the maximum level of demand regardless of which period the demand emanates from. Given two equal periods of unequal, independent demand, we may infer the existence of a peak load problem if the quantities demanded at any price are unequal. Having established the criteria for a peak load problem, it remains to "specify a schedule of prices which will lead buyers to purchase the quantity of output in each period that will lead to the social optimum[2]." What then, is the social optimum? Steiner adopts the traditional approach to this question. A socially optimum result is obtained by maximizing the "excess of expressed consumer satisfaction over the cost of resources devoted to production[3]." Put more simply, this means that one attempts to maximize the sum of producers' and consumers' surplus. Any distributional effects are assumed to be equated throughout the economy.

The demand for output in the two periods is illustrated in Figure 1. The demand curves for the two periods meet the

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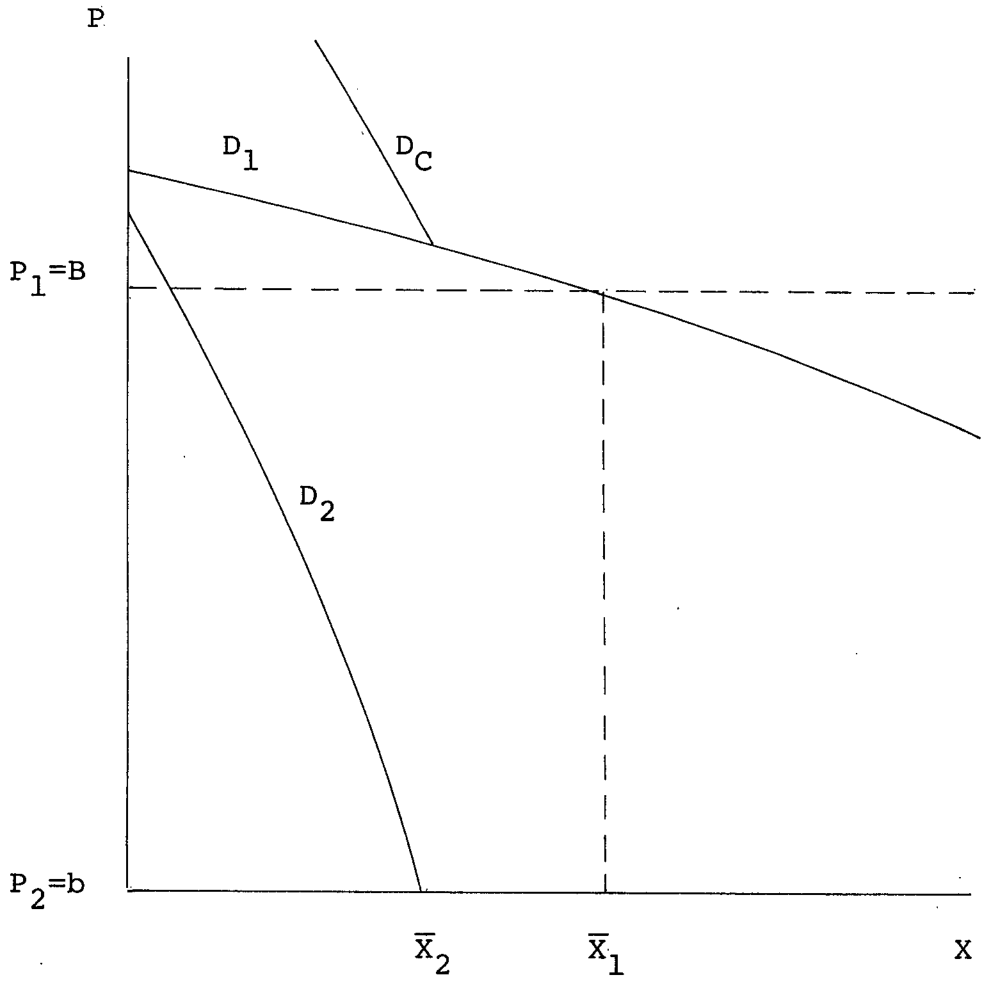
[2] Steiner P.O. Peaks Loads and Efficient Pricing, Quarterly Journal of Economics, 1957.

[3] Ibid.

Figure 1

Firm Peak Case



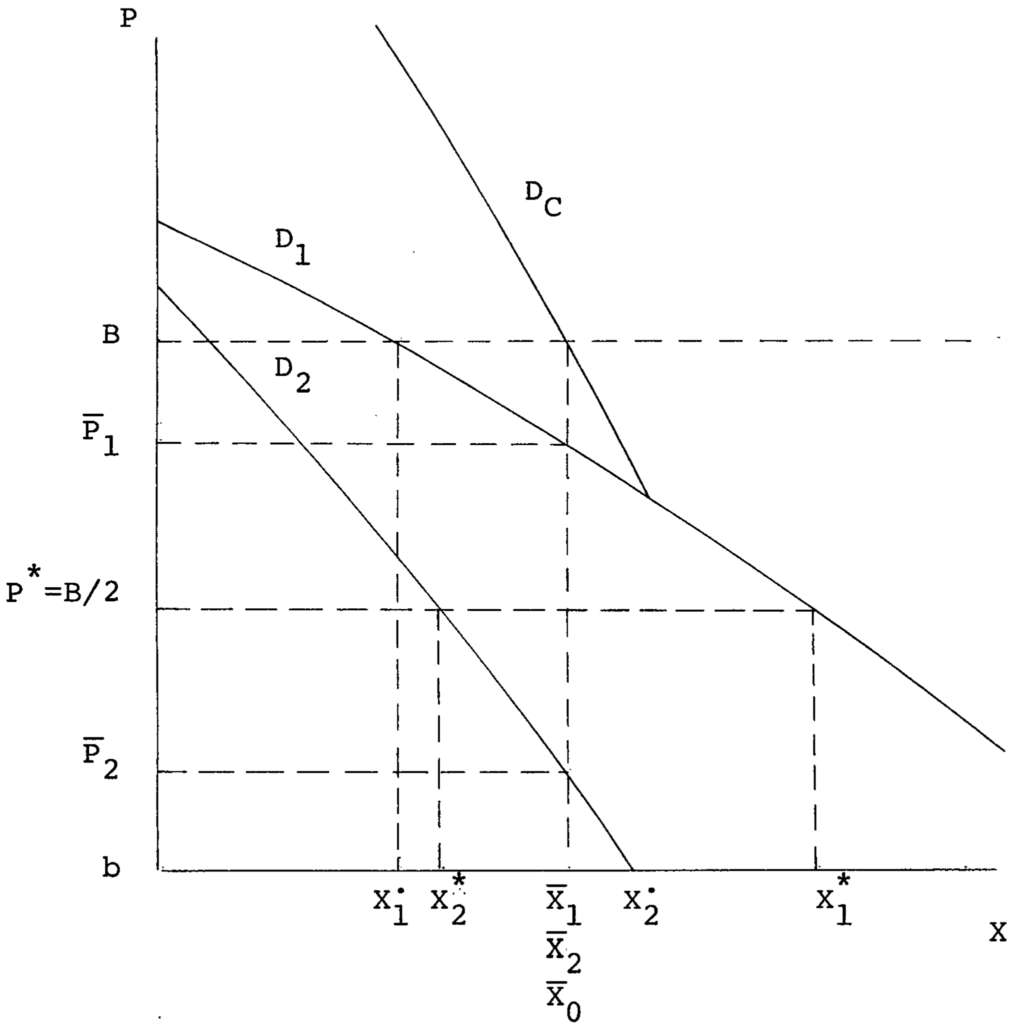
Source: Steiner, P.O. Peak Loads and Efficient Pricing, Quarterly Journal of Economics, 1957.

criteria established above. D_1 is the demand for output in period 1 and D_2 is the demand for output in period 2. The operating costs have been subtracted from these curves so they may be viewed as the effective demands for capacity in their respective periods. Steiner adds these independent demands vertically to obtain the total effective demand for capacity. Only the positive portions of each demand curve are added since ineffective demand (demand that will not even cover operating costs) is not relevant to the decision of pricing. This vertical addition is justified only if the two demands are viewed as complementary, not competitive. We now turn to an analysis of Figure 1; Steiner's "firm peak" case. The total justified capacity is $\bar{X}_1$, (where the total effective demand for capacity is equal to the marginal cost of providing that capacity.) The demand for marginal capacity is made by period 1 users only, therefore these users can be expected to pay for the marginal cost of (additional) capacity: $P_1=b+B$. Because their demand for capacity is much less, the users of period 2 should be charged only the costs of operation: $P_2=b$. This price will persist until period 2 users demand a level of output which exceeds its cost of production. The prices assigned to the two groups of users are not discriminatory, they merely reflect the different costs of accomodating the users.

Steiner then views another application. He asks: What amounts of capacity would be demanded by on-peak and off-peak users if the prices derived from the firm peak case were applied to the case depicted in Figure 2? Here the elasticity of demand in both periods differs from that observed in the first case. Application of P_1 and P_2 to this case results in period 1 users demanding $x_1^{\cdot}$ and period 2 users demanding $x_2^{\cdot}$. This is clearly not an optimum solution; period 2 users are only required to pay operating costs (b) but they are the only users placing a demand on capacity. In this situation $x_2^{\cdot}$ units are required but only $x_1^{\cdot}$ units of capacity are being paid for. It can be seen that even an average price (eg. $\frac{b+B}{2} = P^*$) would not be optimum. Under this scheme, output demanded in periods 1 and 2 would be x_1^* and x_2^* respectively. Capacity equal to x_1^* units would be required at this price but only $\frac{x_1^* + x_2^*}{2}$ would be paid for. The marginal unit of capacity would not be justified by demand for that capacity. Capacity equal to x_1^* would not be utilized in period 2. The correct analysis can be understood by reference to Figure 2. Addition of D_1 and D_2 yields D_c. (the effective demand for capacity). Intersection of the cost of capacity and this effective demand curve yields the amount of capacity justified by the demand in 1 and 2. In Figure 2, this capacity is equal to $\bar{x}_o$ units. At this level of capacity, the outputs in each period may be extended to $\bar{x}_o$ because they exceed the costs of operation (b). Steiner outlines the procedure for deriving the optimum level of capacity and the level of prices associated with that capacity: "...a unit of capacity is justfied if and only if 1. it is justified by the demand in any period alone or 2. it is justified by the combined demands in two or more periods. Once the appropriate

Figure 2

Shifting Peak Case



Source: Steiner, P.O., Peak Loads and Efficient Pricing, Quarterly Journal of Economics, 1957.

capacity is determined, output in each period should be extended to that capacity unless additional units of output fail to cover the operating costs at an earlier output. Then given the optimal outputs in each period and the demand curves, it is routine to determine the optimal prices." In Figure 2, the demand in periods 1 and 2 results in the prices $\bar{P}_1$ and $\bar{P}_2$. Steiner maintains that these two prices are discriminatory. (This point will be debated in succeeding pages). He presents the prices for periods 1 and 2 in terms of a deviation from the average price B/2:

$$\bar{P}_1 = b+B/2+K_1$$

$$\bar{P}_2 = b+B/2+K_2$$

since the sum of the prices is 2b+B; $K_1 + K_2 = 0$.

"If the demand curves are different at $\bar{x}_o$, the prices are unequal and since this is truly a case of joint costs, unequal prices in the face of equal outputs and joint costs means discriminatory prices." The "shifting-peak" case presented by Steiner illustrates a weakness in the attempt to charge peak load users a price which includes a contribution to providing capacity while charging off-peak users a price which only covers the cost of operation. The scheme failed because the prices appropriate to peak and off-peak periods were assigned to specific periods in advance. The boundaries of these periods were determined from historical demand data. Once the prices were assigned, buyers chose to purchase quantities at those prices that led to a different de facto peak. The implications for policy created by this result will be discussed later in the thesis.

J. Hirshleifer[4] responded to the work of Steiner in a comment published by the Quarterly Journal of Economics in August 1958. Hirshleifer's criticism is valuable, because it presents an alternative view of marginal cost when capacity has been reached. Steiner adopted the view that marginal cost is undefined at this point; Hirshleifer depicts marginal cost as infinite. The primary focus of Hirshleifer's work is on the description of the prices to peak and off-peak users. As noted above, these prices are different, the peak users paying a price which includes the cost of capacity. Hirshleifer concedes the difference but contends that this difference is not discriminatory. "...the efficient price differences in a peak load situation shown in Steiner's analysis are not discriminatory because they are equal to the differences in the marginal cost of serving the classes of customers involved."

Hirshleifer maintained that even though his argument could be dismissed as trivial, "it hinges on a semantic interpretation of the work discrimination) it was valuable bacause it presented the problem in a more general sense by differentiating between the short-run and the long-run. Hirshleifer's contribution is presented below.

Hirshleifer differentiates between the short-run solution and a long-run solution. This interpretation is diagrammed in Figure 3. The demand in periods 1 and 2 is shown as two

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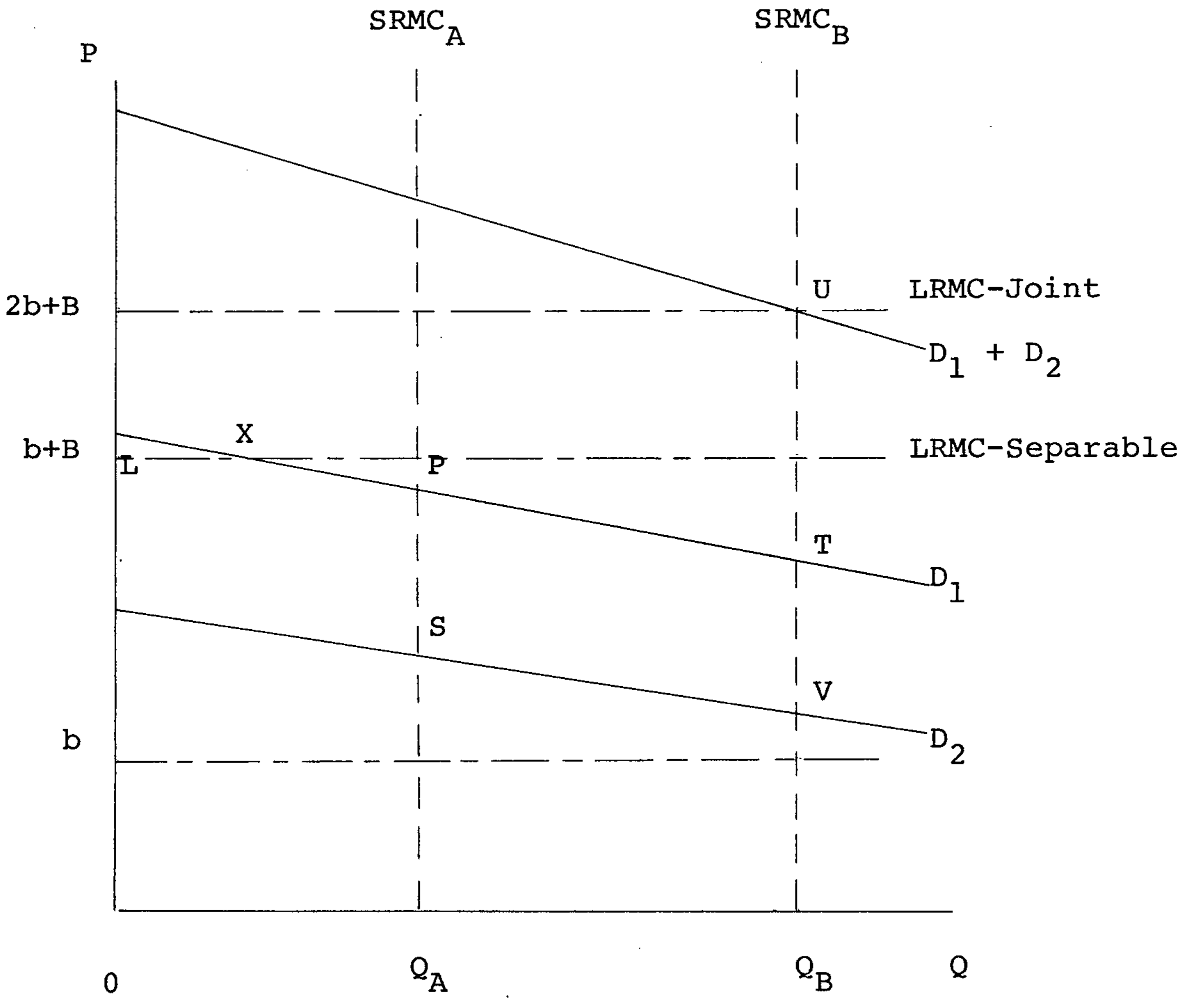
[4] Hirshleifer J. <u>Peak Loads and Efficient Pricing: Comment</u>, Quarterly Journal of Economics, 1958.

Figure 3

Short-Run and Long-Run Solutions, Discontinuous Cost Function



Source: Hirshleifer J., <u>Peak Loads and Efficient Pricing</u>, Quarterly Journal of Economics, 1958.

independent curves D_1 and D_2. Operating costs "b" and capacity costs "B" are assumed constant. It will be noted that in this case D_1 and D_2 are not drawn net of operating costs as was done in Steiner's approach. Capacity cost "B" is a continuous curve under the assumption of perfectly divisible plant. Short-run marginal cost (SRMC) is discontinuous, being equal to "b" at levels of operation below capacity and undefined thereafter. SRMC is shown in Figure 3 as a vertical line at capacity levels of operation.

In the short-run, prices are established by equating demand in each period to the SRMC. Output should be extended to the point where demand equals SRMC. In the present case, output would be extended to capacity in both periods. This solution is optimal for the short-run. If a price less than Q_AS was charged to period 2 users, demand for output would exceed capacity and a rationing scheme would be necessitated. A price greater than Q_AS would, in the short-run, result in a demand less than capacity. It is clear from D_1 and D_2 that the value placed on an additional unit of "q" through the range "0" to capacity is greater than the variable cost of supplying it.

The long-run solution is obtained by equating the relevant demand curve with the relevant Long Run Marginal Cost (LRMC) curve. The first step is the determination of the relevant demand curve. Referring to Figure 3, we can see that in neither period does demand for capacity exceed "b+B" at the existing capacity limit, therefore an expansion of capacity is not justified by either separate demand. If demand in one period did exceed the cost of capacity, expansion would be justified and the relevant LRMC curve for comparison with this demand would be LRMC (separable). This long run cost curve indicates the cost of increasing output for one of the periods, output for the other level being held constant at some lower level. The marginal cost is equal to the sum of capacity cost "B" and operating cost "b" for a single period. The combined demand of periods 1 and 2 is sufficient to justify an expansion of capacity. Expansion should continue up to the point where combined demand is equal to LRMC (joint). The joint long run marginal cost of output is the sum of the operating costs and capacity costs for both periods (2b+B). The optimum level of capacity given this demand is Q_B. The foregoing discussion is merely a modification of Steiner's solution. Hirshleifer compares his solution where demand in only one period is high enough to justify expansion, (LRMC-separable) with Steiner's "firm-peak" case. Steiner's "shifting-peak" case is allowed as being analagous to Hirshleifer's solution where neither period's demand necessitates expansion of capacity but their combined demand does (LRMC-joint). If we accept this interpretation, Hirshleifer's contention that the prices assigned to output are not discriminatory, seems plausible. The above analysis is true for the short-run in the case where the short-run marginal cost curves are discontinuous. The long-run solution, which involves the vertical summation of the independent demands is only valid in the restricted case where the SRMC curves remain discontinuous.

If we abandon the assumption of discontinuous SRMC curves, the solution to the long run remains the same but the technique required to derive it must change. In Figure 4 the SRMC curves are drawn in a traditional shape. Short-run prices are give, as before by the intersection of D_1 and D_2 with the applicable SRMC curve. Once again, there is insufficient demand in either period to justify expansion. Expansion is justified, however by the combined demands of each period. Since price is equivalent to the marginal cost of output, a summation of the demand prices in each period reflects the long-run cost of supplying the total output demanded with existing capacity. ie--the sum of $Q_A^S S'$ and $Q_A^P P'$ is greater than LRMC (joint). We also note that expansion should continue up to the point where the marginal cost of supplying output to meet the combined demand is equal to the sum of the individual period demand prices. (marginal cost of supplying output for each period's demand). Upon reaching optimal capacity, prices are again assigned according to SRMC. With the work of Steiner and Hirshleifer the theory of peak load pricing had reached the point where optimal capacity and pricing decisions could be made, albeit under restrictive assumptions. O.E. Williamson's[5] paper, published in 1966, expanded on the previous work and devised a technique to solve the problem in a more generalized context.

In arriving at a social welfare function, Williamson

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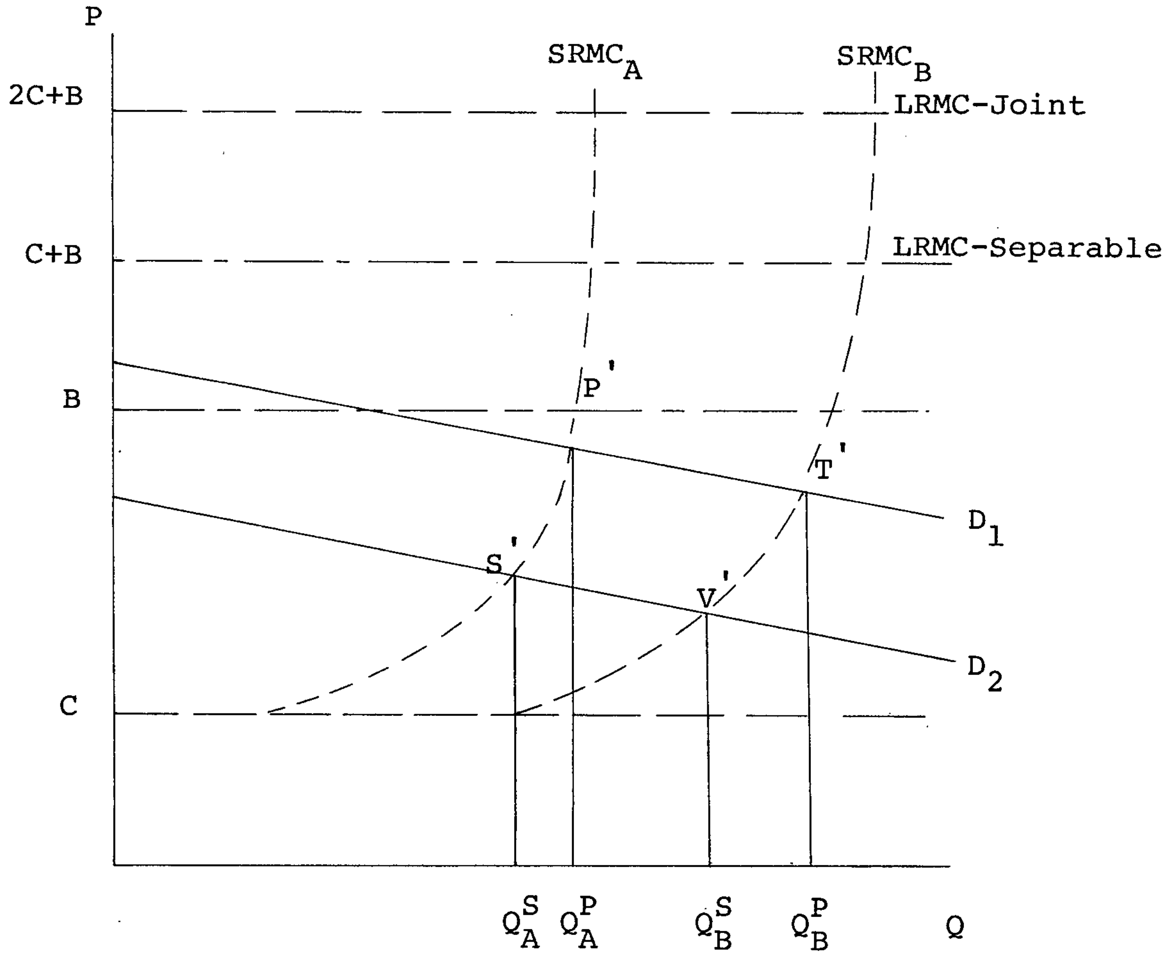
[5] Williamson O.E. Peak-Load Pricing and Optimal Capacity under Indivisibility Constraints, American Economic Review, 1966.

Figure 4

Short-Run and Long-Run Solutions,
Traditional (Continuous) Cost Function



Source: Hirshleifer J. Peak Loads and Efficient Pricing, Quarterly Journal of Economics, 1958.

makes essentially the same assumptions as Steiner and Hirshleifer regarding distributional effect. He defines social benefit in the following manner: "...total revenue plus consumer's surplus. (Social cost,) treated as opportunity cost and assuming no technological externalities, will be separable into total pecuniary cost less intramarginal rent." If we assume that all inputs are available in completely elastic supply, intramarginal rents are zero. Like the preceeding assumptions the latter provides for a simplified analysis; all conclusions reached via the analysis must, of course, be regarded in the light of these assumptions. Given these definitions, Williamson describes his social welfare function as follows:

$$(1) \qquad W = SB - SC$$
$$= TR + S - TC$$

where W = net welfare gain, SB = social benefit, SC = social cost, TR = total revenue, S = consumers surplus, and TC = total cost. Differentiating this expression with respect to output (Q), we obtain the following:

$$(2) \qquad \frac{dW}{dQ} = \frac{d}{dQ}(TR + S) - \frac{d}{dQ}(TC) = 0$$

This relationship implies that P = MC where the second derivative of the expression is less than zero.

$$(3) \qquad \frac{d^2W}{dQ^2} = \frac{dP}{dQ} - \frac{d^2}{dQ^2}(TC) < 0$$

That the first derivative with respect to output of TR + S is equal to price (P) can be seen from the defination of the derivatiave:

$$TR + S = \int_0^Q P(Q)'\,dQ'$$ where $P(Q)'$ is the demand curve. (the quantity Q' demanded at every price P). By differentiating the left hand side of this expression with respect to Q, we obtain by definition:

$$4)\qquad \frac{d}{dQ}(TR + S) = \frac{d}{dQ}\int_0^Q P(Q)'\,dQ'$$

$$= P(Q)'$$

These relations fulfill the necessary and sufficient conditions for a maximum.

Assuming perfectly divisible plant, total costs are defined as the sum of operating and capacity costs times the quantity of output in the period under consideration. In this definition, Williamson adopts the usual notation of "b" for operating costs and "B" for capacity costs.

$$(5)\qquad TC = (b + B)\,Q$$

Operating costs, "b" are assumed constant per unit of output. Referring to equation (2) we can see that optimal scale of plant is obtained when $P = b + B$. If we take the scale of plant as fixed, the optimal price is determined by maximizing the net welfare gain (w) subject to the capacity constraint $(\bar{Q})$:

$$\text{Max. } W = (TR + S) - bQ$$

$$\text{s.t. } Q,\ Q \leq \bar{Q}$$

This expression is set up as Lagrangian:

$$\max.\ L(Q,\lambda) = (TR + S) - bQ - \lambda(Q - \bar{Q})$$

Differentiating partially with respect to Q and , we obtain:

$$\frac{dL}{dQ} = P - b - \lambda$$

$$\frac{dL}{d\lambda} = -Q + \bar{Q}$$

equating to 0, we obtain:

$$P - b - \lambda = 0$$

$$P = b + \lambda$$

$$-Q + \bar{Q} = 0$$

$$Q \leq \bar{Q} \quad \text{(capacity constraint)}$$

If the constrint is not binding, (capacity has not been reached; $Q < \bar{Q}$) is zero and the optimal price is found by equating the short-run cost of providing output (b) with the output demanded. When capacity is reached ($Q = \bar{Q}$) the value of becomes positive and the optimal price exceeds "b". The rule resulting from this analysis is, in essence, a re-statement of the rule derived by Hirshleifer for expanding and retiring capacity. Williamson notes "...if $b + \lambda > b = B$ (and demand is expected to continue at this level), and expansion of plant is signalled, whereas if $b + \lambda < b + B$, plant should be retired."

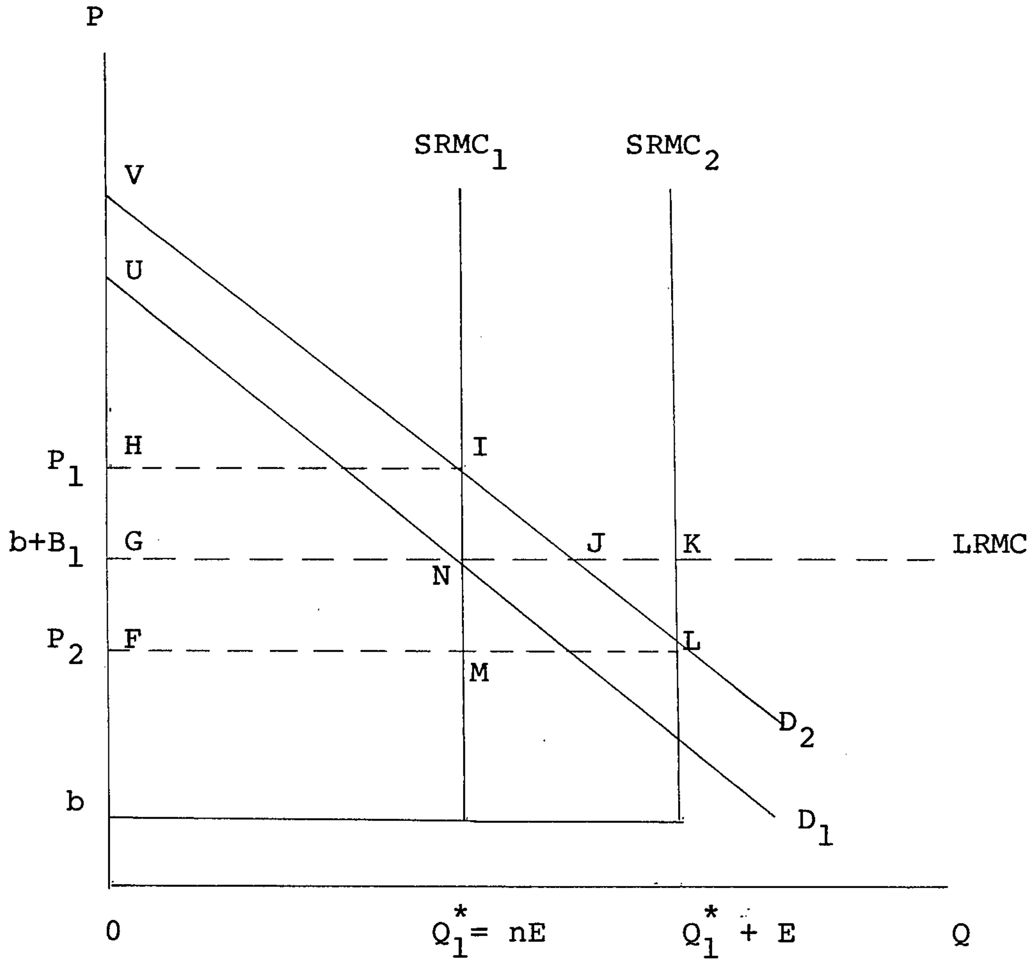
Williamson now begins to relax the assumptions adhered to in the previous analysis. Initially he focuses on the effect of indivisibilities on the solution to the optimal capacity problem. Plant can be supplied in distinct units of size E. He retains the assumption of non-peaked or uniform loads. Because plant can only be supplied in distinct units the short-run marginal cost of operation is sharply kinked at the point of capacity and is undefined beyond this point. The inclusion of plant indivisibilities in the analysis necessitates the modification of the social welfare function to read:

$$W = S + (TR - TC)$$

where S is consumers surplus and (TR - TC) is net revenue.

Figure 5

General Solution



Source: Williamson O., Peak-Load Pricing, American Economic Review, 1966.

Williamson adopts the term "producers surplus" to describe the latter expression. He also retains the terms "b + B" for operating and capacity costs[6].

Initially the enterprise is in long-run equilibrium where long-run marginal cost, short-run marginal cost and price are all equal. Figure 5 depicts the situation. If demand shifts from D_1 and D_2, is investment in another unit of capacity justified. The task at hand is to devise a technique to determine at what point demand is sufficiently large to justify expansion. Williamson's solution involves adjusting demand to the point where the enterprise is indifferent between the status quo and expansion. The enterprise is assumed to be indifferent because at this point (J in Figure 5) the net welfare gain associated with either alternative is the same. Demands greater than D_2 would dictate an expansion.

Proof: Recalling the definition of net welfare gain W, referred to before, we see that at point J, the gain in consumers surplus S is just offset by the loss in producers surplus (TR - TC). This is clarified by comparing consumers and producers surplus before and after the shift from D_1 to D_2.

When demand equals D_1 consumers surplus is given by the area UNG. Producers surplus is zero, therefore the net welfare gain is equal to UNG. When demand shifts to D_2 and capacity

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[6] Williamson regards the cost of capacity as the opportunity cost of the resources employed. The foregone alternative is considered equivalent to an annuity which pays a given amount $\surd$ per period over the useful life of the plant. B, the average capacity cost per period is equal to $\surd/E$ (where E is the unit of capacity) plus the average cost of maintenance per period.

remains the same, the price or output is raised to P_1 to ration existing capacity. At this new price, consumers surplus is equal to VIH and producers surplus is equal to HING. Net welfare gain is given by their sum, VING.

The net effect on the welfare gain resulting from an increase in capacity can be seen by comparing the increase in consumers surplus to the loss in producers surplus. Consumer surplus increases by the amount HING + GJLF + IJN. Producers surplus is reduced by the amount HING + GHLF + JKL. The net gain is equal to IJN - JKL, which by assumption is zero since the level of demand D_2 was drawn to assure this. We can see that based on the criteria of maximizing net welfare gain, any level of demand greater than D_2 will dictate expansion because expansion would result in a positive net welfare gain.

When expansion is complete prices are established by equating demand and SRMC. It is evident from Figure 5 that for any level of demand intermediate between points N and K, the enterprise will operate at a loss in the long run. Williamson also notes that in the real world, demand does not shift "once and for all" but instead fluctuates while it increases over time. His analysis is essentially correct, however, since by allowing for uncertainty, the rules governing expansion still apply. "...the counterpart of our previous criterion is to add capacity whenever $E(IJN) \geq E(JKL)$ where E(.) denotes expectation..." This observation has implications for decision makers in situations where facility expansion is often based on forecasts of existing activity.

Williamson now attends to the problem of peak loads. It is in this analysis that the major contribution of his work can be found. Williamson resists the temptation to assume that the peak and off-peak loads are of equal duration. He feels that any conclusions reached as a result of this assumption cannot be generalized. Instead he takes a period of a day against which to express costs, and allows the two loads any proportion of this period. By adopting this procedure, Williamson permits conventional costing practices normally employed in uniform load analyses to be applied to situations where the loads are periodic. The continuity of this approach merits credit.

Short-run marginal costs and long-run marginal costs are defined as before. The key to this approach is the construction of the demand curves so that they reflect the relative demands of the individual loads. This is done by weighting each demand according to the proportion of the period for which it is effective: "...each demand.. (is weighted) by the fraction of the cycle over which it prevails. Thus demand is expressed as $D_i(w_i)$ where i refers to the subperiod in question and superscript (w_i) to the fraction of the cycle during which the demand in question prevails, with each demand curve showing the amount of output per cycle which would be demanded at every price were the demand in question to prevail over the entire cycle." It is also assumed that the periodic demands are independent. This is a common assumption and was made by Steiner and Hirshleifer as well. Whether it is reasonable is questionable, particularly in the case of periodic demands for landing privileges at an airport.

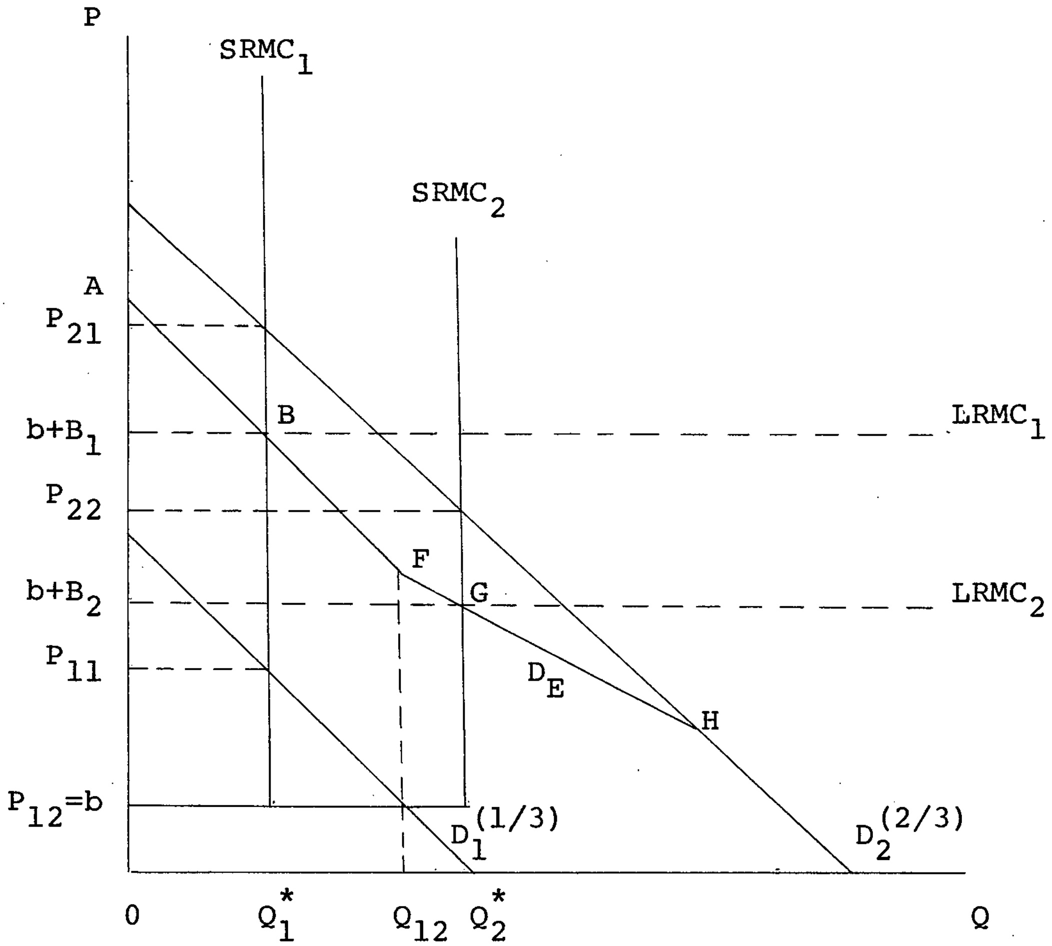
Williamson begins the analysis with the assumption of divisible plant and two periodic loads. Neither assumption is critical to the outcome of the analysis but only serve to simplify it.

The two loads are of eight and sixteen hours length. They are shown in Figure 6 and are entitled $D_1^{1/3}$ and $D_2^{2/3}$ respectively. To determine the optimum size of plant, some way must be found to combine the individual loads into an "effective demand for capacity curve." It will be recalled that Steiner achieved this combination by vertical summation of the individual demand curves. His summation involved demands for capacity net of operating costs and assumed that these demands were not competitive. This technique cannot be incorporated in this instance however because the periodic loads are not of equal duration. Williamson's approach to the design of this geometric solution involved the following reasoning: If we consider each periodic load individually and ignore the other, we must agree that, in order for net revenue to be zero, the price charged against each load must be $b + B/w_i$. w_i is the fraction of the entire cycle that load i is in effect. Total revenue from operation of the plant for w_i hours is given by $P_iQ_iw_i$; total cost for this period is $bQ_iw_i + BQ_i$. If $P_iQ_iw_i - (bQ_iw_i + BQ_i)$ is to equal zero, P_i must equal $b + B/w_i$. In long-run equilibrium with constant returns to scale and divisible plant TR - TC must be zero.

To transform each periodic load curve into a demand for

Figure 6

Unequal Demand Solution



Source: Williamson O., Peak-Load Pricing, American Economic Review, 1966.

capacity curve, the resultant curve must cut the LRMC curve at a level of capacity Q_i consistent with the price $b + B/w_i$.

Williamson devised an ingenious technique which guaranteed this result. One must take the vertical difference between the periodic load curve and the short-run marginal cost curve, multiply this difference by the proportion of the period that the periodic load is in effect (w_i) and vertically add this weighted amount to the short-run marginal cost. This procedure is repeated for both periodic demands. The resultant curve is labelled D_E in Figure 6.

The optimal scale of plant for these periodic demands, where capacity cost $B = B_1$ is found from the intersection of the relevant LRMC curve and the effective demand for capacity curve D_E. This point is consistent with output equal to Q_1^*. Price in the off-peak period is P_{11} and P_{21} is the price in the peak load period. (the prices are obtained from the intersection of the periodic load demand curves and the SRMC curve). It can be seen that the peak demand users pay a higher price for services than do the off-peak users. The amount by which the off-peak users fail to meet capacity costs is just offset by the amount above total costs that the peak users are forced to pay. The same procedure applies when $B = B_2$. Optimal capacity is equal to Q_2^*. In this case off-peak users pay only operating costs b and all capacity costs are met by the peak loadusers.

Williamson also demonstrates algebraically that his pricing rules are appropriate and not just the result of a conveniently arranged diagram.

Recalling the social welfare funciton introduced initially: $W = TR + S - TC$, and using the subscripts 1 and 2 to refer to peak and off-peak demand, where w_1 and w_2 are the fractions of the period accounted for by each demand, we obtain:

$$W = (TR_1 + S_1)w_1 + (TR_2 + S_2)w_2 - bQ_1 - bQ_2w_2 - BQ_2.$$

If, as in the first case in Figure 6 where capacity is fully utilized during both demand periods, we have $Q_1 = Q_2$. Letting $Q = Q_1 = Q_2$, and substituting into the welfare function, we obtain:

$$W = (TR_1 + S_1)w_1 + (TR_2 + S_2)w_2 - bQ(w_1 + w_2) - B_1Q$$

To obtain the optimum plant size, we differentiate this function with respect to Q, and set it equal to 0.

$$\frac{dW}{dQ} = P_{11}w_1 + P_{12}w_2 - b(w_1 + w_2) - B_1 = 0$$

$$P_{11}w_1 + P_{12}w_2 = b(w_1 + w_2) + B_1$$

Substituting 1/3 for w_1 and 2/3 for w_2 in the above expression, we obtain:

$$P_{11}w_1 + P_{12}w_2 = b + B_1$$

This is exactly the same result obtained in Figure 6 for the case where $B = B_1$. This solution is general for any number of periodic demands regardless of the relative time that each demand is in effect during the period.

If however, as in the case where $B = B_2$, plant is fully utilized only during one demand period, the original formulation of the welfare function is retained.

Optimal capacity is found by differentiating paritally, first with respect to Q_1, then with respect to Q_2.

$$W = (TR_1 + S_1)w_1 + (TR_2 + S_2)w_2 - bQ_1w_1 - bQ_2w_2 - BQ_2$$

$$\frac{dW}{dQ_1} = P_{21}w_1 - bw_1 = 0$$

$$\frac{dW}{dQ_2} = P_{22}w_2 - bw_2 - B = 0$$

simplifying:

$$P_{21}w_1 = bw_1$$

$$P_{21} = b$$

and,

$$P_{22}w_2 - bw_2 = B$$

$$P_{22} - b = B/w_2$$

once again these results are identical to those obtained from Figure 6. Summarizing, we can see that in the off-peak interval, price is set equal to short-run marginal cost. The price during peak load is set at incremental operating cost (b) plus the fraction of capacity cost attributable to peak load (B_2/w_2).

We now turn to a description of the situation where plant is not divisible. When capacity can only be added in discrete units, the method of deriving optimum capacity and prices remains essentially the same. Williamson merely combines the technique where plant is indivisible and periodic demands are uniform with the technique where plant is divisible and periodic demands are not equal. Succeeding chapters will be concerned with the application of this analysis to airport landing fee pricing. It is evident that in the case of airports, expansion of capacity involves the construction of large units (runways) which, because of operational constraints, are not divisible.

It will be recalled that when we considered indivisible plant and uniform periodic demands, we formulated decision rules for expansion by comparing the welfare gain before an expansion and the envisioned gain after the expansion. This technique is again used with the addition of dissimilar periodic demands. The demands in the off-peak and peak are seen in Figure 7. The effective demand for capacity curve D_E has been constructed by the vertical summation of the weighted periodic demands. The diagram depicts the situation where one is indifferent between adding capacity or not, By construction IJN = JKL. If we disregard D_E and refer to the individual demand curves, it can be seen that the addition to consumers surplus due to expanded capacity and lower prices is just offset by the coincident loss of producers surplus.

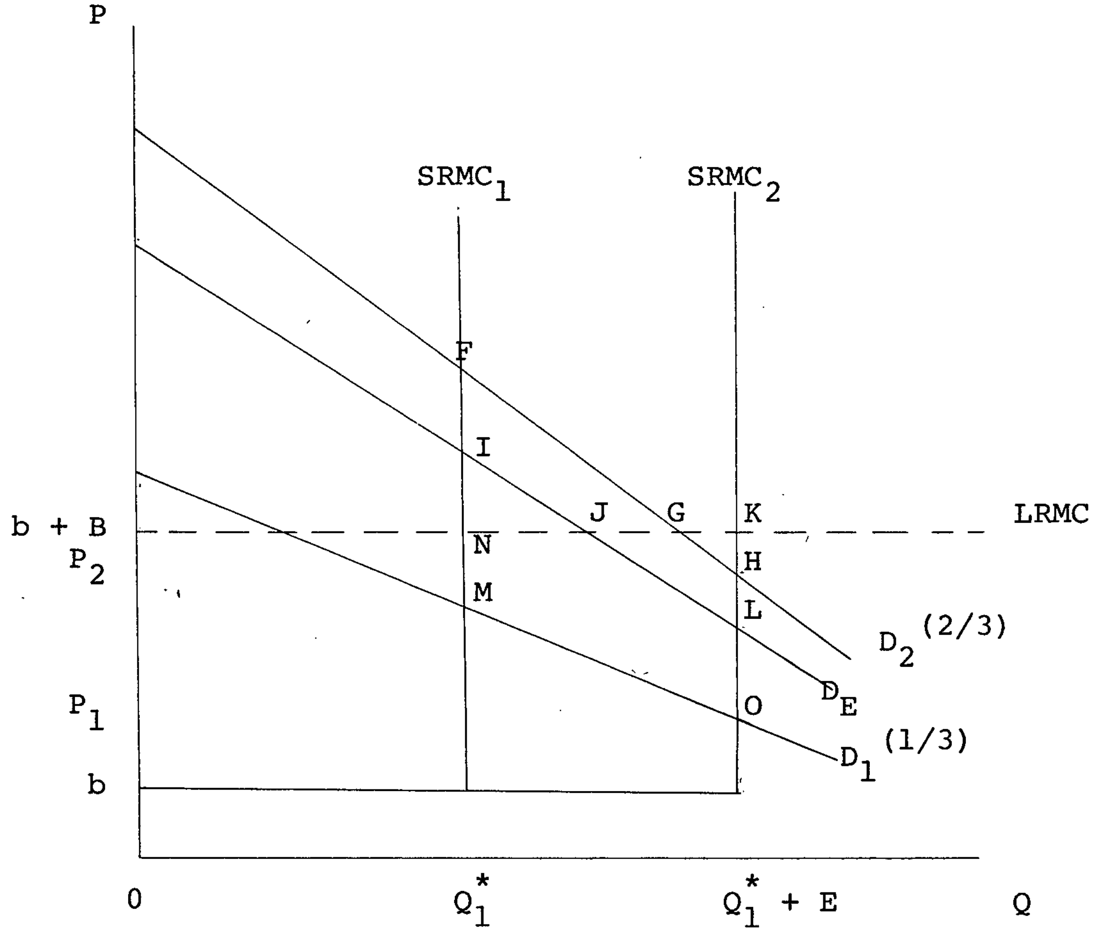
ie. - 2/3(NFG-GKH) is the amount that the gain in consumers surplus exceeds the loss in producers surplus during peak operations; 1/3(MNKO) is the amount that the additional consumers surplus falls short of the loss in producers surplus during off-peak operations. Therefore by definition:

$2/3(NFG-GKH) - 1/3(MNKO) = 0.$

Because plant is indivisible, long-run equilibrium does not guarantee that long-run marginal costs will be met. Peak load prices will not necessarily exceed LRMC although depending on the relative slopes of the periodic demands and the size of the

Figure 7

Indivisible Plant Solution



Source: Williamson O., <u>Peak Load Pricing</u>, American Economic Review, 1966.

unit of expansion, they may.

This chapter has attempted to show how welfare economic theory can be applied to the field of pricing, particularly of utilities and transportation services. The latter areas are notorious for periods of excessive demand as well as very low levels of demand. Application of the theory presented in this chapter to an actual situation is very difficult if not impossible. Knowledge of short or long-run marginal costs is very difficult to obtain. Even if such information was available, equating SRMC to demand would result in a highly variable price. Some compromise would ultimately be necessary. The next chapter will discuss some recent attempts to reconcile theory and reality.

Chapter II

In both Canada and the United States the growth of air traffic in the last ten years has been phenomenal. The public has responded enthusiastically to this fast mode of transport, and the demand continues to grow. The capacity of airports to accommodate this burgeoning demand has not kept pace. The result has been congestion, particularly at airports which serve large, metropolitan areas. Traditionally all airport users have been treated equally - on a "first come, first served" basis. Those aircraft which arrived first would be accommodated before any successive arrivals. This philosophy was reasonable at a time when demand was light, and the resources necessary to meet such demand were readily available. But resources are neither plentiful nor cheap. Devoting resources to expanding airports leaves less for other uses; expansion of the supply of airport facilities can be accomplished only at a cost. If airport capacity is not sufficient to meet demand it must be rationed among users in some manner. At present it is allocated to the persons most willing to wait. The most common method of rationing goods and services in "Western" society, is to let people bid for things in money terms--with goods going to whoever is willing to pay the most. This method, however is rarely used for airports. The result is that existing capacity is very poorly utilized and demand for greater capacity intensified.

The demand for air travel is characterized by peaks and troughs. Over a twenty-four hour period, the pattern varies little; peaks in the early morning and late afternoon when travel for business is convenient. Traffic also varies to some extent according to the day of the week and the season of the year. Since landing fees and ticket prices do not discriminate between any of these factors, demand for service is greatest during preferred travel hours. The capacity of the airport to accommodate demand is not only affected by the number and configuration of its runways but also by wind direction and weather. When the weather deteriorates, aircraft using the airport must operate under Instrument Flying Rules (IFR)[1]. This situation requires more spacing between aircraft, which slows the rate of landing and departures.

The demand for airport use is a function of the cost of making a trip at a particular time, as well as the cost of making the same trip at another time. The costs involved in making the trip vary with the amount of congestion present in the system at the time of the intended trip. For a passenger, the largest cost is the money cost of his fare. For the aircraft operator, the relevant expenses are the operating costs of the aircraft plus the landing or departure fee. It is evident that during delays, the total cost of travel will not be uniform across users, nor will costs be consistent with travel at times of the day when

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[1] IFR becomes effective when the cloud base descends below 1000 feet and the horizontal visibility from the threshold of the runway is less than three miles.

no delays are experienced. The total cost of travel is composed of the out of pocket costs plus the costs of congestion. Because aircraft operators are not assessed differential landing fees and passengers are not assessed differential ticket prices, there is no incentive to alter travel times, and capacity is rationed by congestion. Those travellers most willing to endure delays continue to travel at peak demand times, while the others adjust their travel plans and use the airport when it is less congested. Such a system rewards the users who value the service least, while penalizing those who value it greatest. To date, very little progress has been made in modifying the system of pricing used at airports. The major emphasis still continues to be placed on expansion of capacity. A number of studies have been conducted recently to analyze the principles at work in the production of congestion. The results of these studies, and the recommendations made from the results share a common theme: the capital cost of expanding capacity at congested airports far outweighs the benefits that could be derived from such expansion. On the other hand, a change in the schedule of prices currently used at these airports would ration existing capacity efficiently and provide a useful criterion for ultimate expansion. Three of these studies will be reviewed here. The first analysis by Michael E. Levine, serves as a synopsis of the problem.

When analyzing the role of public policy toward airports, one invariably concludes that airports as a public utility should be operated so as to earn "a reasonable return on a prudent investment[2]." Even though this view is widely held, the basis on which costs should be recovered (cost recovery pricing based on total aircraft weight) does very little to achieve this goal. Levine summarizes this dilemma: "For reasons which are never explicitly stated, discussions of public-utility-type, 'cost-recovery' pricing of airport services always center on the revenue generating function of prices and never on the allocation and investment regulating functions. The emphasis is on paying for a known level of capacity, and little attention is devoted to questions of maximizing the value of use of existing facilities and determining the amount of capacity which ought to be provided. Capacity is always matched to "need", and need is determined independently of price."

In the United States, landing fees are established through negotiation between the major carriers and the airport operator. Fees for General Aviation users are usually set at a specific amount (regardless of aircraft weight) and are often waived in lieu of fuel purchases. On the other hand fees for terminal facility concessions are sold to the highest bidder. Unfortunately, this procedure results in the highest bidder acquiring a monopoly position as the sole provider of a service. The problems of higher than optimum prices and restricted output

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[2] Levine M.E. Landing Fees and the Airport Congestion Problem, The Journal of Law and Economics, 1969.

usually associated with monopolistic enterprises apply in this case as well. M. Levine illustrates the procedure adopted at many large American airports for pricing landing fees. Because of a fear that the concessionaires in the airport terminal building will abuse their position, the airport operators impose monopoly restrictions on output. The large profits, received from the concessionaires as rent, are then used to subsidize users of the landing area. The resultant very low landing fees further encourage the use of these facilities, compounding the problem. The following agreement is extracted from Levine's article and is included here to illustrate very clearly, the process by which landing fees are calculated. The major airports of the United States use essentially the same methods in setting landing fees:

Airline Parties Flight Fee Requirement Chicago-O'Hare International Airport for the six months ending June 30, 1968.

Estimated Total Airport Expenses First 6 months of 1968.	$16,194,602
Estimated Total Airport Revenues Excluding Flight fees, first 6 months of 1968.	8,437,200
Estimated Total Flight Fee Revenue Requirement First 6 months of 1968.	7,757,402
Estimated Flight Fees from other (Non-Parties) Airline, First 6 months of 1968.	104,556
Estimated Total Flight Fee Revenue Requirement Airline Parties, First 6 months of 1968.	7,652,836
Estimated Total Landing Weight, Airline Parties, First 6 months of 1968. (000 lbs.)	18,659,137
Estimated Flight Fee per thousand pounds, Airline Parties, First 6 months of 1968.	$.410

The airlines support this method of calculation as do the airport operators. "That the airlines should take this view is hardly surprising, since it treats their primary activities as a 'last resort' for revenues, and then assesses charges against them only to the extent necessary to cover costs. That the airport operators should regard this as an appropriate formula is odd since it is a principle cause of their present problems."

This procedure is not followed in Canada, however. Concessions are awarded to the highest bidder, and revenues are collected from the contract winner, but these revenues are not applied against landing fees. Landing fees were set by the federal government in 1967. General Aviation and Air Carriers have resisted any attempts to revise these rates in recent years. Appendix illustrates the existing rate structure as well as a breakdown of operating costs and revenues associated with current levels of airport use.

Under the present system of landing fees, there is no differentiation with respect to aircraft type or the time of day that the landing takes place. Even though the landing field is not subsidized by the terminal users, the fees currently imposed are low enough to encourage its use by many low value users.[3] The landing fees currently in effect in Canada are among the lowest in the world.

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[3] By a low value user is meant an individual who places little value on the priviledge of landing at a particular airport at a given time. Many General Aviation flights come under this category.

Despite some differences in the technique by which landing fees are established, the rationale behind the provision of landing access is the same in both Canada and the United States. All airport users are considered equal and are entitled to the same service regardless of their size or the value of their operation. Users are served on a "first-come, first-served" basis. It is this basis that is the subject of the next section.

Under the present basis for allocating landing rights, users are treated in a uniform manner. During peak-hour periods, when congestion occurs, all aircraft wishing to land suffer delays. Light aircraft, (which often carry fewer than six people) impose delays and are the recepients of delay. The costs that these aircraft impose on other larger aircraft are far greater than the costs that are imposed on them by these same aircraft. Regardless of the difference in operating costs between these two classes of aircraft, the aircraft enduring greater hardship (in terms of cost) is not given any priority over the smaller aircraft. Furthermore, the larger aircraft does not even have the opportunity to express his willingness to skirt the queue by paying a higher landing fee. It is this last point that is directly responsible for the distortion in the amount of monies allocated to airport construction and expansion.

Having presumed that airport users are equal, one is obliged to service their demands without hesitation even if such service necessitates continued expansion of facilities. If however, we observe that different users place different values on the right to land an aircraft, we can extract the economic rent associated with that desire by pricing landing fees differentially. At present, those users who are the most willing to tolerate delay (due to congestion) are the ones who are being served. If we assume that greater delay means greater cost, (both in operating costs and opportunity cost to the traveller) then it is apparent that those users enduring equal delays are not suffering identical costs. Each aircraft operating in a period of congestion experiences only the average delay of all the aircraft operating at that time. The marginal cost of delay due to an additional aircraft can conceivably be much greater than the average cost. This is evident in a situation where both air carriers and general aviation share an airport. Because of slower approach speeds, the dangers of wake turbulence from larger aircraft, and the limited availability of special runways and procedures, a light aircraft may cause even more delay than an additional airliner. The example cited by the most adamant of the airline interests involves a large commercial jet (et. - DC-8) being compelled to lose his landing sequence to avoid overtaking a smaller, slower general aviation aircraft which is landing. The obvious comparison is made between the relative operating costs of the two aircraft, with the DC-8 being the most expensive. Levine describes some other aberrations from economic efficiency which can be traced to the flat-rate system of landing fees:

I. The current system of landing fees discourages airlines from scheduling their equipment tightly and thereby increasing utilization. There is also no incentive to reduce schedules; any company that removes an aircraft from the schedule is disadvantaged by a competitor who simply substitutes one of his aircraft into the vacancy.

II. The current system of landing fees also distorts allocations between modes of transport. The system delays equally, short haul passengers who have many substitutes for air travel and long haul passengers, who have few substitutes. In consequence, long haul passengers are prevented from out-bidding short haul passengers (for the right to fly and of course, to land) who might otherwise use trains, buses or private automobiles.

III. The present pricing system also discourages the development of smaller facilities in metropolitan areas. Most of the airports which cater to general aviation traffic exculsively, are not located in as convenient an area as the major airports. In addition, these airports are not as sophisticated in terms of navigation and landing assistance equipment. Because landing fees are not discriminatory, any general aviation aircraft willing to endure some congestion may use the major airport. Adjustment of the schedule of landing fees could make these ancilliary airports more attractive to general aviation aircraft and further alleviate congestion at the hubs. As a concluding objection to a system of weight based landing fees, Levine challenges the incentives that such a system creates. As mentioned above, weight based landing fees encourage high frequency (low load factor) scheduling of aircraft. This is especially true in the case of lighter aircraft. Smaller aircraft can be scheduled at relatively high frequency during peak hours and will incur the same airport charges as would be incurred by fewer larger aircraft carrying the same number of passengers. The total weight of an aircraft, which is used to assess landing charges does not reflect the variable cost of runway use in terms of wear and tear of the runway surface. This wear is a function of "footprint pressure" of the aircraft landing gear. The size, number and arrangement of the gear determines how the total weight of the aircraft is distributed on to the bearing surface. Many smaller jets, with simple landing gear arrangements, place heavier loads on the runways than do the latest generation of large, wide-bodied jets. Undoubtedly, aprons and taxi-ways must be enlargened to accommodate the larger craft and such additional investment must be noted, but at present the landing fee schedules provide dis-incentives to the designers of aircraft insofar as the provision of landing gear which conserves runways.

At most large airports, general aviation aircraft pay either a flat fee for landing or substitute the purchase of fuel. Air carrier aircraft pay both the landing fee and the fuel flowage fee. The rationale behind a fuel flowage fee will be discussed at length elsewhere in this chapter, so only a brief mention will be made of it here. Basically, heavier, (faster) aircraft are charged more than lighter (slower) aircraft. The higher charge is a function of the larger volumes of fuel sold to the larger aircraft. Aside from the debate over the equity of this scheme, one must observe what incentives are created by its use. Air carrier equipment is scheduled with scant consideration to the price of fuel at each successive stop. (This has traditionally been the case when fuel was plentiful and cheap, its relevance may have changed dramatically since the Middle-East war and the Arab oil embargo.) The amount of fuel purchased is usually related only to the stage length just flown, the speed and altitude of the flight and the anticipated payload for the next stage length. General aviation aircraft, particularly the very light variety, consume far less fuel than their air carrier counterparts. This low rate of consumption, combined with the waiving of landing fees often encourages use of the airport for frivolous purposes. Levine mentions the recreational flight for a cup of coffee or the student pilot familiarization flight as examples of such use. The frivolity of such flights can be debated but the major thrust of the criticism of fuel flowage fees remains valid: the collection of fees for the purchase of fuel at airports encourages their use by light weight, economical aircraft with low value missions while simultaneously penalizing heavier aircraft which consume more fuel.[4] In summarizing his argument, Levine develops a parallel comparison between free enterprise market activity and the sort of activity we observe at airports. The question of resource supply and allocation at airports is presented in the light of economic justification. Economic principles have been abandoned in

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[4] The fact that a particular aircraft consumes more fuel to fly a given route than does another aircraft cannot be construed (necessarily) to mean that the "thirstier" aircraft is less economical. Consideration must be had, amoung other things, of the number of persons accomodated by each aircraft.

establishing prices for airport services and in determining the timing for further investment. The following quote from Levine's work summarizes this failing and sets the stage for the ensuing discussion:

"Most goods and services are supplied and allocated according to a system of market prices. These prices serve two primary functions: they distribute the stock of goods and services in existence at any given time to those uses in which they can be employed to maximum consumer satisfaction; and they determine over time the pattern of investment in production ensuring a mixture of production best adapted to consumer wants... (it has been) seen that the existing price system for airport services fails to allocate the existing capacity so as to maximize it's value. It fails also to guide investment in airports so as to achieve the appropriate mix and level of output with a minimum investment of resources. This failure is socially wasteful in two ways--through congestion and inappropriate facilities it prevents the air transport industry from maximizing consumer satisfaction, and by failing to appropriately match investment to output it wastes resources which could be used to satisfy wants elsewhere in the economy."

In the market place, production of goods and services is called forth by the demands of consumers. Excessive demand (over available supply) increases the price over production costs and attracts investment in expectation of a profit. The resultant increase in production, reduces prices until an equilibrium is reached where further investment stops and the price stabilizes at a level commensurate with a normal rate of return. This process continues however as entrepreneurs seek to diversify their products and find a market. Differentiation of products will continue up until the point where the cost to the producer of seeking a market for and producing a differentiated product exceeds the value to the consumer of the differentiation. By understanding why entrepreneurs seek to differentiate their products within a free market environment, it becomes easier to apply this reasoning to the air transportation industry.

Transportation may be characterized as a service. Demand for this service typically varies cyclically over time, being very heavy during some periods and very light during others. The production of air transportation employs some resources for considerable periods of time. These fixed costs are incurred regardless of demand. Facilities which were constructed to produce a service available to consumers during periods of high demand are automatically available without additional cost to production in other periods. In periods of low demand the only additional cost of producing the service is the cost attributable to each unit of the variable cost. With fixed costs of production treated as joint between periods of high and low demand, it is in the best interests of the entrepreneur to stimulate demand for his product at other-than-peak periods. This is often done by price differentials which attract consumers not in the market at peak demand prices. Some consumers also shift from using the service at peak times to using it at a reduced price during off-peak times.

Because a weight based landing fee is assessed the users of air transportation services, there is no incentive for airport managers to seek out users with different needs and develop differentiated facilities for them. It is evident that the users of airports are not homogeneous. Different categories of aircraft differ greatly in their demands for airport services. Light aircraft require less elaborate landing aids and can be accomodated by short runways of low strength. As aircraft size, weight and speed increase and all weather operation consistency becomes essential, more sophistication in instrument landing systems are required to ensure safe operations. The use of sophisticated aircraft also necessitates provision of long runways capable of supporting high loads. Aircraft operators are compelled to pay a landing fee which (to some degree varies with the type of aircraft) reflects the weight of their machine. Because they pay a flat rate, regardless of the characteristics of the runway they use, aircraft operators are not inclined to use the simplest facility consistent with their needs. Predictably, because of the lack of demand for such facilities, they are not supplied. The mechanism through which demand may be directed, is missing here. The weight based landing fee does not permit the aircraft operator the opportunity to signal his preference. The same reasoning applies in the case of electronic landing approach aids. Such devices are invaluable to the pilot and provide assistance in approaching the airport as well as descending on the ideal glide slope to a safe touchdown. The complexity of these instruments varies widely. The more precise the guidance system, the more costly it is to manufacture and install. Despite opinions to the contrary, the degree of precision required to guide an aircraft approaching a runway at speeds less than 120 miles per hour, is not great. The approach guidance equipment at airports frequented by both general aviation and air carrier aircraft is often ideal for the faster commercial aircraft but superfluous for the slower, lighter aircraft. Both the Federal Aviation Administration (FAA) in the

United States and the Ministry of Transport (MOT) in Canada insist on the installation of the ultimate in guidance equipment regardless of it's suitability. The aircraft operator, because he is not charged (directly) for the use of instrument aids, does not economize in his use of them. Levine feels that much of the equipment is supplied to U.S. airports without consideration of need. "...and the FAA whose existence and annual appropriation depends in part on its identifying and satisfying a 'need' for its services, encourages operators to expect and demand sophisticated electronic assistance needed or not."

The previous discussion has shown how the system of weight based landing charges distorts the allocation of resources at airports. For the most part, this discussion centred on design aspects of the airport and the consequences of not differentiating between users. The following deliberations will be concerned with the effect that the present system of landing fees has had on decisions to invest in the airport.

Landing fees which are not time dependent nor which vary between seasons, encourage overinvestment to accommodate peak demands. As mentioned before, the value of a delay-free schedule varies among aircraft operators. At one extreme we have air carriers which rely heavily for patronage on their ability to fly under most weather conditions as well as schedule flights at times convenient to the traveller and ensure that the flight will be punctual. At the other extreme, we have a general aviation aircraft, whose operator flies for recreation and to whom time is of little consequence. The capacity of the airport is competed for by all users but the terms of this competition-delays due to congestion, favor the operators who value time least. The net effect of large volumes of traffic and competition for capacity is strong pressure to expand landing facilities. This pressure is invariably initiated by those operators who value time highly. In the United States, at least, an expansion of the airport facilities is financed (to some degree) by those users who place little value on time and would otherwise be content to endure congestion. Aircraft operators contribute to expansion through higher landing fees. This compulsory contribution "encourages greater peak-hour use by low value users who are entitled to use the peak-hour facilities they pay for and who accomodate themselves to reduced congestion by increasing their operations. The result is still more investment, higher fees and no reduction in congestion.[5]

The low level of the landing fees is not the only problem however. Combined with this is the lack of exclusive possession of landing rights for aircraft operators. Without some guarantee of access to the landing area, an aircraft operator will be reluctant to contract his schedule. Any reduction in schedule frequency that he makes will be matched by an increase in activity by another user. This phenomenon was mentioned before but here it will be embellished. To allow the aircraft operator the opportunity to maximize his utility, he must be permitted to express

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[5] Levine M.E. Landing Fees and the Airport Congestion Problem, The Journal of Law and Economics, 1969.

his willingness to obtain exclusive rights to the landing area. Such an expression could be reflected in a bid registered by the aircraft operator or the acceptance by him of a peak-hour surcharge established by the airport manager. The extraction of greater revenue from existing resources would benefit society as a whole.

As we have seen, the level of landing fees in Canada and the United States, is very low. This low rate inevitably attracts many users, with congestion occuring at popular times of the day. We have observed the effect that the low-level, flat-rate landing fees have had on investment decisions. In the following sections, The rationale behind the current pricing scheme will be examined and the equity debate surrounding the proposed revisions will be described.

The scheme currently used to assess the charges made for airport services is a compromise between arbitrary rationing and direct charging. By direct charging is meant a price which is related directly to the cost of providing a service. It is generally agreed that rationing by physical or administrative means is unsatisfactory as a permanent policy for the outputs of public utilities. Physical rationing is necessarily arbitrary and is only rarely successful in dispensing services so that the benefits derived are equivalent to the costs of supply. It also offers no guidance for investment decisions. Direct charging techniques are ideal expressions of marginal cost pricing rules. Airport administrators, for unheard of reasons, choose to charge for airport services, using criteria that are not direct. As substitutes for direct charges, the prices derived depart from the ideal. This departure is inevitable for practical considerations often make the realization of an ideal, impossible. Unfortunately, because the criteria selected for charging (landing weight and fuel consumption) departs so dramatically from marginal cost rules, we are left with little more than a convenient device with which to collect revenue. Guided by the existing pricing system, decision makers automatically increase capacity when existing capacity approaches full utilization. In other words, at this point more capacity is deemed to be "required." Clearly, in the absence of a signal to invest of the kind described in the previous section, it can rarely be certain that the value of the additional consumption made possible by the investment will exceed the costs thereby incurred. Even if the investment will ultimately be required, using the existing pricing scheme almost guarantees that such investment will be made prematurely. J. Warford, in his book, "Public Policy Toward General Aviation[6]," has developed a decision framework within which one may evaluate a particular approach to pricing. It is recognized that this framework is very theoretical and would not likely be used by policymakers as they debate the merits of various prices. Despite this weakness, it provides a good basis from which to work. Having been exposed to the ideal situation, we are put in a better position to critically analyse the reasoning behind the current pricing scheme. Warford has

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[6] Warford J.J. Public Policy Toward General Aviation, The Brookings Institution, 1971.

selected three criteria against which a pricing scheme is evaluated. He describes these criteria as "influences (which determine) the attitude of a public authority toward charging a price for services supplied." The first of these influences is:

1. Presence of technological external economies-- "If the consumption of a commodity results in a net real gain to society over and above that accruing directly to the purchasers, so that the marginal cost of consumption is less than its marginal <u>social</u> cost (that is, net of any external marginal benefits), the case for pricing that commodity is correspondingly weakened. Although theory states that price whould equal marginal social cost, the extent of the divergence between marginal cost and marginal social cost is rarely known with any accuracy. To the extent that this is so, price becomes less useful in aiding the investment decision or allocating resources in the short run."

Aircraft operators argue that there are technological externalities associated with their activity at an airport. In many cases it is attested that the economic benefits which result from this activity, and which accrue to the remainder of society, exceed the costs which are incurred to maintain it. Such a situation would qualify for subsidy, in this case the maintenance of low landing fees.

2. Intangible factors: policy makers may consider the maintenance of high safety standards, and the concurrent preservation of human life as reasonable justification for low landing fees. The value of human life can be measured to some degree in

monetary terms (ie. - costs of hospital treatment, lost productivity etc.) but the cost of suffering associated with injury or death cannot be quantified with consensus. It may be thought that a revision of landing fees would effect safety standards adversely and would cost more than would be gained from additional revenues.

3. Excessive cost of the price mechanism itself: In many cases, the costs of introducing a pricing mechanism are too great relative to the benefits provided. This argument is often heard in relation to charging for the use of enroute navigation aids. These aids usually consist of a VORTAC facility.[7] Charging for the use of airport instrument guidance equipment has also been considered. The difficulty inherent in the monitoring of usage as well as the billing for usage appears (with present technology) to outweigh the benefits. It has been suggested that where the marginal cost of output is close to zero, pricing is invariably inefficient.[8] This may be the situation with regard to runways, at least in the short-run. However, a necessary condition is that long-run marginal cost also be zero. The decision maker is then confronted with the choice of implementing direct charge pricing system. His decision must consider both the costs and the benefits associated

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[7] Very High Frequency Omni-Directional receiver used in conjunction with DME (distance measuring equipment). Monitoring of this facility enables a pilot to navigate very accurately with virtually no reference to the physical features of his course.

[8] J.G. Head, "Public Goods & Public Policy," Public Finance, Vol. 17 #3, 1962.

with the system; in essence he must conduct a type of cost-benefit analysis. "The benefits of obtaining an optimal investment decision may alone warrant the introduction of pricing; the fact that short-run marginal cost is zero is not a sufficient condition for its rejection. The costs of extending capacity may be substantial; consequently so would be the benefits of deferring or obviating that investment by charging a price and thereby providing decision makers with realistic data about demand."

The system of charges in effect at North American airports represents a tradeoff between monetary and non-monetary costs and benefits. The degree to which this tradeoff departs from the ideal outlined in the second chapter depends on the priorities established by the policymakers. The following section will discuss some elements of the equity debate surrounding suggested changes in these priorities.

Traditionally, aircraft operators have been levied fees for the use of airports and airways which supposedly reflected the value of their use. This goal of charging according to the presumed value of facilities has not been realized. To achieve such a goal would have involved charging a fee directly related to the use of facility. Direct charging was applied in the case of landing fees but as we ahave seen, the schedule of fees although direct, was not designed to permit the operators to indicate their perception of the value of the services. This value was construed by the airport operators and applied independently. Indirect charging is used to collect revenue for the use of the en route navigation services. Aside from the structure of landing fees, (which will be the subject of another chapter) most of the controversy surrounding pricing is in the proxy selected for indirect charging as well as the concept of indirect charging itself. The Ministry of Transport (Canada) and the FAA (USA) use the same system in collecting revenue for the use of en route navigation systems. As we have seen, in the United States, the rate charged may differ from that charged in Canada, but the principle remains the same. Essentially, a fuel tax is charged and a fee is collected from the air carriers for each passenger on board the aircraft. In Canada, the passenger tax is a function of the capacity of the aircraft, and does not reflect load factors on any particular day. In recent years, pressure has been exerted on these two governmental bodies to amend the indirect charge approach in pricing the services of the airway system. The FAA responded to this criticism with a statement which to its satisfaction, justified the policy: "A system of direct charges, under which a specific dollar charge would be levied for each use of a component or service of the airway system, would meet the requirement of an equitable program of user charges if the direct charges were related both to the use made of and the benefits derived from individual facilities and services. However, the operational and administrative problems inherent in direct charging (eg. - charging for each flight plan filed, each radio contact made, etc.) appear to preclude its consideration for the domestic Federal Airway System in the aggregate. The large variety of facilities and services in use would require a complex schedule of fees that would have to be extensively planned before installation. A vast and expensive administrative establishment would undoubtedly be required to administer and to collect such fees throughout the United States. A further objection to direct charges is that their imposition could adversely affect the safety of flying by decreasing the readiness of some civil users to avail themselves of all appropriate facilities and services."[9] Although no equivalent policy statement was available from the Ministry of Transport at the time of this writing, the author was assured by a MOT spokesman that the Ministry concurs with the stance of the FAA.

Having observed the position adopted by government, it remains now to reconcile this position with that of the users. Ideally, charges for use of air services should reflect the costs involved as a result of different types of activity. Users vary as to the demands that they place on the system. Bearing in mind the costs of distinguishing between users, the airport operator should attempt to associate particular users with particular costs. As user distinction becomes finer, so does the cost of isolating and assigning costs. The temptation to distinguish arbitrarily between different users for the purpose of simplifying the administration of prices must be overcome if any degree of equity is to be achieved. The oft-referred to example of arbitrary distinction

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[9] Administrations Proposals on Airway User Charges, Hearings before the House Committee on Ways & Means, 89 Cong. 2 sess. (1966).

concerns the different treatment of traffic flying under instrument flight rules (IFR) and visual flight rules (VFR). To charge IFR traffic a higher fee than VFR traffic regardless of the prevailing conditions is to discriminate in favor of VFR users. This is acceptable except when both users are operating simultaneously. Under such conditions, IFR traffic being positively controlled, provides greater safety for VFR traffic which is not so controlled. Equitable treatment would result in no distinction being made between these two classes of traffic when visual flight rules are in effect. It is recognized that any form of indirect charging is necessarily imperfect from the aspect of efficiency in resource allocation and of equity. The official stance on direct charging for airway services has already been noted. With the present state of technology, it is generally agreed that the cost of detecting each individual use of this system and tabulating these uses would exceed the resultant benefits. The concomitant hazard to safety which could result from a direct charge to instrument regulated flights is also justification for indirect charging. In practice, therefore, the demands of equity and efficiency can probably best be satisfied by levying an indirect charge. The proxy for assessment should relate as closely as possible to the use made of airway services. At present, the fuel flowage fee is the system under use. The fuel consumed by an aircraft is directly related to that aircraft's weight and payload as well as to the distance flown. It may also be true that to an individual aircraft operator, the net monetary benefit resulting from each mile flown is greater, the greater the gross weight of his aircraft. Given these assumptions, fuel consumption may be used to reflect the use made of the airway systems and the benefits derived from this use. Cost recovery of this kind discriminates in favor of light weight, slow aircraft. Recalling that the intention of pricing airway services was to efficiently allocate resources in addition to ensuring equity, we see that a pricing scheme based only on fuel consumption rates would have perverse effects. This type of scheme would invariably encourage greater than optimum use of smaller aircraft and less than optimum use of larger aircraft. Warford discusses the relative merits of the fuel tax as it affects operators of large aircraft: The use of fuel consumption as a proxy for taxation will, on occasion, work to the detriment of larger aircraft. As a rule, larger heavier aircraft are faster and consequently spend less time in the airways. This fact is not recognized by a fuel tax. Lighter, slower aircraft, while consuming less fuel for a given trip, take more time to complete it. Distance has been suggested as an alternative proxy for the assessment of the fuel tax. This too has disadvantages. The area over which the distance is flown will reflect the cost incurred to provide navigation aids. Obviously a flight over a remote part of the Yukon is not comparable to a flight of similar distance in a very congested airspace. The resolution of the problem of proxy selection has been left to default. Neither distance nor fuel consumption is an ideal proxy, both have disadvantages in certain applications. Fuel consumption is used primarily because of the ease of collecting the tax. The machinery of collection already exists and collection does not necessitate a complex calculation to equate the tax burden to amount of use.

This section has shown how weight based landing fees and indiscriminant fuel flowage fees can lead to congestion on the one hand and a distortion of efficient equipment utilization on the other hand. The following chapter describes the work done for the Port of New York Authority by the Rand Corporation. This author understands that this work represents the most extensive research done in this field in recent years. The report develops a model for pricing airport runway capacity which is economically efficient and resolves many of the problems of equity alluded to above. The data for the model was collected from observations made at Kennedy International Airport. The presentation in this chapter follows the same sequence as the original paper. There are four sections:

Section I -- the theoretical formulation of the model.

Section II -- the development of empirical estimates of traffic and delays that are required to calibrate the model.

Section III -- the calibration of the model is outlined.

Section IV -- delay reductions resulting from traffic volume reduction are estimated and summarized.

Chapter III

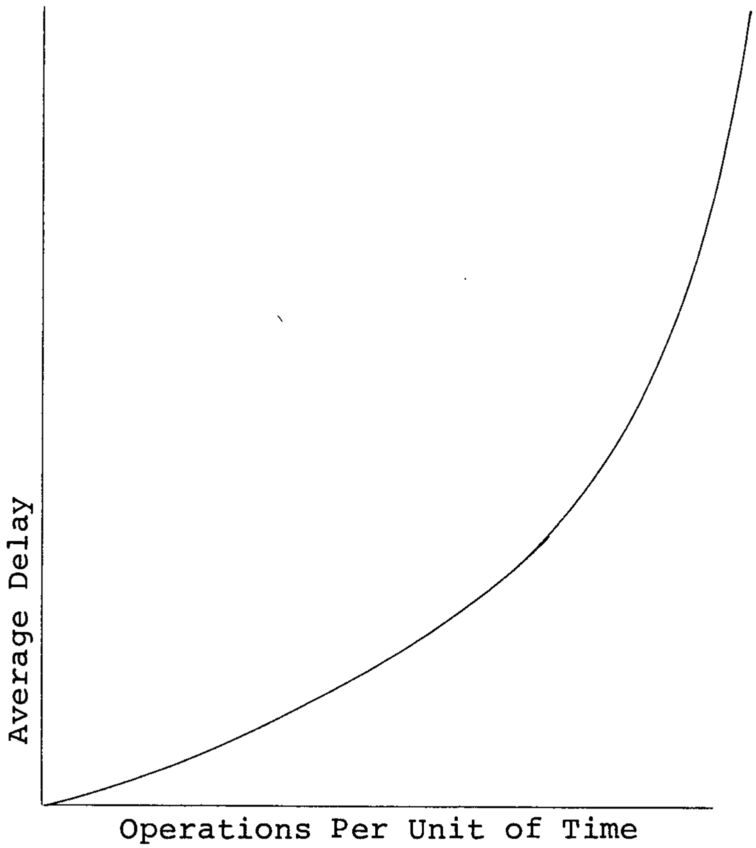
I Theoretical Model

Airport capacity studies have usually used a steady state queueing model in which average delays are related to the number of operations. As the figure below depicts, as the number of operations per unit of time increases, so does the average delay per operation. A steady state solution can be found at low rates of arrival. However as the arrival rate approaches the rate at which the aircraft can be accommodated, average delay approaches infinity and no steady state solution exists. Figure 1 is adopted from studies conducted by the Airbourne Instruments Laboratory (AIL). It can be seen that misleading results could obtain from the use of such a model in a situation where the arrival rate frequently exceeds the acceptance rate. Carlin and Park elected to use a deterministic queueing model. The model is deterministic in that arrival and departure frequencies are not time invariant; they are related to the time of day as well as the season of the year. (The day of the week is also a determinant). In this model the arrival rate varies throughout the day and exceeds the service rate for substantial periods of time.

The arrival rate A(t) is defined as the rate at which arrivals or departures would land or take off if there were unlimited capacity to accommodate them. This is the pattern of traffic that would ensue if there were no delays. The acceptance rate, c, is defined as the maximum number of operations that an airport can

Figure 1

Average Delay as a function of Operational Frequency



Source: Carlin & Park "Model of Long Delays At Airports," Journal of Transport Economics and Policy, 1970.

accept during a given period of time. This rate results in a higher capacity than that predicted by AIL model.[1] The acceptance rate is the number of operations at which the average delay curve becomes vertical. Reference to Figure 1 will elucidate this point. This rate is dependent on weather conditions and the runway in use among other things.

While considering these definitions it becomes easy to visualize the sequence of events which take place when the arrival rate $A(t)$ exceeds the acceptance rate c, during the course of a day. Figure 2 is an illustration of the hypothesized relationship between $A(t)$ and c when $A(t)$ is very smooth and c is unvarying. Neither of these assumptions is realized under normal conditions but relaxing the standard of rigour facilitates the treatment of the variables without much loss of precision. When the arrival rate rises above the acceptance rate at time t_0 not all aircraft can be accommodated and backlog or queue begins to develop. This queue eventually equals the number of aircraft represented by the shaded area under the $A(t)$ curve and above the acceptance rate curve c. Put more specifically, the length of the queue in aeroplanes at any time t, for $t_0 \leq t \leq t_2$, equals:

1. $$Q(t) = \int_{t_0}^{t} \left[A(t) - c\right] dt$$

where t_0 is the initial point that the queue begins to develop. The delay to an aircraft which arrives at the airport at time t

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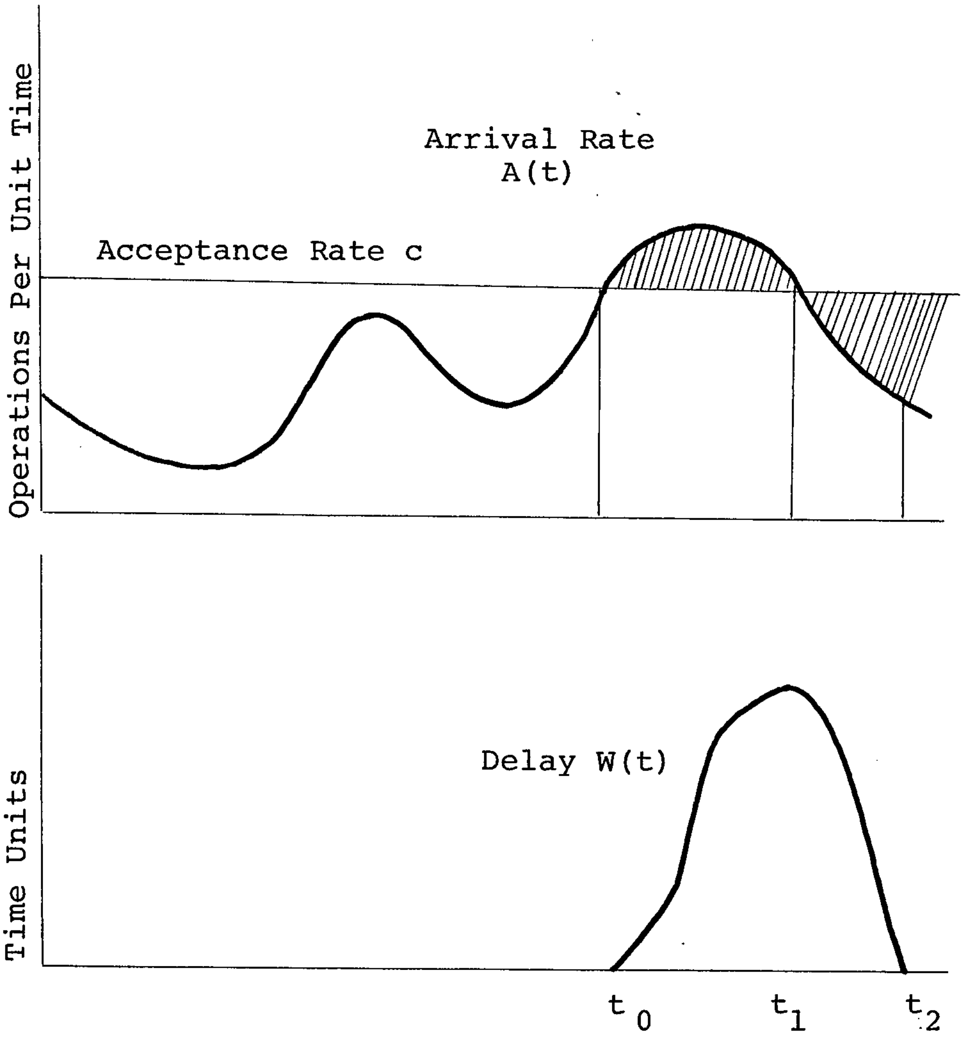
[1] The AIL criterion for capacity is the experience of an average delay of four minutes to all aircraft requiring accommodation. This criterion and its application in the AIL model will be examined in detail in the next chapter.

Figure 2

Arrival Rate as a Function of Acceptance Rate



Source: Carlin A. Park R.E., <u>A Model of Long delays at Busy Airports</u>, Journal of Transport Economics and Policy, 1970.

is equal to the length of time required to work through the queue in existence at that time.

2. $$W(t) = \frac{Q(t)}{c}$$

Substituting for Q(t), we obtain:

3. $$W(t) = \frac{1}{c} \int_{t_0}^{t} \left[A(t) - c\right] dt$$

Total delay D is simply the summation of each of the delays experienced by the individual aircraft:

4. $$D = \int_{t_0}^{t_2} A(t) \cdot W(t)\, dt$$

Delay W(t) reaches a maximum at t_1 where the arrival rate once again equals the acceptance rate. Delays will return to zero at time t_2. At this point, the queue which developed as a result of excess demand will have dissipated. This fact is portrayed by the equlity of the two shaded areas between times t_0 and t_1 (when the queue begins and reached a maximum) and times t_1 and t_2 (when the queue is at maximum to when it dissipates completely). It is evident from this model that there is no simple relation between arrival rate and average delay during a particular hour. Rather, the average delay depands upon the pattern of demand as well as the acceptance rate, both which are variable.

Carlin and Park recognize that the above model is too simple to be used in explaining actual observed data. If the model is to be used for data explanation, some complicating factors must be considered. The smooth arrival rate pictured in Figure 2 is an ideal. In reality there are major intra-hourly variations in arrival rates. A more accurate characterization would be a trend line with many sharp peaks and troughs on either side of it. The peaks will contribute to periodic queues even though the average arrival rate does not exceed the acceptance rate. A further unresolved complication is the relationship between arrivals for landing and arrivals for takeoff. Obviously these two competing activities affect each other. The degree to which each affects the other is dependent on such things as the configuration of the runways in use as well as any restrictions on the airspace around the airport. The amount of interdependence between these arrivals will determine their net effect on the usefulness of the model. The final caveat concerns the range of validity for the model. "The model holds strictly only for individual days. An attempt to test it or apply it on the basis of average data may be misleading. The greater the day to day variation in the elements of the model, the more important is this qualification."[2] In the succeeding sections, this last reservation is incorporated into the model,

II

The variables described in the above section are now estimated from data collected at Kennedy International Airport. Recalling the final qualification to utilization of the model, all estimates are disaggregated by weather and season.

The authors experienced considerable difficulty in obtaining records of delays to individual flights. The scheduled carriers kept records of delays relative to scheduled times but

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[2] Carlin, A. & Park, R.E. The Efficient Use of Airport Runway Capacity in a Time of Scarcity, The Rand Corporation, 1969.

since schedules have a substantial allowance for delay built into them, the estimates for delay would have been downward biased. The same carriers also recorded flight-plan time for each flight. These times were used as estimates of undelayed flight time. Subtracting flight-plan time from actual time elapsed in flight would yield a fairly reliable estimate of arrival delays. The resulting estimates would have been slightly biased upward since the flight-plan times assume optimal altitudes and routings that are not always realized. Because of these problems as well as the problems inherent in collecting data from different sources while presuming homogeneity of variance both within and between sources, the authors elected to use an indirect statistical estimating technique. This technique has the following properites:

Flight times are asssumed to be the sum of three elements;

1. an average undelayed flight time T (which depends only on the route flown and the type of aircraft used.
2. an average delay time D (which depends initially only on the time of day).
3. a random error term U (this term represents all of the influences which cause the actual flight time to deviate from the average flight time).[3]

Formally stated, the expression is:

$$O_{ijk} = T_i + D_j + U_{ijk}$$

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[3] The actual time spent in flight will now be referred to as the actual off-to-on time where <u>off</u> refers to the takeoff and <u>on</u> refers to the subsequent landing of an aircraft.

O_{ijk} is the actual off-to-on time for a particular flight. T_i is the average undelayed flight time for the ith route segment and equipment combination. To clarify the expression, we refer to the text of the original article:

"For example, if O_{ijk} is the actual off-to-on time for a 727 flight from O'Hare to Kennedy, T_i is the average undelayed jet flight time form O'Hare. D_j is the average delay during the jth period, which for the moment we shall treat as though it were a function only of the time of day when the flight is scheduled to arrive. If our flight is scheduled to arrive at 1643, D_j is the average delay to flights scheduled to arrive at Kennedy between 1600 and 1659 (hours). U_{ijk} is the ramdon error term."[4]

The data used in this indirect estimating technique was supplied by American Airlines and United Air Lines. It consisted of complete and accurate records of the actual off-to-on times of aircraft using Kennedy International Airport. The computational procedure consisted of the regression of these data, O_{ijk} on two sets of dummy variables. The first set of dummy variables represented the airport of origin and the type of aircraft making the flight. Recalling the above example, the first set of dummy variables would equal zero except the one variable representing jet flight from O'Hare, which would equal one. The second set of dummy variablel represented scheduled arrival time. By referring to the example once more, we can see that the second set of dummy

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[4] Carlin, A & Park, R.E. A Model of Long Delays at Busy Airports, Journal of Transportation Economies and Policy, 1970.

variables would equal zero except the one that represents arrivals between 1600 and 1659 hours, which equal one. The regression program used, omitted the constant term which usually appears in regression equations. The regression of O_{ijk} on the dummy variables yielded estimates of T_i as coefficients of the first set and D_j as coefficients of the second set.

Unfortunately, estimating techniques of the sort just described do not produce unique coefficients. The mutual addition and subtraction of constant amounts of time from each of the T_i and D_j estimates would not affect the value of O_{ijk}. To enable the estimates to be uniquely determined, the authors arbitrarily removed a degree of freedom from the D_j estimates. They chose a reference point during the early morning hours and specified zero delays during that period. Having done this, the interpretation of delay is changed. A delay of any length of time could no longer be regarded as absolute but only relative to delays in the reference period. The reference period selected was the hours between 0200 - 0700. Because of the exceptionally low volumes of traffic using Kennedy International at that time, it was felt that a reference delay of nearly zero would not invalidate subsequent estimates.

Table I shows the results of the two regressions for aircraft arriving at Kennedy International. In the first regression dummy variables were assigned to reflect only the hour of scheduled arrival. The coefficients resulting from this regression are therefore estimates of overall average delays by time of day.

Table I

Average Delays, W(t), to Kennedy Arrivals,
April 1967 through March 1968
(minutes)

Hour of	Overall Average		Summer G.W.*		Summer B.W.**		Winter B.W.		Winter B.W.	
	AD	SE	AD	SE	AD	SE	AD	SE	AD	SE
00-01	2.6	.8	6.1	1.2	7.2	2.0	.4	1.2	.8	2.3
01-02	1.1	.8	2.5	1.2	4.9	2.1	1.4	1.1	3.6	2.4
02-06	0.0		0.0		5.5	1.9	0.0		.9	1.8
06-07	0.0		0.0		5.2	1.1	0.0		2.1	1.1
07-08	5.1	.9	4.5	1.7	8.0	2.2	3.1	1.6	16.2	3.1
08-09	3.0	.7	.7	1.0	6.2	1.2	.6	1.4	13.0	2.4
09-10	2.5	.7	2.6	1.0	6.3	1.3	.2	1.2	6.6	1.9
10-11	3.4	.7	2.7	1.2	8.3	1.8	1.0	.8	15.1	1.5
11-12	4.5	.7	3.8	.9	8.7	1.2	3.0	.9	14.3	1.6
12-13	3.9	.6	4.3	.8	8.8	1.1	1.3	1.7	15.0	1.4
13-14	2.5	.7	2.0	.9	8.4	1.5	1.1	.8	13.4	1.5
14-15	4.5	.6	3.9	.7	12.0	1.1	1.8	.7	12.6	1.4
15-16	11.0	1.3	9.4	1.5	15.7	2.5	4.3	2.5	28.0	5.6
16-17	13.7	.5	13.7	.7	31.7	1.2	8.0	.6	37.5	1.1
17-18	19.7	.5	20.9	.6	43.5	1.0	9.6	.6	45.5	1.2
18-19	24.9	.5	25.6	.6	56.8	1.0	8.9	.7	51.4	1.3
19-20	17.2	.6	19.0	.7	47.2	1.2	5.5	.7	34.7	1.5
20-21	14.4	.5	13.9	.7	42.7	1.1	5.7	.7	34.9	1.2
21-22	11.8	.6	10.6	.7	35.2	1.3	3.3	.9	25.6	1.7
22-23	6.7	.6	7.9	.8	21.1	1.2	2.6	.7	13.4	1.4
23-24	2.3	.5	5.8	.7	11.4	1.2	2.2	.7	1.8	1.4

Source: Carlin, A & Park, R., A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970.

*Good Weather
**Bad Weather
AD--Average Delay
SE--Standard Error

In the second regression, the variables were assigned to reflect season and weather in addition to time of day. The resultant regression coefficients reflect average delay in arrival by the time of day as well as the weather and season in effect at the time of arrival. The estimates in Table I are based on 31,890 observations recorded by American Airlines and United Airlines during the period April 1, 1967 through March 31, 1968. The nineteen most frequently served cities were used as originating points for aircraft arriving at Kennedy. The definition of weather and season as used in the study is as follows:

a) good weather--ceilings of at least 2000 feet and visibilities of at least five miles.

b) bad weather--the weather is considered bad if limits fall below those associated with good weather. In their original work for the Rand Corporation, Carlin and Park selected a different criteria for weather categories: Ceilings of at least 2000 feet accompanied by visibilities of at least 5 miles were classed as "good VFR". VFR weather conditions, that is, ceilings of at least 1000 feet and visibilities of at least three miles, that did not qualify as good VFR fell in to the "marginal VFR" category. Below this, with ceilings down to 500 feet and visibilities down to one mile, comes a "marginal IFR" category. The worst category with ceilings less than 500 feet or visibility less than one mile was called "bad IFR." The regressions using these weather categories suggested strongly that the relation of delays to weather conditions is continous rather than dichotomous. Stated simply, the worse the more pronounced the delays. In their later work, the authors chose to use a dichotomous relationship however. Based on the results of the Rand study, Carlin and Park felt that the dichotomous distinction in weather that they had selected, (good and bad weather) fitted the observed delay patterns much better than the standard VFR/IFR dichotomy. The seasonal dichotomy used in calculating delay pattern was as follows:

c) Summer -- the first half of the year in which daylight savings is in effect. In the sample period used, this was from April 30, 1967 through October 28, 1967.

d) Winter -- the balance of the period studied.

Returning to Table I, we can observe the pattern of delays to arriving aircraft at Kennedy airport. The results show that the longest average delays were experienced by flights scheduled to arrive between 1800 and 1900 hours, regardless of the season or the weather. The first column, entitled "Overall Average" (delay) shows the average delay during this period to be 24.9 minutes. The standard error associated with this estimate is .5 indicating the range of accuracy of the estimate to be 24.9 $\pm$ 1 minute. The confidence limit of this estimate is approximately 95 percent. The standard error of estimate is probably biased slightly downward because the variance of the error term U_{ijk} associated with each estimate, is not constant. Least squares regression assumes that error is randomly distributed with a zero mean and constant variance. Almost certainly, the variance surrounding the arrival delay estimates, is not constant, varying with each airport of aircraft origin. The size of the standard error depends on the variability of delay times within a particular time category as well as on the number of observations that fall in that category and the number of observations in the reference period (0200-0700 hrs). Thus at higher levels of delay, when there are generally more operations and hence more observations during each period, the size of the standard error tends to decline not only relative to the size of the estimated delay, but also absolutely. This can be seen from Table I. Considering this caveat, we can better interpret the table's results.

Estimates were also made of the pattern of arrivals for landing. These patterns of arrivals are not the actual rates at which aircraft land or takeoff. As described in the introduction to this chapter, arrival rates A(t) are the rates at which aircraft are <u>ready</u> to land or takeoff. ie- the rate at which the present total number of landings and takeoffs would occur if there were no delays. As above, direct observations of A(t) are not made. The nature of A(t) in the absence of delay is something which may be estimated but because delays currently exist, cannot be observed. Two sources of data were used to make these estimates: Airline schedules and observations on actual landings by general aviation aircraft. It was evident to Carlin and Park, that airline schedules as published, contain an allowance for taxi times and are usually expressed in terms of gate arrival instead of actual touchdown on the runway. They chose to accept these schedules verbatim however, because the use of scheduled arrival times ensured comparability with W(t) estimates (the delay to an aircraft landing at time t). Having scrutinized the airline schedules, the average schedules for airlines operating at Kennedy during the first week of September 1967 were selected as typical of the summer half of the year. Similar schedules for the first week of February 1968 were selected as typical of winter. Along with other data, these arrival rates are shown in Table II. The general aviation component of A(t) posed a more difficult problem. Other than air taxis, general aviation traffic does not operate on a scheduled basis. Because of the nature of the aircraft composing this category[5] any estimates of arrival rates must be based on direct observations. Rather than observe the activity first hand, the authors used the records of the Federal Aviation Administration. These documents, called Runway Use Logs, contain records of both air carrier and general aviation traffic by runway used and time of day. A random sample of days from January 15, 1968 to July 31, 1968 was selected. Two additional adjustments were necessary before the general aviation estimates could be added to the air carrier schedules to give a total A(t). The primary interest of the study was in the demands placed on air carrier duty runways. The first adjustment therefore, was to subtract general aviation traffic that did not use duty runways. Subtracting general aviation traffic that did

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[5] General aviation is a category that includes all traffic other than air carrier and military operations. It includes air taxi, business and private aircraft. Many private aircraft are used for instructional or recreational purposes.

Table II

Arrival Rates, A(t), for Kennedy Arrivals, April 1967 through March 1968 (air carrier equivalents)

Hour of Day	General Aviation on Duty Runway	Carrier Schedules Summer	Carrier Schedules Winter	A(t) Summer	A(t) Winter	A(t) Av.
00-01	.4	14.7	15.0	15.0	15.3	15.2
01-02	.1	8.6	10.1	8.7	10.2	9.6
02-03	.2	4.9	5.7	5.1	5.9	5.5
03-04	.4	4.4	5.3	4.7	5.6	5.2
04-05	.2	2.4	3.8	2.6	4.0	3.3
05-06	.2	5.4	5.0	5.6	5.2	5.4
06-07	.8	15.1	19.4	15.8	20.1	18.0
07-08	2.9	11.6	8.4	14.1	10.9	12.5
08-09	3.8	17.6	18.3	20.9	21.6	21.3
09-10	2.4	17.3	12.8	19.4	14.9	17.2
10-11	2.6	18.4	22.1	20.7	24.4	22.6
11-12	2.8	21.6	12.8	24.0	15.2	19.6
12-13	2.1	24.4	25.1	26.2	26.9	26.6
13-14	3.8	20.0	22.7	23.3	26.0	24.7
14-15	3.8	28.0	30.5	31.3	33.8	32.6
15-16	3.0	30.7	34.0	33.3	36.6	35.0
16-17	2.7	48.6	49.2	50.9	51.5	51.2
17-18	3.5	42.7	37.1	45.7	40.1	42.9
18-19	2.2	40.3	34.2	42.2	36.1	39.2
19-20	2.4	32.0	24.5	34.1	26.6	30.4
20-21	2.2	34.7	34.1	36.6	36.0	36.3
21-22	1.5	30.7	18.7	32.0	20.0	26.0
22-23	1.8	17.7	17.0	19.3	18.6	19.0
23-24	.7	13.6	13.8	14.2	14.4	14.3

Source: Carlin, A. & Park, R. A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970

not use duty runways was justified it, in actual fact, those aircraft landing on non duty runways had no effect on aircraft landing on duty runways. While this assumption may not be absolutely correct, it seems reasonable.

The second adjustment to be made to the general aviation component of A(t), concerns the equating of demand for capacity between air carrier and general aviation traffic. Not all kinds of operations place the same demands on the runways; general aviation traffic, composed of relatively small aircraft, requires less service time than the larger machine of the air carriers. Using the AIL Airport Capacity Handbook, Carlin and Park estimated relative service times for the two classes of aircraft. It was found that at Kennedy International, an average general aviation landing requires 0.87 times the service time of the average air carrier landing. This factor was then used to weight general aviation landings so that they could be added to the air carrier component to produce a final A(t).

Having ascertained estimates of delay and trafffic volumes at Kennedy International during the year April 1967 to March 1968, and estimate of total delay to aircraft arriving during that period could be made. During each hour of operation, an average of N aircraft were delayed an average of W minutes. Total delays per day could then be estimated by use of the relationship introduced earlier:

$$D = \sum_{t=1}^{24} N(t) \quad . \quad W(t)$$

This relationship was applied separately to general aviation (on duty runways) and air carriers (average of winter and summer schedules of arrivals). Average delay data from Table I was substituted into the expression for $W(t)$ and arrival rates from Table II were substituted for $N(t)$. Estimates were multiplied by 366 to determine total annual delay. Delay to air carriers for the period chosen was estimated at 1.74 million minutes; general aviation aircraft were delayed 0.14 million minutes.

Discussion:

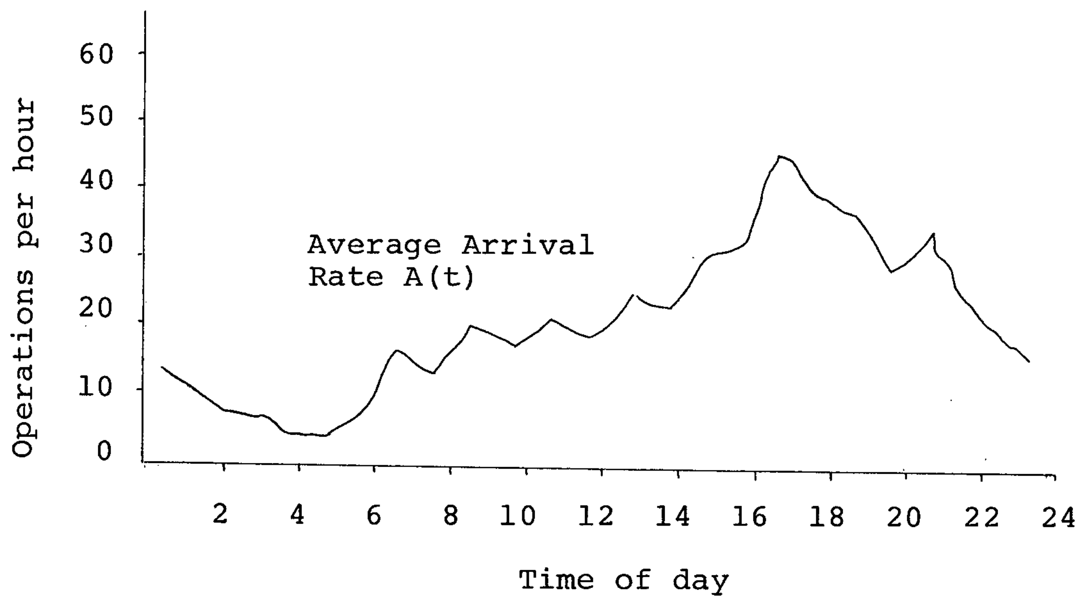
The drawbacks usually associated with averaging of data and the use of data under debatable assumptions apply in this study. Because the data is not ideal, one would not expect it to fit the proposed model very well. Despite these obvious failings, the model as presented does account for much of the observed delay. Figure 3 is a plot of the average arrival and delay data found in Tables I and II. The resemblance between the theoretical Figure 2 and the actual Figure 3 is startling, particularly the position of the delay peak relative to the arrival peak. The arrival peak is found between 1600 and 1700 hours; the delay peak occurs two hours later.

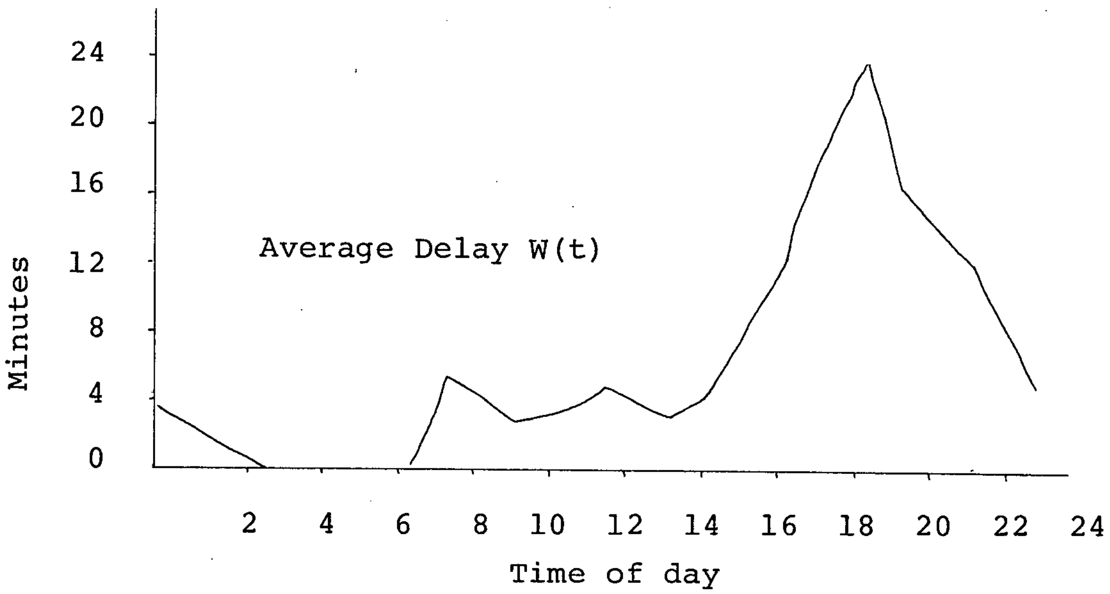
III The "Schedule Evaluator"

The first two sections dealt with observed arrival patterns and average delays. These estimates, taken together, enabled total delay to be calculated. Carlin and Park have also constructed a model to evaluate the effect on delay of different patterns of arrivals. The integrals, introduced in the first section, are replaced with corresponding summations so that hourly data may

Figure 3

Average Delay as a Function of Average Arrival Rate





Source: Carlin & Park, A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970 be used instead of continuous data. To produce a model capable of predicting delay as a function of arrival rate, calibration is necessary. The rationale behind this statement is best understood by reference to Carlin and Park:

> "The schedule evaluator takes arrival rates A(t) and acceptance rates c as input, and calculates delays W(t) as output. We have data on average A(t) and W(t), but none on average acceptance rates; that is, data on one of the required inputs is missing. Calibration consists of trying different values of c together with observed A(t), to see which most closely reproduces observed W(t). The values of c that produce the best fit are accepted as being average acceptance rates. These same values of c can then be used as input with other arrival patterns of interest in order to calculate the delay pattern W(t) that would result from the other A(t)."[6]

In section I, a number of caveats were issued to prepare the reader in evaluating the long delay model as applied to real situations: short period fluctuations in the arrival rate, interdependence of landings and takeoffs and the problem in the averaging of data. Predictably, these same limitations must be considered when working with the schedule evaluator. Ideally, data would be available for very short time periods, for instance, five minute intervals. An ability to gather data in such small increments would dampen intra-hourly variations in arrival rates. Unfortunately, the data used in the model represents the average of hourly arrival rates. As such, the model is incapable of predicting delays during periods when the arrival rate A(t) is below the acceptance rate and a queue carries over from one hour to the next. Obviously, because of high intra-hourly variation in arrival rates, delays

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[6] Carlin, A. & Park, R.E. <u>A Model of Long Delays at Busy Airports</u>, Journal of Transport Economics & policy, 1970.

could be experienced within the hour period. On the basis of average hourly arrival rates and average acceptance rates, however, no delays may be predicted. Because of this limitation, the model was fitted to arrivals at Kennedy between 1600 and 2100 hours, when the arrival rate consistently exceeds the acceptance rate and queues exist. Given the resultant calibration, the model predicts delays of up to five minutes for periods of very light traffic, whereas the long delay model predicted zero delay for the same period.

The dilemma of interdependence between landings and take-offs was resolved in exactly the same fasshion for this model as for the unmodified long-delay model. Even though traffic at Kennedy uses two, independent, non-intersecting runways, there is mutual influence from the aircraft using the runways. Neither runway is used exclusively for takeoffs or landings. Departures sometimes use the landing runway and arrivals sometimes land on the takeoff runway. An assumption of independence between activity on each runway was made. The justification for this assumption is debatable but its acceptance facilitated the development of the model.

To provide greater detail and reduce averaging error, the data was disaggregated into four classifications. The categories used in the development of the long-delay model were retained:

1. Summer, good weather
2. Summer, bad weather
3. Winter, good weather
4. Winter, bad weather

In the first two categories, a high and low acceptance figure is used with arrival rates A(t) from Table II. Numbers 3 and 4 are obtained in essentially the same manner, except that winter A(t) data from Table II is used in conjunction with high and low acceptance rates. Calibration is accomplished by adjusting the capacity figures used so that the calculated delays match observed delays (from Table I) as closely as possible in each of the four cases. The criterion selected for matching calculated to observed delays was:

$$\sum_{t=17}^{21} \left[\frac{\text{calculated } W(t) - \text{observed } W(t)}{\text{standard error } (t)}\right]^2$$

This sum of squared normalized deviations in minimized. The average capacities that resulted in the best fit are:

1. Summer, good weather - 40.8
2. Summer, bad weather - 36.1
3. Winter, good weather - 43.3
4. Winter, bad weather - 34.5

Using the capacity figures above, the associated delay patterns were averaged to obtain an overall average delay pattern.[7] Table III, which is presented below, shows the delays calculated by the schedule evaluator for each of the disaggregated cases as well as the observed delays. Comparison shows the fit to be consistently good.

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[7] Each delay sample was weighted by the fraction of total observations that "belonged" to it.

Table III

Delay Calculation--Schedule Evaluator Technique

Hour of Day	Overall Average		Summer G.W.		Summer B.W.		Winter G.W.		Winter B.W.	
	Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs	Cal	Obs
Average delay in minutes:										
16-17	13	14	10	14	27	32	8	8	37	37
17-18	22	20	21	21	42	43	12	10	46	46
18-19	23	25	25	26	52	57	6	9	49	51
19-20	18	17	21	19	48	47	2	5	35	35
20-21	15	14	13	14	48	43	2	6	37	35

G.W. Good Weather
B.W. Bad Weather

Cal Calculated
Obs Observed

Source: Carlin, A. & Park, R. A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970

The schedule evaluator is potentially valuable as a predictor of the effectiveness of schemes designed to ration the capacity of an airport. Throughout this thesis, a path has been sketched from theoretical discussion. The schedule evaluator represents the first successful attempt to produce a tool capable of monitoring the effect of changes in policy. Admittedly, the tool is rudimentary, but it is nonetheless valuable.

The application of the schedule evaluator is very simple. First, the arrival patterns are altered. (Usually to remove some portion of the original traffic.) The modified arrivals are then evaluated using the acceptance rates derived before.

To test the effect on delays of a reduction in arrivals, Carlin and Park reduced A(t) (the general aviation component) by fifty percent, leaving the air carrier component untouched. This reduction in anticipated general aviation traffic was due to an arbitrary twenty-five dollar minimum landing fee established in August, 1968. After the introduction of this minimum fee, approximately 50% of general aviation traffic originally using the facility, diverted to other airports or shifted from duty to non-duty runways. Being cognizant of this shift, Carlin and Park sought to anticipate the reduction in delays and compare this to observed delays. The schedule evaluator calculated a peak average delay of 18 minutes whereas the delay associated with the then current arrival pattern, was 23 minutes. Table IV shows these figures. For aircraft arriving at Kennedy International between 1600 and 2100 hours, total delays were calculated to drop from

Table IV

Peak Average Delay

Hour of Day	Actual	50% of Actual General Aviation	No General Aviation	50% of Actual General Aviation and 47 Schedule Limit
Average delay in minutes:				
16-17	13	12	11	10
17-18	22	18	15	16
18-19	23	18	14	16
19-20	18	13	9	12
20-21	15	10	6	9
Total yearly delay to carrier planes in millions of minutes:				
16-21	1.27	1.01	0.80	0.88

Source: Carlin, A. & Park, R. A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970

1.27 million minutes per year to 1.01 million minutes per year.

A second suggestion for the alleviation of congestion was the banning from duty runways of all general aviation aircraft. With no general aviation traffic and with unchanged carrier schedules, the schedule evaluator estimated an eight minute reduction in peak average delay,[8] and a 0.47 million minute reduction in total yearly air carrier delay for the period from 1600-2100 hours. The last policy evaluated was the inclusion of $25 minimum fee and a limit on planned operations during bad weather. The authors anticipated a reduction in general aviation activity equal to the case where only the minimum fee was in effect. Air carriers would be restricted to eighty movements per hour between 1700 and 2000 hours and seventy movements per hour for the rest of the day. Anticipated limit for air carrier activity was set at forty-seven per hour if bad weather persisted for the five hour period. The pattern of calculated delays for this reduced arrival pattern falls approximately between the first two. Peak average delays would be reduced by eight minutes and total delays during the five hour period by about 0.39 million minutes annually.

The model that was described in this section was developed from data gathered at Kennedy International Airport. It sought to relate the pattern of arrivals to the acceptance capability of the facility. This relation was then described in terms of delay

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[8] The peak average delay in actual conditions was found to be 23 minutes for the period 1800-1900 hours. The peak average delay for the condition of banishment for general aviation aircraft was found to be 15 minutes for period 1700-1800 hours.

to arriving aircraft. The pattern of arrivals, given an acceptance rate, was shown to determine the pattern of delay. The policy changes investigated modified arrival patterns through enforcement of arbitrary minimum landing fees or exclusion of all general aviation traffic from duty runways. The next work reviewed, also by Carlin and Park, results from an extension of the study which produced the schedule evaluator. Here we once again encounter marginal cost pricing of services; the marginal cost of delay is estimated and this cost is included in a proposed price to ration landing capacity.

Marginal Cost Pricing of Airport Runway Capacity-

The situation repeatedly queried throughout this study is the congestion costs that an additional user (of the airport) imposes on the aircraft using the facility at the time of his arrival. If an aircraft lands or takes off at a time such that it causes another aircraft to wait, it delays the other aircraft and its passengers with resultant costs to both. During times of congestion, queues develop, and each user imposes some delay on all following users until the end of the busy period. The busy period ends when the queue dissipates. The effect that an additional aircraft has on the aircraft already in the queue can be illustrated quite well by referring to a discussion found in the original Rand Report prepared for the Port of New York Authority:

"... the length of queue and delays on a particular day at a congested airport, by time of day (are) shown by the heavy line in Figure 4. In this illustration, the addition of the one more aircraft desiring service at, say, time 04 would result in the queueing pattern indicated by the enclosed area plus the single cross-hatched area. Note that although the additional airplane would be serviced during minute 07, the effects on other aircraft would be much longer lasting. In this case, all aircraft arriving after the additional one would be delayed by one minute until minute 18. The total delay imposed on the other airplanes can be seen to be equal to the single cross-hatched area, or 13 minutes."

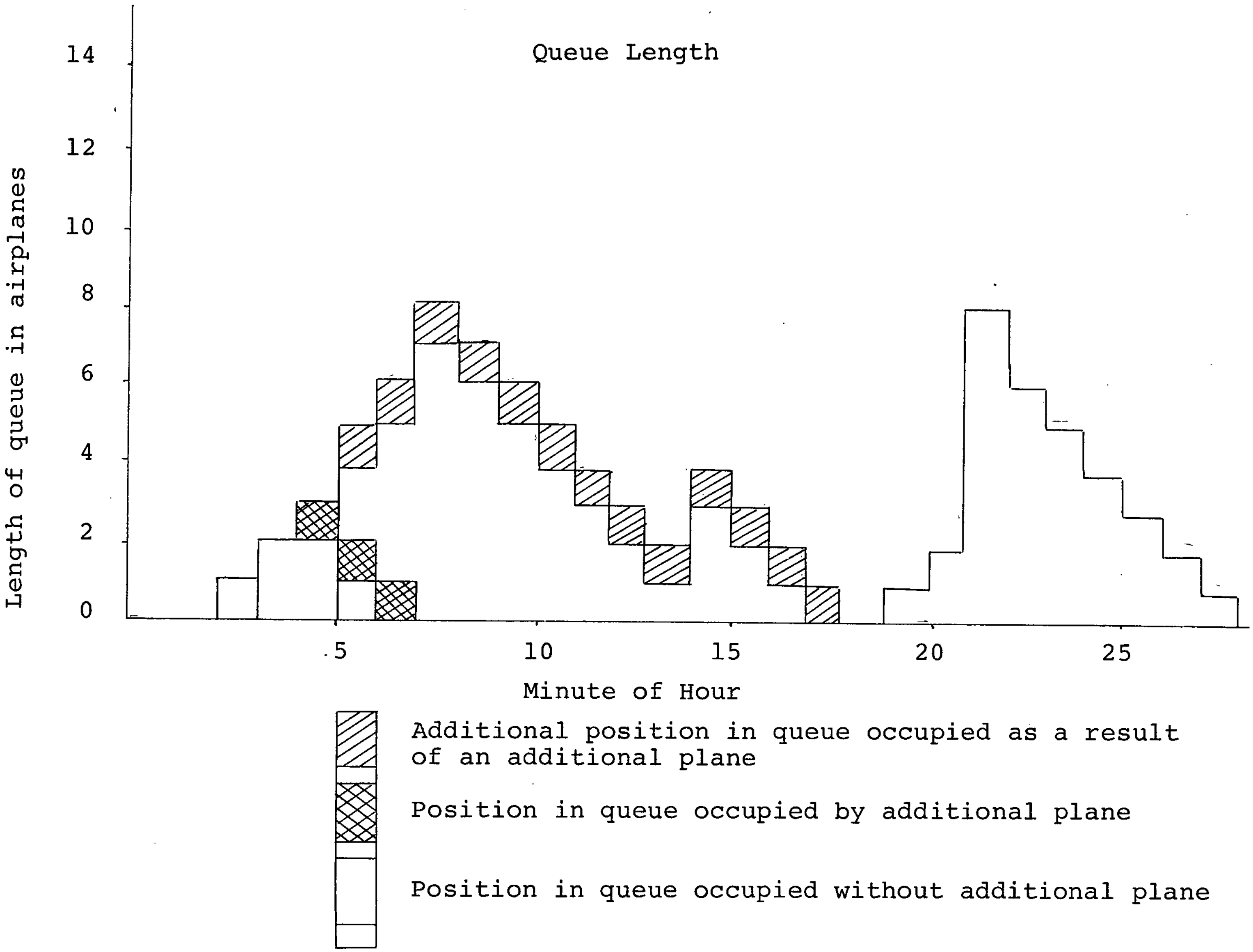
The model developed in this study, was designed to determine the "cost of delays C_i imposed by users of type i at a time t when the remaining busy period equal B minutes". Use is defined with reference to the type of aircraft and by specification as to whether the aircraft is landing or taking off. The time required to service each type of operation is designated S_i. The number of operations of each type that would occur from time t until the end of the busy period is designated N_i. The cost per minute of operation is defined as c_i.

If all of these parameters were known with certainty, it would be quite simple to calculate the marginal cost of an additional user of type i in terms of imposed delay.

1. $$C_i = S_i \sum_{i=1}^{m} N_i c_i$$

The additional operation delays each of the $N = \sum_{i=1}^{m} N_i$ operations for S_i minutes at a cost to each of c_i per minute. But absolute service times S_i, and numbers of type i operations N_i are difficult to estimate. With the availability of data, it is somewhat easier

Figure 4



Source: Carlin A. & Park R.E., _The Efficient Use of Airport Runway Capacity in a Time of Scarcity_, The Rand Corporation, 1969 to estimate relative servi times,[9] $s_i = S_i/s$, and proportions of various types of operations,[10] $n_i = N_i/N$. The above relationship was transformed into a more usable form by first defining a second relationship: "The length of the remaining busy period must just equal the sum of the time necessary to service each of the airplanes that lands or takes off before it (the remaining busy period) ends."

$$2. \qquad B = \sum_{i=1}^{m} N_i S_i$$

Dividing C_i by B, we obtain:

$$3. \qquad \frac{C_i}{B} = \frac{S_i \sum_{i=1}^{m} N_i c_i}{\sum_{i=1}^{m} N_i S_i}$$

Simplifying, we obtain further, (both the numerator and the denominator of the above expression are divided by $S_1 N$)

$$4. \qquad \frac{C_i}{B} = \frac{s_i \sum_{i=1}^{m} n_i c_i}{\sum_{i=1}^{m} n_i s_i}$$

In this relationship we have the marginal cost per minute of the remaining busy period $\left(\frac{C_i}{B}\right)$ expressed in terms of use proportions (n_i), relative service times (s_i) and the cost to individual aircraft per minute (of delay), c_i.

Four kinds of operations were selected as a description

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[9] The method for estimating the s's evolved using the Airport Capacity estimates made several years ago by the Airborne Instruments Laboratory. The AIL capacity figures vary according to the mix of large and small planes and the mix of landing and takeoffs, making it possible to estimate service time.

[10] Estimates of the n's were obtained from aggregate traffic statistics, corrected to eliminate that fraction of general aviation traffic that used non-duty runways.

of activity at LaGuardia Airport:

1. air carrier landings
2. air carrier takeoffs
3. general aviation landings
4. general aviation takeoffs

For the case of an air carrier landing, $s_1 = 1$. Therefore the marginal delay cost due to an air carrier landing C_1 at time t is equal to:

$$C_1 = \frac{s_1 \sum_{i=1}^{4} n_i c_i}{\sum_{i=1}^{4} n_i s_i} \quad B$$

5. $$C_1 = (1) \frac{n_1 c_1 + n_2 c_2 + n_3 c_3 + n_4 c_4}{n_1^{(1)} + n_2 s_2 + n_3 s_3 + n_4 s_4} \quad B(t)$$

From the above calculation, it is evident that to calculate the marginal delay costs attributed to any other operation, one need only find the product of C_1 and the relative service time of the selected operation s_i.

The value of each term in the above expression changes over time. As mentioned earlier, relative service time s_i, varies as a function of aircraft mix and runway configuration. The cost of operation varies as a result of changing load factors. The relative proportions of air carrier and general aviation aircraft also changes hourly. The cost of dealing explicitly with each of these complexities is very large. Therefore yearly average values were used in lieu of empirical estimates (transformed by allowance for changing conditions). The value of B(t), the remaining busy period is averaged as well, but each average accounts for one hour of the day.

Table V shows the estimates of these parameters for LaGuardia Airport. Traffic proportions n_i, were obtained from traffic statistics aggregated for the year 1967. To maintain consistency, these data were corrected to eliminate the fraction of general aviation aircraft not using duty runways. Relative service times were estimated using a previously mentioned technique: The Airborne Instrument Laboratory airport capacity manual was used to derive service time ratios for various mixes of aircraft. Line three in Table V illustrates the cost of operation, in dollars per minute to aircraft owners. Each figure contains in addition to direct variable costs of fuel, oil and crew time, some allowance for indirect variable costs such as maintenance and depreciation. The value of passenger time is also included in Table V. Despite the controversy surrounding any estimate of the value of time of various individuals, Carlin and Park have included this estimate. The marginal cost of delay is sensitive to estimates of the value of time. A sensitivity analysis was performed using time values of \$3 and \$6 for air carrier and general aviation passenger time respectively. The costs shown in Table V would be reduced by approximately 25%. If the estimates of passenger time were increased to \$12 and \$24 per hour, the costs would be increased by \$49. Line four in Table V represents the marginal delay costs per minute of remaining busy period. These figures are obtained by substituting into expression 5, the values estimated for n_i

Table V

Cost of Delay

	A.C. Land.	A.C. T.O.	G.A. Land.	G.A. T.O.
Proportion of total traffic on duty runways, n_i	.32	.32	.18	.18
Service time relative to air carrier landings, s_i	1.00	.86	.54	.46
Cost to aircraft owners (dollars per minute)	6.50	2.60	1.00	.50
Passengers per operation	46.80	46.80	1.80	1.80
Cost of passenger time (dollars per minute)	4.68	4.68	.36	.36
Marginal cost of delays (dollars per minute), c_i	11.18	7.28	1.36	.86
Marginal cost of delays per minute of remaining busy period (dollars), $C_i\,/B(t)$	8.15	7.01	4.40	3.75

A.C. Air Carrier
Land. Landing
T.O. Takeoff
G.A. General Aviation

Source: Carlin, A. & Park, R. A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970

s_i and c_i.

Average remaining busy period, B(t):

The calculation of the average remaining busy period was based on data supplied by American Airlines and United Air Lines. The data was used to distinquish times during the day when the airport was busy. (ie- aircraft attempting to use the airport encountered delays). Briefly, the method used to calculate the remaining busy period is as follows: For some flights, particularly American Airlines, pilot reports of delays enroute and in the New York terminal area were used. In some cases, the pilot reports were missing, and delay estimates were based on the excess of actual over planned flight time. Unfortunately, this type of estimate reflects other influences, notably enroute wind and weather forecast errors. For departure delays, the difference between gate departure and takeoff, less a standard taxi-time was calculated. On some occasions, data was not available from the Airlines and use was made of the FAA Runway Use Logs which record the time of landing or takeoff to the nearest minute. After obtaining the data on delays, the information was tabulated at ten minute intervals from 0100 to 2400 hours for fourteen sample days. In addition, the six busiest hours of airport operation were critically examined for each of fourteen extra days. All of these values were then averaged over the sample days to estimate the average expected busy period remaining by time of day. Table VI shows the hourly average of the ten minute estimates of the expected remaining busy period. Table VI also shows estimates of the

Table VI

Hourly Average of Expected Remaining Busy Period

Hour of Day	Remaining Busy Period (minutes)	Full Marginal Delay Costs ($/incremental op.) AIR CARRIERS Arrivals	AIR CARRIERS Departures	GENERAL AVIATION Arrivals	GENERAL AVIATION Departures
0000-0700	0.0	0	0	0	0
0700-0800	7.4	60	52	32	28
0800-0900	33.1	270	232	146	124
0900-1000	33.2	271	233	146	125
1000-1100	19.9	162	140	88	75
1100-1200	11.4	93	80	50	43
1200-1300	30.1	245	211	132	113
1300-1400	72.9	594	511	321	173
1400-1500	85.2	694	597	375	319
1500-1600	133.7	1094	937	588	501
1600-1700	118.2	963	829	520	443
1700-1800	96.4	786	676	424	361
1800-1900	74.5	607	522	328	279
1900-2000	44.6	364	313	196	167
2000-2100	19.5	159	137	86	73
2100-2200	7.2	59	50	32	27
2200-2300	1.7	14	12	8	7
2300-2400	.4	3	3	2	2

Source: Carlin, A. & Park, R. A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970

full marginal cost of an additional operation for each hour of the day. Columns 2 through 5 in this table are average values of the delay costs imposed on other users by the incremental user. The magnitude of these costs must, of course, be interpreted in the light of the assumptions underlying their estimation. The sensitivity of these costs to changes in the assumptions regarding the value of time is the same as that mentioned earlier.

Thus far, this study has shown in a very unique manner, estimates of the delay costs attributable to aircraft using the airport at a time of severe congestion. Despite the debate surrounding the value of time component of these costs, the inefficient use of runways under the current weight based schedule of landing fees is evident. The question still remains however, of what sort of pricing scheme to implement so that efficiency will prevail and the airports will continue to be used. The latter qualification is not as facetious as it first appears. For instance; what is an obvious outcome if the marginal costs of an incremental operation were charged as landing fees? The numbers of aircraft using the airport would be drastically reduced. This reduction in the number of users would reduce the marginal cost of operation and thereby force a reduction in the price of landing privileges. If the reaction to the full marginal cost price was dramatic enough, subsequent user charges could conceivably be lower than the current level of charges. Under these lower charges, traffic volumes would exceed the current level. Allowed to continue, this situation would never converge to an equilibrium.

Faced with this possibility, the problem of improving efficiency in runway use becomes one of introducing a pricing system which is directly related to the marginal cost of operation but which is practical. Ideally, such a system would reflect the elasticity of demand for landing. In other word, the pricing analyst would know beforehand what the pattern of traffic would be under different sets of prices. Obviously such knowledge is not available. An alternative to either full marginal cost pricing or the optimum system mentioned above is a scheme whereby an increasing percentage of the full marginal cost is charged as recomputed after each successive increase. Carlin and Park considered this and other alternatives. The major drawback, they felt, to pricing schemes based on recovery of delay costs, was the resistence to implementation by the airlines. The authors felt that because of commitments for additional aircraft and the size of existing fleets of aircraft, the airlines would not accept higher landing charges. The net effect of the higher charges would be felt in reduced fleet sizes and higher load factors thus assuring more efficient operations for the airlines. However these adjustments to fleet size and the improvement in load factors are long run effects; even though the airlines could appreciate these benefits in the long run, their resistance to the policy (higher landing charges) that would generate the benefits would be based almost exclusively on the short term problems that the policy would create.

The initial step toward the ultimate solution of efficient use of the runways is proposed by Carlin and Park. This solution combines aspects of marginal cost pricing with practical constraints to assure acceptance by the users. The approach described below limits <u>total</u> airline runway use payments to what they would be under agreements currently in effect. However the basis on which fees are levied is changed so that fees during any (one) hour are proportional to those that would prevail under full marginal cost pricing. The proportion of marginal cost charges and the rationale underlying its calculation are as follows:

As mentioned above, the total of all fees paid by airlines is assumed to remain constant. To determine the proportional adjustment of the individual airline payments, the hypothetical amount due under full marginal cost pricing was first computed. This was done by using the average of September 1967 and February 1968 Airline schedules for an activity estimate and then calculating the resulting charges from the full marginal delay costs in Table VI. Data on actual charges was also available for runway use during the period March 1967 to February 1968. By dividing the actual charges by the hypothetical charges, a percentage was determined. Applying this percentage against the total of actual fees collected resulted in the "proportional cost" fees shown in Table VII.

To answer the question of acceptance by the airline industry, Carlin and Park compared what airline payments would have been using the prices from Table VII with what payments actually were for the period studied. The results were encouraging: without exception the major carriers were not adversely affected but the local service airlines were. This was undoubtedly

Table VII

Proportional Marginal Cost Prices for LaGuardia Airport

Hour of Day	AIR CARRIER		GENERAL AVIATION		POST-AUGUST 1968 ACTUAL MINIMUMS	
	Arr.	Dep.	Arr.	Dep.	Dep.	Either
0000-0700	0	0	0	0	5	
0700-0800	7	6	3	3	5	
0800-0900	30	26	16	14		25
0900-1000	31	26	17	14		25
1000-1100	18	16	10	9	5	
1100-1200	11	9	6	5	5	
1200-1300	28	24	15	13	5	
1300-1400	67	58	36	31	5	
1400-1500	78	67	42	36	5	
1500-1600	123	106	66	57		25
1600-1700	109	94	59	51		25
1700-1800	89	76	48	41		25
1800-1900	69	59	37	32		25
1900-2000	41	35	22	19		25
2000-2100	18	15	10	8	5	
2100-2200	7	6	4	3	5	
2200-2300	2	1	1	1	5	
2300-2400	0	0	0	0	5	

Proportional Marginal Cost Prices for LaGuardia ($ per operation)

Arr. Arrivals
Dep. Departures

Source: Carlin, A. & Park, R. A Model of Long Delays at Busy Airports, Journal of Transport Economics and Policy, 1970

due to the types and frequency of operation of the aircraft used by these firms. Considering the effect that the $25 minimum fee had on general aviation activity at major New York airports, (an average of 40% reduction in general aviation movements) the proportionately higher fees for operations between 1300 and 1900 hours would have a very large effect.

In this last section, we have seen another approach to improving the efficiency of use of airport runways. We observed the attempts to quantify the marginal cost of delay attributable to incremental operations during times of congestion. We also observed the practical constraints on introducing pricing schemes based exclusively on theoretical principles. Carlin and Park have made a major contribution to this field of endeavor by successfully aligning economic theory with practical considerations for policy.

In the next chapter, we begin the analysis of the situation at Vancouver International Airport. The problem will be approached, in a sense, from behind. The proposals for expansion will be outlined and the techniques which resolve the issue will be introduced. After a thorough explanation of the analysis, the data from Vancouver Airport will be presented and subjected to scrutiny.

Chapter IV

There has been discussion among Minsitry of Transport Officials for the last fifteen years, of the need for an additional runway parallel to the 08-26 facility. At present, Vancouver airport has two intersection runways: 08-26 and 12-30. The runways are labelled as such because of their alignment with compass headings. The general layout of these runways in relation to Vancouver city, Richmond, and the adjoining water can be seen by reference to Figure 1. The proposed runway is shown to the north of the current 08-26 facility. Complete with connecting taxiways, this runway has been shaded in grey. The following is a detailed description of the runway as envisaged by the Aviation Planning and Research Division of the Ministry of Transport.

Runway-- Class 'A', 11,000 feet x 200 feet concrete

Taxiways -- High speed exit type positioned at 4500 feet, 6500 feet, and 7500, feet from each end of the runway. Each taxiway is 75 feet wide and is constructed of concrete.

Lighting:

Runway-- 1. Full Category II standard with high speed and end exit marking.

2. Approach; high intensity Category II standard 08L, Category I standard 26R.

Taxiway-- Medium intensity taxi-edge lighting.

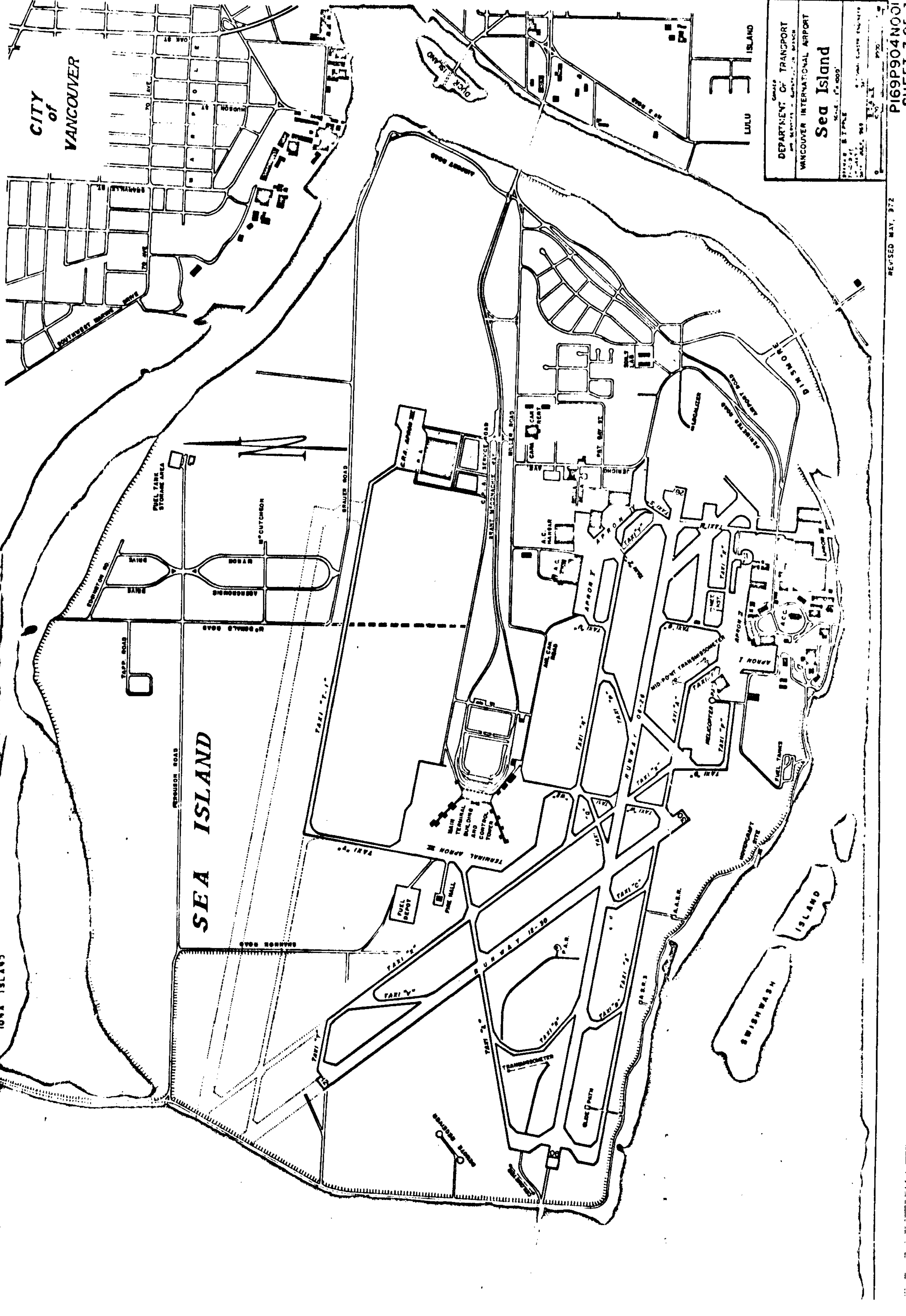

CITY of VANCOUVER
SEA ISLAND
LULU ISLAND
IONA ISLAND
SWISHWASH ISLAND
DEPARTMENT OF TRANSPORT
VANCOUVER INTERNATIONAL AIRPORT
Sea Island
MAIN TERMINAL BUILDING AND CONTROL TOWER
RUNWAY 08-26
RUNWAY 12-30
FUEL DEPOT
FIRE HALL
FUEL TANK STORAGE AREA
P169P904N001
SHEET 3 OF 3

Figure 1

Navigational Aids	- Category II Instrument Landing System (ILS)-08L
	- non-categorized ILS-26R
	- middle marker (MM) 08L,26R
	- outer marker (OM) 26R
	- Non-directional beacon (NDB) at MM 08L and at OM 26R
Transmissometers	- Three units; each touchdown zone and rollout
Additional	- Runway and taxi way pointing, signs, windsock etc. as required.

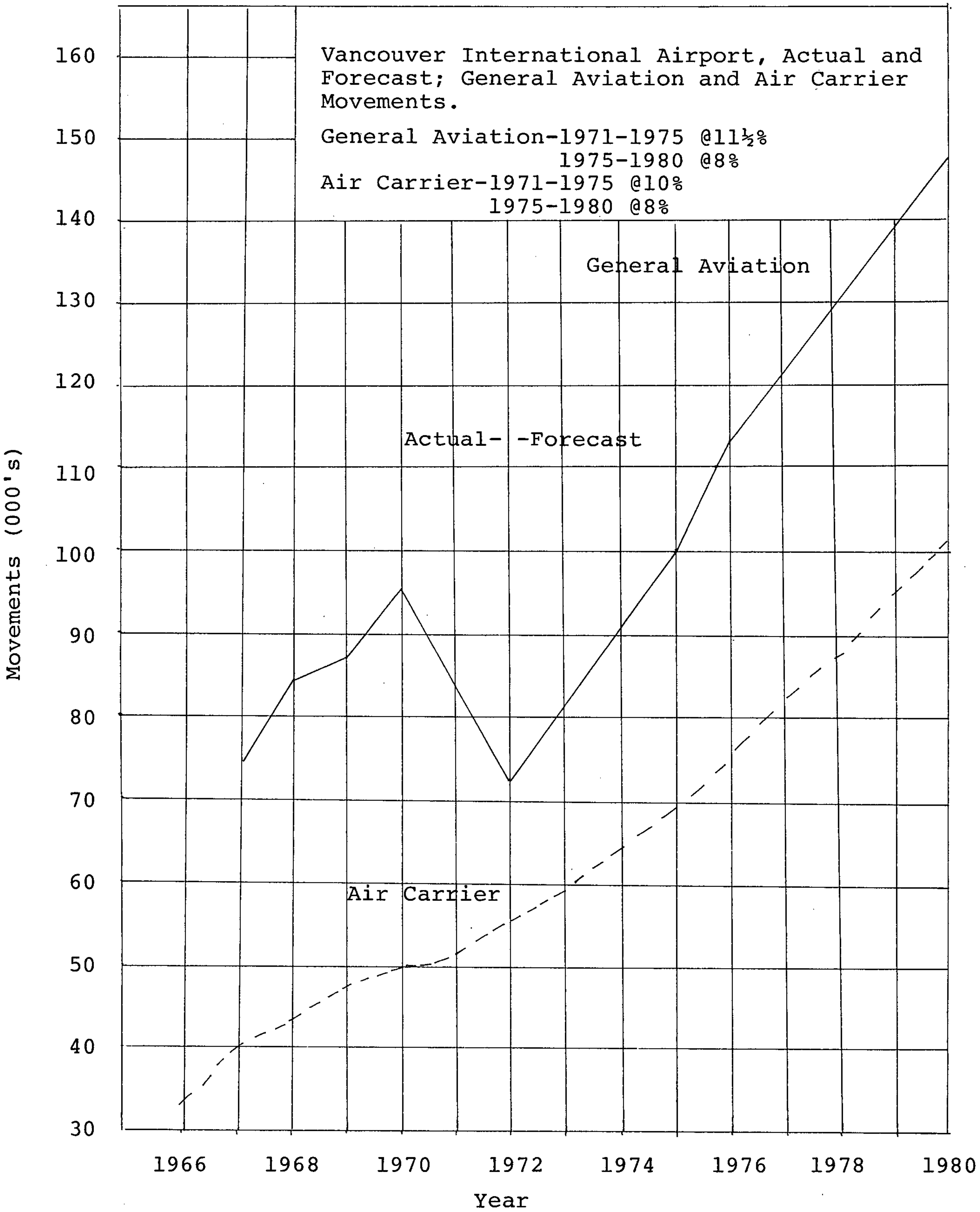
The latest resurgence of interest in this project occurred in the fall of 1971 when the Aviation Planning and Research Division of the MOT completed a report entitled "Vancouver International Airport Capacity/Demand analysis for selected Runway configurations." Despite the recommendations of the report, which concluded that the construction of a parallel runway would be the most expensive solution in the short term, the MOT decided to initiate expropriation proceedings to purchase the land on Sea Island required for construction of the runway. The Ministry justified its decision to construct the additional runway by presenting data on forecast demand at the airport and the requirement to close the 08-26 runway for rehabilitation. This section will not be concerned with the debate surrounding the claim for immediate reconstruction of runway 08-26. Instead it will concentrate on the requirement for expansion based on predictions of traffic volumes and the resultant lack of future capacity.

In their analysis of the requirement for a runway parallel to 08-25, the Ministry of Transport assumed a growth trend for the years 1971-1975 of 12-15% for domestic traffic and 8-10% for International traffic. These analysts maintained that even though the growth in domestic aircraft movements was moderated by the use of large wide-bodied aircraft, (capable of handling up to 400 passengers) the increasing incidence of international charters would offset this growth reduction and produce an overall growth rate of 10%. General Aviation activity was expected to taper off in the same period. A growth rate of 11½% was given for General Aviation for the period 1971-1975. The following figure depicts this projected increase for both aircraft groups.

Since the MOT report was compiled, significant changes have taken place in the supply of petroleum products to the world's airlines as well as to general aviation aircraft. The Arab-Israeli conflict and the oil embargo that resulted from it, severely restricted the supply of jet fuel and aviation gasoline. The price of fuel has increased by more than 100% since 1973. This dramatic increase in fuel costs has precipitated a significant reduction in the frequency of flights offered by the carriers. This reduction has been moderated to some extent since the removal of the Arab oil embargo, but fuel prices have not fallen measureably and could conceivably go up again. With airline profits often very tenuous, a further shrinkage of the profit margin with higher fuel costs will, in all likelihood, cause future reductions in flights. It remains to be seen exactly what the effect on air carriers will be from higher fuel costs, but it seems very conservative to suppose that the MOT projections of future traffic flows

Figure 2

Air Movement Forecast



Source: Aviation Planning & Research Division, Ministry of Transport, Vancouver International Airport-Capacity/Demand Analysis For Selected Runway Configurations, 1971.

are optomistic.

The above comments are admittedly, conjecture based on an attempt to relate MOT traffic predictions to a since increased price of fuel. In the absence of factual data, no meaningful statement can be made about future traffic flows. The same cannot be said however about the "ability" of the Vancouver Airport to accommodate traffic. There has been considerable work done in the field of airport design and airport capacity. The majority of this work was done by the Airborne Instruments Laboratory, of New York. This group produced a handbook in 1963 designed for use in determining the ability of an airport to accommodate traffic. The book was updated into a second edition, published in 1969. It is the second editon that will be referred to hereafter. The handbook was also used by the MOT in the preparation of its report about the capacity of the Vancouver Airport. Calculations derived using techniques outline in the handbook will be presented in the final section of this chapter. Because of the reliance placed on the handbook in the remainder of this thesis, it is essential that the reader be very familiar with the rationale behind it and the techniques and procedures followed in the calculation and understanding of <u>airport</u> <u>capacity</u>.

The following section is a brief description of the techniques used in calculating airport capacity. Reference to Appendix B, at the end of the thesis will facilitate understanding of the terms used throughout the description.

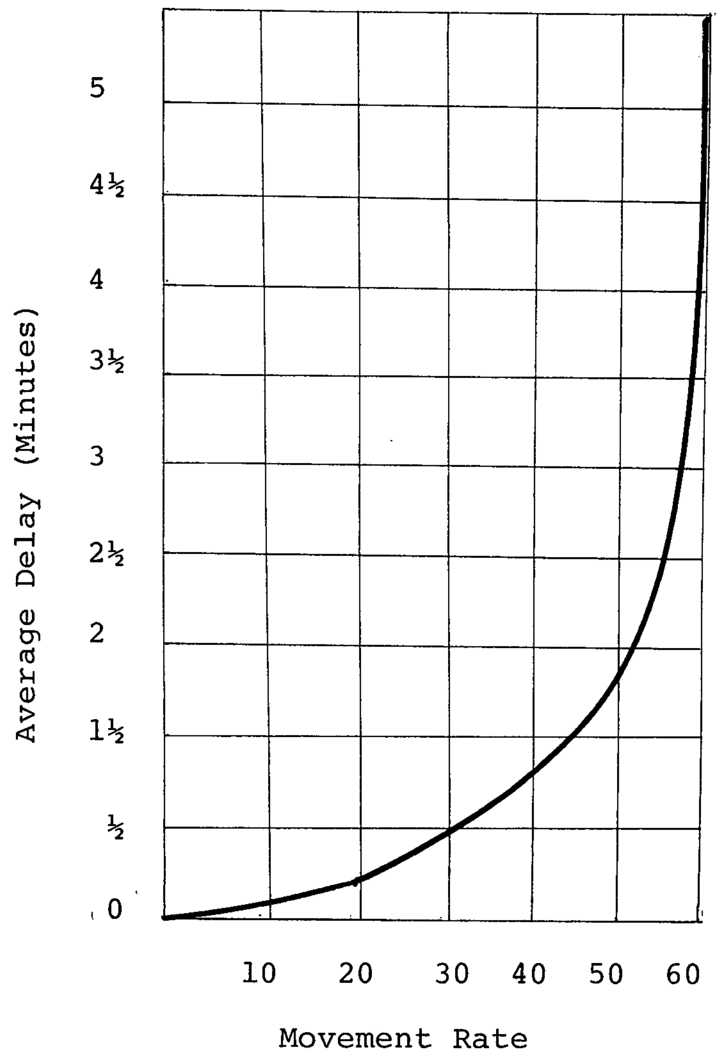
The capacity of an airport is the number of operations that the facility can process when delays to the aircraft using it has reached an arbitrary maximum. It is apparent that if two aircraft wish to use a runway simultaneously, one of the two will be delayed in his use. In other words, all aircraft compete for the use of runways; those which arrive subsequent to others are compelled to queue up for the use of the runway. The length of time that an aircraft spends waiting is equivalent to the time that it is delayed. Delay is dependent upon a number of factors. One factor governing delay is the number of aircraft using the airport. The higher the "movement rate," the longer the delays per aircraft. The parameters that affect the service time of aircraft are diverse yet related. Each contributes something to the determination of delay and each is present in the airport environment. The goal of the AIL group was to develop, via computer programs, a technique whereby these parameters are compared and a limit of capacity determined, (for any given airport).

A four minute average delay criterion was selected for a number of reasons: Observations in the field indicated that beyond a four minute average delay point, small increases in the movement rate resulted in a very marked increase in average delay. The following figure has been extracted from the AIL Handbook and represents a typical average delay curve. The distribution of delays under a four minute average was such that maximum delays did not exceed twenty minutes while minimum delays were of a few seconds duration.

At airports where departures and arrivals use the same runway, arrivals are given priority over departures. Both types

Figure 3

AIL Delay as a Function of Movement Rate



Source: Airborne Instruments Laboratory, <u>Airport Capacity Handbook-Second Edition,</u> New York 1969.

of traffic are handled on a first-come, first-served basis.

Having established traffic priorities, all that remains to affect airport capacity is the spacing or intervals between aircraft movements. Aircraft service times are affected by six factors. The effect that any factor has in determining service time (and subsequently determining capacity) hinges on other elements. These elements will be discussed in the succeeding section.

Service time is directly proportional to the following factors:

1. Weather (ie.-IFR, VFR) and its effect on procedures
2. Runway configuration (single runway, intersecting runway)
3. Aircraft population (the mix of aircraft types)
4. Individual runway design (length and number of runways, type and location of turnoffs)
5. Runway use (mixed operations, arrivals only, departures only)
6. Airspace considerations (departure routings directly after takeoff)

The number of operations that can take place varies with the weather. When weather deteriorates, so does the number of operations that can be safely accommodated. Normally, weather conditions are categorized according to the location of the cloud base and the runway visibility. Visual Flying Rules and Instrument Flying Rules are the traditional divisions for ideal and marginal weather. The AIL research group found a poor correlation between capacity and weather when these accepted weather classifications were used. They altered the classification, changing the limits for each, and found that airport capacity was more significantly affected by the change in criteria. The new criteria were labeled VAW or Visual Airport Weather -- cloud base of 700 feet and visibility of 2 miles, and IAW or Instrument Airport Weather -- cloud base and visibility equal to VAW minimums or lower.

Runway configuration and design, as mentioned above, affects the capacity of the airport. The exact influence that each factor has on airport capacity is difficult to ascertain, but estimates have been made with the computer available to the AIL. These estimates, have in turn been verified by observations. Feedback from field observations has been applied to the computer program, resulting in a tool which has validity. The factors which influence runway capacity under VAW and IAW are respectively:[1]

VAW - the use of runways by arrivals will be influenced by:

- wind direction and strength
- length of runway
- runway occupancy (runway rating). Poor turnoffs on an intersecting system of runways will encourage pilots and controllers to use the one-approach system, but

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[1] Excerpted from the AIL Airport Capacity Handbook, 2nd ed. June, 1969.

then to "break-off" some arrivals at close ranges to use a second runway, to avoid wave-offs due to excessive occupancy of preceding aircraft on the main runway.

- local noise regulations - preferential runways.

IAW - In IAW for any configurations, the number of approach paths is restricted to the number of ILS installations or VORTAC approaches Therefore although a configuration might have three runways, only one will be used for arrivals if only one runway has an instrument approach capability.

IAW or VAW - the use of runways by departures will be influenced by:

- relative closeness of runway to departure gate or parking area
- direction of departure once airborne
- runway length
- wind direction and strength
- local noise regulations - preferential runways
- aircraft population

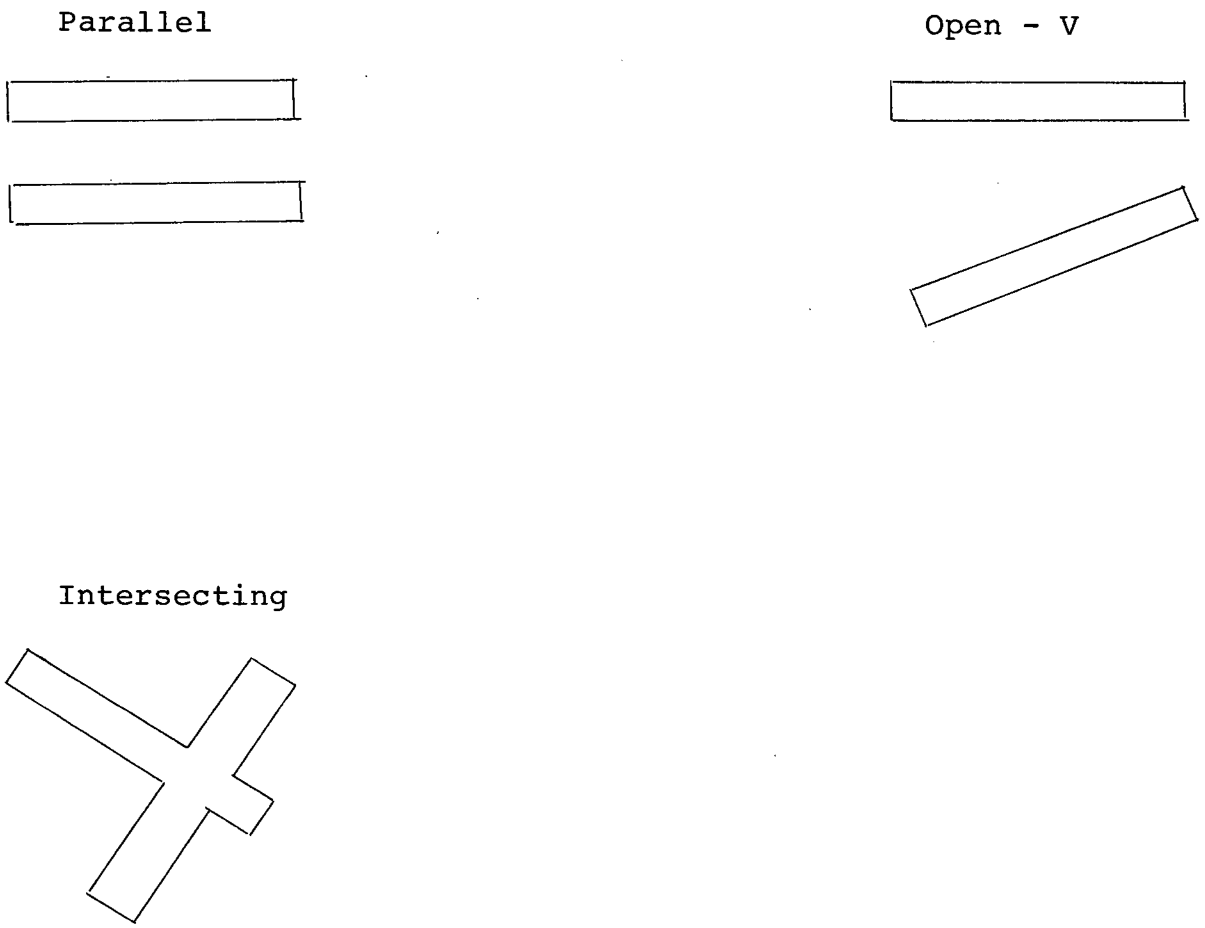
Another factor that can greatly influence runway use by arrivals and departures is the relative positions of the runways to each other and to the terminal and parking areas. For example, it is a more complicated traffic control task to cross taxiing aircraft across a landing runway than a takeoff runway. Therefore, on two close parallel runways with the terminal on one side, the inner runway can be used primarily for departures, and the outer runway for arrivals. Exception to this use could result from runway length considerations (one may have to be used by large aircraft) or noise problems.

Having familiarized himself with the criteria affecting aircraft service times, the reader may now apply these criteria in the determination of airport capacity.

The following paragraphs are an explanation of the actual technique used for calculating airport capacity: Initially, the airport is classified according to the configuration of its runways. The runway configuration may consist of one, two or periodically three individual strips. The orientation of the runways, one to the other(s), is also included in the configuration. Typical configurations include: parallel, intersecting and open V. The parallel arrangement consists of two runways located beside each other in a parallel fashion. The intersecting arrangement is self-evident. The open-V configuration consists of two runways separated from each other by more distance at one end than at the other. Figure 4 presents an example of each type of arrangement. Having classified the airport according to the number and configution of its runways, one must then determine the composition of the population of aircraft using the airport. The AIL Handbook classifies airport population according to runway requirements. The normal loaded weight of the aircraft is included in these requirements; for class A aircraft, the length of runway required for takeoff or landing is an additional requirement. AIL designations referred to in succeeding airport population discussions can be

Figure 4

Runway Configurations



found in the following list of aircraft classifications:[2]

Class A aircraft --

All jet aircraft normally requiring runway lengths exceeding 6000 feet (corrected to sea level) for takeoff and/or landing.

BAC (Vickers) VC10	Convair 880 990
Boeing 707 720 747	Douglas DC8 DC10
DeHavilland (H.S.) Comet	Sud Carvelle
	Lockheed 1011

Class B aircraft --

1. Piston and turboprop aircraft having a normal loaded weight in excess of 36,000 pounds.

2. Jet aircraft not included in Class A but having a normal loaded weight in excess of 25,000 pounds.

BAC 111	Lockheed Constellation Electra Jetstar Martin 404
Boeing 727 737	
Canadair CL-444	Vickers Viscount Vanquard
Convair 240/340/440 58/600	
Curtiss C-46	
Douglas DC-4 DC-6 DC-7 DC-9	

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[2] AIL Airport Capacity Handbook, 2nd ed. New York, June 1969.

Class C aircraft --

1. Piston and turboprop aircraft having a normal loaded weight greater than 800 pounds and less than 36,000 pounds.

2. Jet aircraft having a normal loaded weight greater than 8000 pounds but less that 25,000 pounds.

Aero Commander Jet Commander	Grumman Gulfstream I Gulfstream II
Beech 18 PACAIR RAUSCH VOLPAR	H.S. 125
Beech King Air	Lear Jet 23 24
Dassault Fan Jet Falcon	Lockheed 18 Lodestar
Douglas B-26 DC-3	Lockheed PV-2
Fairchild F-27/F-227	Oakland Pacaero Nord 262 North American Sabreliner

Class D aircraft --

All light twin-engined piston and turbo-prop aircraft having a normal loaded weight less than 8000 pounds, and some high-performance single-engine light aircraft. They are small, light, twin-engined aircraft with the exception of those marked with an asterisk (*).

Aero Commander (500, 600, 700 series Grand and Turbo)

Beech Bonanza*
Debonair*

Beech Baron
Travel Air
Queen Air
Twin Bonanza

Cessna 310
320
411
336/337

H.S. Dove

Navion-Camair 480 and Temco-Riley Twin

Piper Apache
Aztec
Twin Comanche

Class E aircraft--

All single engine aircraft with the exception of the Mustang (C) Bonanza (D), and Debonair (D) and small STOL aircraft. The most common types of class E aircraft are:

Cessna series 150 through 210

Mooney 20 series

Piper series, Colt, Tri-Pacer, Cherokee and Comanche

Beech Muskateer, D.H. Beaver, Bellanca, Helio Courier, Luscombe, Navion, and Stinson.

In addition to the aforementioned information, one also requires data on the ratio of arrivals to departures at the airport as well as knowledge of the type and amount of control and approach aids. With this information, the Practical Hourly Capacity (PHOCAP) of the airport can be calculated.

<u>Procedure</u>:

The method used in the AIL Airport Capacity Handbook involves segregating activities into two categories - those which take place during Visual Airport Weather and those which take place during Instrument Airport Weather. Computer derived nomograms are used to determine the hourly arrival and departure capacities under both weather conditions. The PHOCAP for VAW conditions is initially taken as the sum of the hourly arrival capacity (HAC) and the hourly departure capacity (HDC) or twice the HDC, which ever is less. The same procedure is used in calculating PHOCAP under IAW conditions except that consideration is given to the sophistication of Air Traffic Control devices at the airport in question.

In addition to the PHOCAP, the AIL Airport Capacity Handbook provides a means through which to calculate the Practical Annual Capacity (PANCAP) of an airport. PANCAP refers to the number of movements that an airport can process before delays exceed some index level. The index used in the handbook allows five minute delays to occur for 8 percent of the year (541 hours). A ten minute average delay is permitted to occur 4 percent of the year. Especially poor weather may cause average delays of 40 minutes. The criterion incorporated into the index permits delays of this duration to occur for 1 percent of the year.

The PANCAP of an airport is dependent on the types of aircraft seeking accomodation and the facilities available at the airport to service these aircraft. Apart from approach and navigation aids, the primary facility at an airport is the runway The length of the runway and the number and nature of the exit ramps and taxi-ways determine capacity. If there is more than one runway, the position of each runway, relative to the others is a determinent of capacity. Weather conditions, especially the wind strength and direction influence PANCAP as well.

Procedure:

Using the technique outlined in the handbook, one determines the index figure for overload comparison. An hourly test demand is compared with the hourly capacity and an indication of overloading (if the test demand exceeds the hourly capacity) is produced. This overload criterion is then weighted by the annual percentage of such demand situations and the product is compared with the index figure. Because the index figure has been calculated to ensure only a certain amount of overloading, its comparison with the overload-criteria-annual-use product is the test of completion for the PANCAP calculation. Usually successive attempts to recalculate the test demand must be made before an equality between the index figure and the test demand can be reached. Once equality is attained, the test demand is multiplied by annual utilization to attain PANCAP.

The Ministry of Transport (Canada) has used the AIL Handbook to calculate the PHOCAP and PANCAP of Vancouver International Airport. The next section will show how this calculation was made, some of the limitations to its conclusions as well as a brief analysis of the data utilized.

The first step taken in the calculation of capacity at Vancouver International Airport was an inspection of the configuration of runways. Figure 1 depicts the organization of runways and taxiways at Vancouver. The two runways intersect each other at point A. This point is 5700 feet from the threshold of runway 12

1600 feet from the threshold of runway 30. The point of intersection is 4800 feet from the threshold of runway 08 and 5800 feet from the threshold of runway 30. Each runway is labelled according to the direction in which it is oriented.

Next, data were assembled to determine the distribution of the classes of aircraft using the airport. Classification of aircraft types was accomplished using the criteria established by the AIL (see pp 103 - 105, this paper). The population distribution appears in Table I. Two assumptions were made by the MOT study group: 1. There are no restrictions on the use of airspace around the airport. 2. The ratio of arrivals to departures is one. The calculations performed by the MOT are illustrated in Tables II and III. It can be seen that total capacity under both VAW and IAW is at the least, double the departure capacity. The final column in Table III represents the percentage of total annual use that the particular runway combination was in use. The figures in this column, as well as the PHOCAP figures were used in the calculation of PANCAP.

Table IV represents the first iteration of the process through which the annual capacity of the airport is determined. Annual utilization and annual capacity figures are given for both "public-desire" and "off-peak use" categories. The public desire capacity figure may be interpreted to mean the capacity of the airport when the distribution of traffic is a function of public demand for transportation. A distribution typical of public desire would have two distinct peaks, one in the morning and the other in

Table I

Vancouver International Airport

POPULATION DISTRIBUTION - JUNE-JULY 1970

Aircraft Class	Population Distribution VAW	Population Distribution IAW
A	10%	20%
B	24%	51%
C	8%	11%
D	19%	10%
E	39%	8%

Source: Vancouver International Airport - Capacity/Demand Analysis for Selected Runway Configurations, #R-71-8, MOT, 1971

Table II

Calculation of Multiple Runway Capacities

(movements per hour)

Runway Configurations	VAW Arr. Capacity	VAW Dep. Capacity	VAW Total Capacity	IAW Arr. Capacity	IAW Dep. Capacity	IAW Total Capacity
Takeoff 26 Land 30	40	40	80	38	27	54
Takeoff 30 Land 26	40	37	74	38	25.5	51
Takeoff 12 Land 08	40	33	66	38	25.5	51
Takeoff 08 Land 12	40	35	70	38	26	52

IAW Instrument Airport Weather
VAW Visual Airport Weather

Source: Vancouver International Airport - Capacity/Demand Analysis for Selected Runway Configurations, #R-71-8, MOT, 1971

Table III

Percent Annual Runway Use

Weather Condition	RUNWAY CONFIGURATION Description		Capacity	% Used	% of Time Applicable
Below IAW		-	-	-	3.36
IAW	I1	08	45	50	4.47
8.9%	I2	12	44	50	4.47
VAW	V1	TO-26			
87.71%		L-30	80	3	2.63
	V2	TO-30			
		L-26	74	9	7.89
	V3	TO-12			
		L-08	66	9	7.89
	V4	TO-08			
		L-12	70	9	7.89
	V5	08	58	35	30.70
	V6	26	58	35	30.70

Source: Vancouver International Airport - Capacity/Demand Analysis for Selected Runway Configurations, #R-71-8 MOT, 1971 the late afternoon. Off-peak capacity is always greater than public desire; it allows for a modification in public demand so that otherwise quiet times of day become busy as demand "spills over" from peak periods. It is assumed that the travelling public would not use the off-peak periods if capacity at peak periods was greater. In Table IV column 7, the test demand figure is determined from reference to a nomogram. Column 8's derivation is described in the table, as are columns 9 and 10. It can be seen that the resultant annual overload of 14.02 is not equal to the capacity index of 23. Successive iterations were performed resulting in a final overload criteria of 24.02. Annual capacity figures under both public desire and off-peak curves were determined using the final overload criteria.

Limitations of the Study-

The VAW and IAW population distribution in Table I is, in actuality, the distribution associated with IFR and VFR weather. Because of the mild nature of Vancouver's weather, little difference seems to exist between the theoretical VAW-IAW aircraft population distribution and the distribution found in the MOT study. This same distribution is applicable only for the peak period of June, and July 1970. This author attempted to audit the technique used by the MOT study group in their calculation of the Practical Annual Capacity of Vancouver Airport. (Reference to Table IV will resolve any confusion arising from the following discussion.)

It will be recalled that one step in the calculation of

Table IV

Capacity Calculation

Code	Configuration	HDC	HAC	% Annual Use	TD	OF	OC	Annual Overload Criteria
V1	TO-26	40	X	2.63	36	-	-	-
	L-30	X	40		36	-	-	-
V2	TO-30	37	X	7.89	36	-	-	-
	L-26	X	37		36	-	-	-
V3	TO-12	33	X	7.89	36	1.09	.09	.71
	L-08	X	33		36	1.09	.09	.71
V4	TO-08	35	X	7.89	36	1.03	.03	.24
	L-12	X	35		36	1.03	.03	.24
V5	TO-08	29	X	30.70	36	1.24	.18	5.53
	L-08	X	29		36	1.24	.18	5.53
V6	TO-26	29	X	30.70	36	1.24	.18	5.53
	L-26	X	29		36	1.24	.18	5.53
I1	TO-08	22.5	X	4.47	21	-	-	-
	L-08	X	22.5		21	-	-	-
I2	TO-26	22	X	4.47	21	-	-	-
	L-26	X	22		21	-	-	-
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

TD Test Demand
OF Overload Factor; Column 7 ÷ Column 3; Column 7 ÷ Column 4
OC Overlad Criteria; From Table 13-1, AIL Handbook

Capacity Indiex = 23
Final Annual Overload Criteria = 24.02
IAW Demand Factor = 58%
VAW Peak Hour Demand - 36 x 2 = 72 movements per hour
Approximate Annual Utilization - Public Desire = 3160 hours
Approximate Annual Utilization - Off-peak = 3740 hours
Annual Capacity - Public Desire = 3160 x 72 = 227,520 movements
Annual Capacity - Off-peak = 3740 x 72 = 269,280 movements

Source: <u>Vancouver International Airport - Capacity/Demand Analysis</u>

Practical Hourly Capacity involved the determination of departure capacity, (in addition to arrival capacity) for a particular combination of runways. Once the departure capacity was available, the total capacity of the runway(s) could be ascertained. Table II depicts the values of arrival, departure and total capacity for four runway combinations. In three cases, the departure capacity is less than the arrival capacity. AIL instructions stipulate that total capacity is determined by the doubling of either the arrival or departure capacity, which ever is less. This has been done in the PHOCAP calculation. When we address the calculation of PANCAP, however, AIL instructions provide for inclusion of the original PHOCAP arrival and departure capacities. In effect, each individual capacity, as determined from the AIL Handbook should be entered into its respective place in columns three and four of Table IV. However, we find that the figures located in these positions have been obtained by halving the total capacity figures obtained from Table II. This is only acceptable when, by coincidence, arrival and departure capacities are identical. The overall effect of this oversight is slight. Practical Annual Capacity figures are only very slightly affected. The practical capacity of the airport using the modified procedure is 243,320 movements annually under the "Public Desire" criterion and 286,440 movements annually under the "Off-Peak Use" criterion -- a 6.5% difference. Table V and VI show the difference in the capacity data selected as well as the eventual annual capacity figure. If one accepts the MOT forecasts of traffic at Vancouver Airport, it is readily apparent

Table V

Capacity Calculation--Data Revision

Code	Configuration	HDC	HAC	% Annual Use	TD	OF	OC	Annual Overload Criteria
V1	TO-26	40	X	2.63	38	-	-	-
V1	L-30	X	40	2.63	38	-	-	-
V2	TO-30	40	X	7.89	38			
V2	L-26	X	37	7.89	38	1.03	.03	.24
V3	TO-12	40	X	7.89	38	-	-	-
V3	L-08	X	33	7.89	38	1.15	.13	1.03
V4	TO-08	40	X	7.89	38	-	-	-
V4	L-12	X	35	7.89	38	1.09	.09	.71
V5	TO-08	29	X	30.70	38	1.31	.30	9.21
V5	L-08	X	40	30.70	38	-	-	-
V6	TO-26	29	X	30.70	38	1.31	.30	9.21
V6	L-26	X	40	30.70	38	-	-	-
I1	TO-08	22.5	X	4.47	22	-	-	-
I1	L-08	X	38	4.47	22	-	-	-
I2	TO-26	22	X	4.47	22	-	-	-
I2	L-26	X	38	4.47	22	-	-	-
					Annual	Overload	--	20.40
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

TD Test Demand
OF Overload Factor; Column 7 ÷ Column 3; Column 7 ÷ Column 4
OC Overload Criteria; From Table 13-1, AIL Handbook

Capacity Index = 23
Initial Annual Overload Criteria = 20.40
IAW Demand Factor = 58%
Initial Test Demand = 1.3 x 29 = 38 (VAW)
Initial Test Demand = .58 x 38 = 22 (IAW)

Table VI

Capacity Calculation--Final Iteration

Code	Configuration	HDC	HAC	% Annual Use	TD	OF	OC	Annual Overload Criteria
V1	TO-26	40	X	2.63	38.5	-	-	-
	L-30	X	40		38.5	-	-	-
V2	TO-30	40	X	7.89	38.5	-	-	-
	L-26	X	37		38.5	1.04	.04	.32
V3	TO-12	40	X	7.89	38.5	-	-	-
	L-08	X	33		38.5	1.17	.14	1.10
V4	TO-08	40	X	7.89	38.5	-	-	-
	L-12	X	35		38.5	1.10	.10	.79
V5	TO-08	29	X	30.70	38.5	1.33	.34	10.44
	L-08	X	40		38.5	-	-	-
V6	TO-26	29	X	30.70	38.5	1.33	.34	10.44
	L-26	X	40		38.5	-	-	-
I1	TO-08	22.5	X	4.47	22.3	-	-	-
	L-08	X	38		22.3	-	-	-
I2	TO-26	22	X	4.47	22.3	-	-	-
	L-26	X	38		22.3	-	-	-
					Annual	Overload --		23.09
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

TD Test Demand
OF Overload Factor; Column 7 ÷ Column 3; Column 7 ÷ Column 4
OC Overload Criteria; From Table 13.1, AIL Handbook

Capacity Index = 23
Final Annual Overload Criteria - 23.09
IAW Demand Factor = 58%
Final Test Demand = 38.5 (VAW)
Final Test Demand = .58 x 38.5 = 22.3 (IAW)
Approximate annual utilization - public desire = 3160 hours
Approximate annual utilization - off-peak = 3720 hours
Annual capacity - public desire = 3160 x 77 = 243,320 movements
Annual capacity - off-peak = 3720 x 77 = 286,440 movements
VAW peak hour demand = 38.5 x 2 = 77 movements per hour

that existing capacity rationed at existing prices is sufficient to meet demands until 1980.

Based on an analysis of the procedure adopted by the Ministry of Transport, it is reasonable to conclude that Vancouver International Airport has sufficient facilities to accommodate the public demand for air travel. The question still remains however, of whether the rationale behind the schedule of prices, which rations this capacity, is efficient or even equitable. When the MOT forecasts demand, it does not provide for the effect on demand that a price change precipitates. The following chapter will examine one approach to pricing airport capacity that this author considers exemplary. Initially, the approach will be described generally; the latter part of the chapter will be an application of the approach to Vancouver Airport.

Chapter V

Throughout this thesis, the rationale behind the pricing of transportation has been queried. We have seen how poorly the present weight based system of landing fees serves as an instrument for efficiently rationing runway capacity. The gross take off weight of an aircraft is, at best, a poor barometer of the cost of landing or taking off. Joseph Yance, in his article "Movement Time as a Cost in Airport Operations" has proposed a method to determine landing fees which reflects, very well, the relative cost of operating an aircraft at a congested airport. The variable under study in this proposal is the length of time an aircraft movement takes relative to other aircraft. Yance used a technique developed by the AIL to determine what the relative demands of the classes of aircraft were. Aircraft were grouped according to the population classifications outlined by the AIL Handbook. Yance calculated the capacity for the airport (Washington National) when the proportion of the total aircraft population represented by class A and B aircraft was as low as 0 to where it was as high as 100. This study has been replicated using data available from Vancouver International Airport and the Meteorological Branch of the Ministry of Transport. Table I was produced from the AIL Airport Capacity Handbook. Certain adjustments were made to the technique used by Yance in the construction of a similar table found in his study:

1. Because the second edition of the AIL handbook was used, arrival and departure capacities were interpolated from a figure which (under the "A" airport classification) was limited to and A+B population percentage of 11. To determine the capacity of the airport (Vancouver International) when the A+B population percentage was less than 11, nomographs relating to a general-aviation-type airport were used. Because of this limitation, the reader is cautioned when interpreting the capacity figures for A+B populations less than 11 percent.

2. In the calculation of arrival capacity at a general aviation airport, an accurate estimate of touch and go operations is required. Since a precise figure was not available, the following technique was adopted: The data for aircraft movements for the peak of months of June, July and August, 1973 was examined. The totals for local[1] and itinerant[2] flights under Visual Flying Rules were extracted. Local operations were then compared to the Total Movements which occurred under Visual Flying Rules. The average of each month's calculated proportion was used as the percentage of Touch and Go operations taking place at Vancouver International Airport.

3. As in other references to AIL work, VFR criteria have

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[1] A local flight is defined as a movement in which the aircraft remains at all times under tower control, such as in circuits around the airport for practice landings and take offs. Each touch and go operation is counted as one landing and one takeoff and hence as two movements.

[2] An itinerant movement is one in which the aircraft enters or leaves tower control.

been displaced by VAW criteria. Because of data limitations, a precise tally of movements taking place under VAW could not be obtained. However, data was available from the MOT Meteorological Branch and aircraft movements could be matched to prevailing weather with reasonable accuracy. Because the proportion of time that weather conditions were below VAW criteria was so small (June - .8%, July - .3%, August - 3.8%) little detail was lost by overlooking the discrepancy. The total capacity figures seen in Table I were obtained in the following manner: The runway combinations from Table II of the last chapter were selected as representative examples of runway use at Vancouver International. The Hourly Departure Capacity and Hourly Arrival Capacity was calculated for each configuration and the total capacities determined. Each total capacity was then weighted[3] and the resultant products averaged to determine an average practical hourly capacity. The figures in columns three and five of Table I were obtained as follows. With all movements consisting of general aviation aircraft, capacity is reached at 113 movements per hour. If the population mix becomes 89 percent general aviation, 11 percent air carrier, total capacity falls to 90 movements per hour. This capacity is equivalent to 9.9 air carrier aircraft (.11 X 90) and 80.1 general aviation aircraft (.89 X 90) per hour. The remainder of the columns are derived in a similar manner.

Initially, an increase in the movement rate of air

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[3] The weights used were the percentage annual use made of each runway combination.

carrier aircraft of 9.9 requires a reduction of general aviation movements by 32.9. The trade off in terms of the time demand of the two classes of aircraft is therefore

$$\frac{\Delta C}{\Delta G} = \frac{9.9}{32.9} = 0.30$$

Table II gives the relative time demands of general aviation and air carrier aircraft. For the most part, the ratio increases as the proportion of carrier aircraft in the population increases. There is a curious "bump" in the data for air carrier population proportion of 11 - 20 percent as well as a reduction in the ratio for air carrier populations exceeding 70 percent. The reasons behind these aberrations were not fully explored. Some of the causes that suggested themselves included:

1. The technique inherent in the initial calculation of total capacities; because the AIL Airport Capacity Handbook requires data on the individual proportions of A and B aircraft in order to calculate HAC, an estimate was made of the respective proportions of A and B aircraft (theoretical) in airport populations where the A + B population exceeded that encountered at Vancouver. With present traffic, Vancouver airport consists of 10 percent A aircraft, 24 percent B aircraft and 66 percent C + D + E aircraft. The ratio of A to B aircraft currently in evidence at Vancouver was assumed to persist at higher A + B populations. This assumption has a major effect on the ultimate determination of total capacity.

2. The total capacities were derived using a weighted average. The AIL Handbook has no provision for the averaging of

Table I

Capacity for Two Intersecting Runways for
Various Mixes of Class A, B and Class C, D, E Aircraft at
Vancouver International Airport

	CLASS A + B		CLASS C,D,E	
Total Capacity	%	No. Aircraft/Hr	%	No. Aircraft/Hr
113	0	0	100	113.00
90	11	9.90	89	80.10
88	20	17.60	80	70.40
81	30	24.60	70	56.70
77.5	40	31.00	60	46.50
75	50	37.50	50	37.50
73	60	43.80	40	29.20
71.5	70	50.05	30	21.45
67	80	53.60	20	13.40
59	100	59.00	0	0
(1)	(2)	(3)	(4)	(5)

Table II

Trade-off between Carrier and General Aviation Aircraft at
Vancouver International Airport

% Carriers	$\frac{\Delta C}{\Delta G}$	Relative Demands G.A. to Air Carrier
0-11	9.90/32.90	0.30
11-20	7.70/9.70	0.79
20-30	6.70/13.70	0.49
30-40	6.70/10.20	0.65
40-50	6.50/9.00	0.72
50-60	6.30/8.30	0.76
60-70	6.25/7.75	0.83
70-80	3.55/8.05	0.44
80-100	6.60/13.40	0.49

capacities associated with individual runway configurations. Normally, the Practical Hourly Capacity of a runway configuration is incorporated into the Practical Annual Capacity of the Airport, given data on prevailing runway use proportions. The attempt, in this instance, to condense individual PHOCAPs into an average PHOCAP represents a new utilization of the AIL methodology. Refinements to the above technique would undoubtedly improve the progression of ratios found in Table II.

Having derived trade-off ratios between air carrier and general aviation aircraft it now remains to apply these ratios to observed movement rates. Traditionally, movement rates at Vancouver International Airport are at a maximum during the warm summer months of June, July and August. It is during this period that congestion, if any, occurs. Referring to the Monthly Report on Aircraft Movements for Vancouver International Airport, we can see that movements during August 1973 reached a maximum of 1006 daily on the 18th of this month. The total number of movements for August 1973 reached 21,115. This total translates to peak-hour totals of 92, 91, 88 and 87 for 1600, 1200, 1900 and 1300 hours respectively for peak days during the month. Average hourly totals are considerably lower however, (see Table III). Air carriers accounted for as high as 30.4 percent of total movements during the month of June 1973, and as high as 28.0% during the month of July 1973. Reference to Table II indicates that an air carrier population of 28 percent is in the range where the trade off between relative demands of air carrier and general aviation is .49.

Table III

Vancouver International Airport
August 1973

Peak Number of Total Aircraft Movements

Hour	Peak	Total	Average
	Total A/C Movements		
00	25	202	6.5
01	10	57	1.8
02	2	13	.4
03	4	20	.6
04	2	17	.5
05	7	65	2.1
06	12	178	5.7
07	44	770	24.8
08	61	1077	34.7
09	75	1320	42.6
10	84	1296	41.8
11	80	1349	43.5
12	91	1472	47.5
13	87	1512	48.8
14	82	1541	49.7
15	76	1371	44.2
16	92	1623	52.4
17	85	1736	56.0
18	74	1590	51.3
19	88	1417	45.7
20	54	1052	33.9
21	42	576	18.6
22	37	490	15.8
23	27	371	12.0

Source: Monthly Report on Aircraft Movements for Vancouver International Airport, Aviation Statistics Centre, August, 1973

<u>Relative Landing Fees</u>:

The time that a movement takes has an "opportunity cost" associated with it. This opportunity cost can be viewed in two ways. If an additional movement takes place during peak times when the airport is operating at capacity, the average delay to all aircraft is increased. If average delay is to be kept constant, an additional movement by one class of aircraft must be accompanied by a decrease in the movement rate of another class. Yance concentrated on the latter definition of opportunity cost because it referred to the relative level of landing fees for different classes of aircraft. The same view is adopted here.

The previous chapter illustrated that under the 4 minute average delay criteria, Vancouver International Airport is not operating at its potential capacity. The above technique was developed by Yance for application to Washington National Airport which, in 1965, was operating at capacity and was periodically experiencing very high delays to departures. The fact that Vancouver airport is currently not experiencing these problems should not detract from the potential usefulness of such a technique in determining a landing fee schedule which would meet efficiency criteria. The example which is used to illustrate the application of Yance's technique is not representative of normal activity at Vancouver. It does however focus on a likely solution to the inevitable increase in demand for service at Vancouver International.

In a previous paragraph, we saw that air movements at Vancouver reached a level of 1,006 on August 18, 1973. Of these movements, 159 were air carrier. This proportion of air carrier aircraft (16%) falls into the range of trade-off of 0.79. Because of the uncertainty surrounding this ratio, we will instead use the next ratio of 0.49. From the definition of opportunity cost adopted above, we see that to increase the movement rate of general aviation aircraft by one movement per hour, keeping the average delay constant, the movement rate of carrier aircraft would have to be reduced by 0.49 per hour. The opportunity cost of accommodating a general aviation aircraft is 0.49 as much as that of an air carrier aircraft. However, the landing fees paid by general aviation are in a much lower ratio than this to those paid by air carriers.[4]

In money terms, a general aviation aircraft weighing 10,000 lbs. landing at Vancouver after a domestic flight would pay $2.50 whereas an air carrier weighing 100,000 lbs. would pay $25.00 for landing. If we view landing charges from an opportunity cost standpoint, we see that during peak periods the general aviation aircraft pays a fee of $2.50 compared with an opportunity cost of (0.49 x $25.00) $12.25. This example assumes that the air carrier aircraft displaced from landing is domestic; if it was in fact a trans-oceanic flight the opportunity cost of landing the general aviation aircraft would have been (0.49 x 140) $68.60.

It is recognized that the marginal cost of a landing

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[4] For the schedule of fees assessed the users of airport facilities, see Appendix A.

at Vancouver airport is composed of factors other than the opportunity cost of aircraft "displaced" from the landing queue. It is suggested however that (assuming that the current level of landing fees for air carrier aircraft is appropriate) revision of general aviation landing fees would alleviate congestion at peak hours as well as provide a criteria against which to evaluate expansion.

Conclusion

When one initially addresses the topic of pricing, one perceives a seemingly well-ordered world of logical rules which, if pursued, conclude in a precise figure to be charged. Unfortunately, as we have seen, externalities impose on this idyllic setting and compel the analyst to adopt pricing techniques which can only approximate the theoretical ideal. In the field of air transportation, externalities are composed of government interference in what could otherwise be a free enterprise market. In Canada, because of its extreme size and geographic nature, air transportation is a necessity if people and goods are to be transported quickly over great distances. Perhaps it is this aspect of air transportation that separates it from other modes and entices governments to lavish hugh sums of money on its provision. Whatever the reason, large amounts of money are spent annually on the construction of new airports or the maintenance and expansion of existing ones. St. Scholastique in Montreal, and Pickering Airport in Toronto are excellent examples of new construction necessitated by the burgeoning demand for air transportation. The recent history of air transportation in Canada is replete with examples of government spending unmatched by government collections. The Ministry of Transport collects fees from the users of all airport facilities. This thesis has concentrated on landing fees but a brief mention of other facilities serves to illustrate the ever widening gap between revenues and costs. Costs accumulate as a result of activity in the following areas:

Airports

Air Traffic Control & Telecommunications

Control of Civil Aviation

Air Services Administration

Construction Branch

Meteorology, Civil Aviation

Search & Rescue, Civil Aviation

Air Transport Committee - CTC

Revenues are collected from users of the following facilities:

Terminal:

Space rental
Concession Shops and Privileges
Joint User Terminal Facilities Charge
Observational Turnstiles
Sale of Utilities
Miscellaneous

Field:

Landing Fees
Gas and Oil Fees
Aircraft Parking
Mobile Equipment Registration Fees

Terminal Building Area

Telecommunications

Control of Civil Aviation:

Aviation Personnel Licences
Aircraft Registration Certificates
Airport Licence Fees
Airworthiness Certificates

Meteorology

Provincial Aviation Fuel Tax

Depending on the cost of capital figure used, costs have exceeded revenues at an increasing annual rate since 1954 when comparisons were first published. Figure 1 depicts this situation; all figures shown are in 1968 dollars. At the time of writing, this represented the most recent data available.

Inefficiency of any sort should be removed from airport facility pricing if the gap depicted in Figure 1 is to be closed or prevented from enlarging.

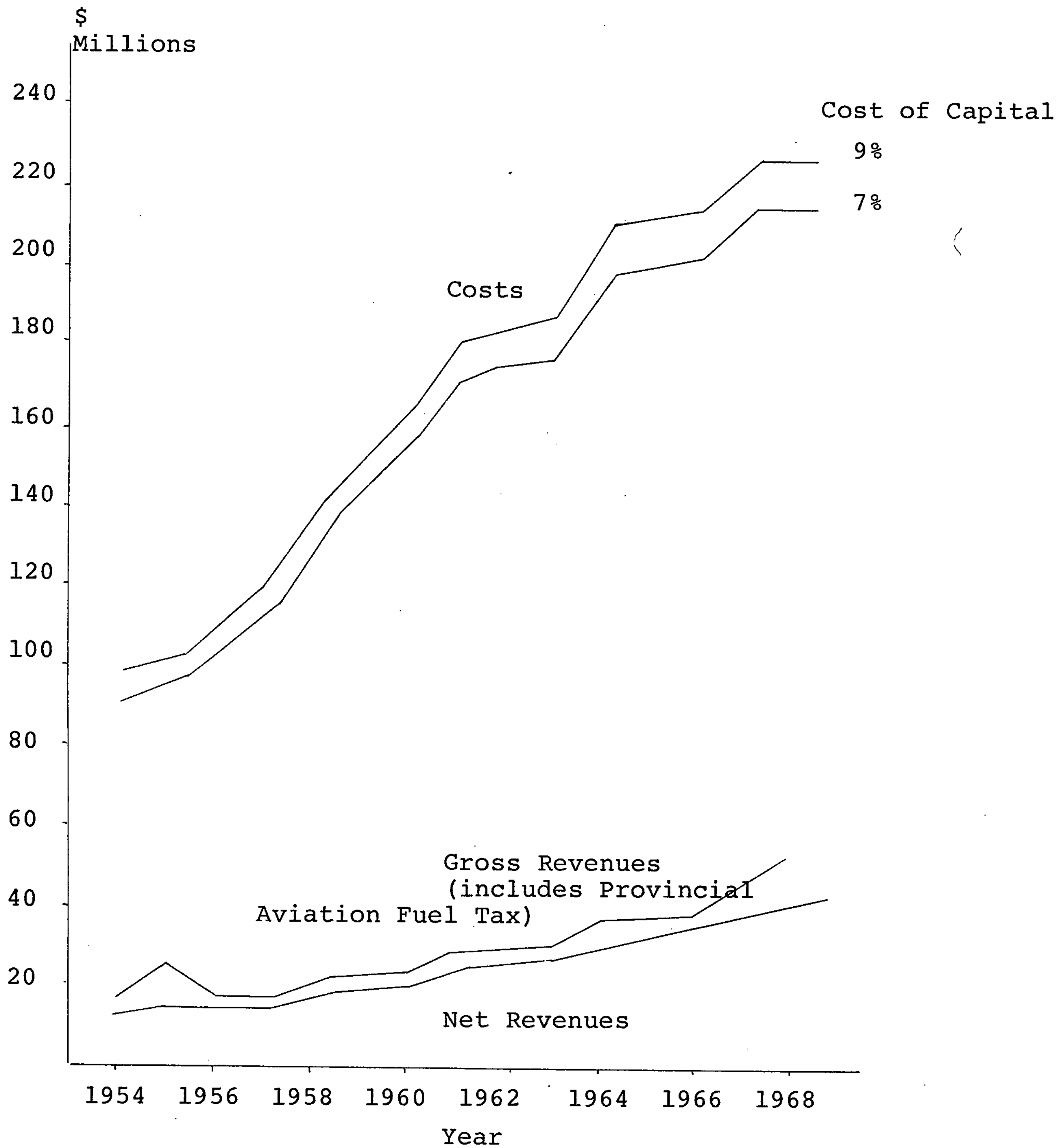
It is apparent from the work described in the first three chapters of this thesis that the derivation of a landing fee schedule which satisfies economic efficiency criteria and is simultaneously applicable, is not a simple task. Once the work of Williamson is understood, the pricing of landing fees under varying levels of demand becomes straight forward. It is the application of this work that comprises the major hurdle.

Carlin & Park are responsible for the most comprehensive attempt to determine a schedule of landing fees which conforms to economic principles. J. Yance, whose work was replicated in the last chapter also was successful in devising a technique which can be used in establishing landing fees.

Ultimately, even the most tenable of arguments must be evaluated in the political arena. The rationale suggested for use at Vancouver International Airport (and indeed at any federal airport in Canada) is the model developed by Yance. The example of a peak-hour landing fee (where the mix of air carrier to general aviation aircraft is .16) of $12.25 for a 10,000 lb. general aviation aircraft would undoubtedly be characterized by general

Figure 1

Annual Costs and Revenues
Canada 1954-68
Civil Aviation Infrastructure
(In Millions of 1968 Constant Dollars)



Source: Haritos Z., Gibberd J.D. Civil Aviation Infrastructure Annual Costs and Revenues, 1954-1968. CTC. 1972.

aviation as discriminatory and not in keeping with the tenets of the law. It is unlikely that any upward adjustment of landing fees will meet with the approval of airport users. The Yance approach to peak-hour pricing is not unique; there are many other approaches which ultimately would achieve the same end -- economic efficiency. This approach was selected for its intrinsic appeal and initial ease of application. There is nothing sacred about the relative time demand ratios and the resultant demand-related landing fees. The latter is completely dependent upon the existing rate structure. If, upon adoption of this technique, demand fell off dramatically at peak times and was not simply redistributed over the remaining hours, the schedule of prices could be revised. The strength of the suggested fee schedule is found in the rationale behind it, not in its relentless application.

Utilizing the demand ratios from Table II of the last chapter, it is possible to construct a schedule of landing fees which reflects the time required to process different aircraft under different conditions. Because of the uncertainty of the general aviation-air carrier demand ratios at either end of the airport population scale, only the ratios related to an air carrier population of 30% - 70% will be used. The following table has been constructed by applying the aforementioned demand ratios to current levels of landing fees. This calculation assumes that the existing structure of fees for air carrier aircraft is appropriate. (A complete description of landing fees at Canadian airports can be seen in Appendix "A".)

Under existing regulations, an aircraft weighing less than 45,000 lbs. (domestic flight) is assessed a charge of $.20 per 1,000 lbs. of gross takeoff weight. An aircraft flying under similar conditions but weighing in excess of 100,000 lbs. is assessed a charge of $.30 per 1,000 lbs. The amounts payable by a general aviation aircraft weighing 10,000 lbs. and an air carrier aircraft weighing 120,000 lbs. would be $2.00 and $36.00 respectively.

Table I

Proposed Fee Schedule at
Vancouver International Airport

% Carriers	Relative Demands G.A. to A.C.	G.A. Fee	A.C. Fee
20 - 30	.49	$ 17.64	$ 36.00
30 - 40	.65	23.40	36.00
40 - 50	.72	25.92	36.00
50 - 60	.76	27.36	36.00
60 - 70	.83	29.88	36.00

It is apparent from Table I that the cost to general aviation aircraft would be significantly increased if landing fees were assessed in this manner. These fees are not completely unfounded; minimum fees of $25.00 for peak-hour use have been in force at Port of New York Authority airports for five years.

It should be stressed however, that the magnitude of these fees is not beyond debate. In fact, it would be surprising were it otherwise. The ultimate success of this approach depends on the manner in which it is implemented. Ideally, this fee schedule would be introduced after a period of discussion. Debate would determine how accurately the relative demand fee schedule reflects the opportunity cost of delays during busy times. After the introduction of the schedule, activity at the airport should be carefully monitored to determine the impact of the new level of prices. The schedule of fees should be modified based on these observations to ensure that the airport continues to be utilized efficiently.

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APPENDIX "A"

PART I

REGULATIONS RESPECTING FEES AND CHARGES FOR CANADIAN CIVIL AIR SERVICES

Short Title

1. These Regulations may be cited as the Air Services Fees Regulations.

Interpretation

2. In these Regulations

"Assistant Deputy Minister, Air" means the Assistant Deputy Minister of the Department;
"commercial flying school" means a flying school licensed by the Air Transport Board;
"Department" means the Department of Transport;
"domestic flight" means a flight between points in Canada;
"flying club" means a flying club that is a member of the Royal Canadian Flying Clubs Association;
"international flight" means a flight between Canada and a place outside of Canada that is not a trans-oceanic flight;
"Minister" means the Minister of Transport;
"owner" in relation to an aircraft, includes a person operating the aircraft;
"state aircraft" means an aircraft, other than a commercial aircraft, owned and operated by the government of any country or the government of a colony, dependency, province, state or territory of any country;
"trans-oceanic flight" means a flight between Canada and a place outside of Canada that passes over or is intended to pass over the Atlantic Ocean, except a flight between Canada and Bermuda, St. Pierre and Miquelon, and the United States; and
"weight" in relation to an aircraft means the maximum permissible take-off weight specified in its certificate of airworthiness or in a document referred to therein.

Application

3. (1) Subject to subsection (2), these Regulations apply to every airport operated by the Department.

(2) Sections 7, 8 and 9 do not apply to any part of an airport held under a lease granted by Her Majesty in right of Canada.

Landing Fees

4. (1) Every owner of an aircraft that is based at an airport and that is owned and operated by a flying club or commercial flying school shall pay

(a) the fees set out in Schedule A for each landing of the aircraft where the aircraft is engaged in flying training at that airport; and
(b) the fees referred to in subsection (2) for each landing of the aircraft where the aircraft is engaged in other than flying training.

(2) Every owner of an aircraft not mentioned in paragraph (1) (a) shall pay the fee set out in

PART 2

SCHEDULE A

Flying Club or Commercial Flying School

Landing Fees
(section 4 (1))

1.	For each hour flown by the aircraft	$ .30

SCHEDULE B

Domestic Flight Landing Fees
(section 4 (2) (a))

1.	For aircraft of not more than 45,000 pounds weight; fee per 1,000 pounds or fraction thereof	.20
2.	For aircraft over 45,000 pounds weight but not over 100,000 pounds weight; fee per 1,000 pounds or fraction thereof	.25
3.	For aircraft over 100,000 pounds weight; fee for 1,000 pounds or fraction thereof	.30
4.	Minimum fee payable regardless of weight	1.00

SCHEDULE C

International Flight Landing Fees
(section 4 (2) (b))

1.	For aircraft of not more than 70,000 pounds weight; fee per 1,000 pounds or fraction thereof	.25
2.	For aircraft over 70,000 pounds weight but not over 147,000 pounds weight; fee per 1,000 pounds or fraction thereof	.35
3.	For aircraft over 147,000 pounds weight; fee per 1,000 pounds or fraction thereof	.50
4.	Minimum fee payable regardless of weight	1.00

SCHEDULE D

Trans Oceanic Flight Landing Fees
(section 4 (2) (c))

1.	For aircraft of not more than 90,000 pounds weight; fee per 1,000 pounds or fraction thereof	1.33
2.	For aircraft over 90,000 pounds weight but not over 125,000 pounds weight; fee per 1,000 pounds or fraction thereof	1.40
3.	For aircraft over 125,000 pounds weight but not over 150,000 pounds weight; fee per 1,000 pounds or fraction thereof	1.46
4.	For aircraft over 150,000 pounds weight; fee per 1,000 pounds or fraction thereof	1.51

SCHEDULE E

Canadian Stations Operating in the International Aeronautical Telecommunications Service
(section 5)

Station	Call Sign
Churchill, Man.	VAP
Edmonton, Alta	VFE
Frobisher, N.W.T	VFF
Gander, Nfld.	VFG
Goose Bay, Nfld.	VFZ
Moncton, N.B.	VFX
Mont Joli, P.Q.	VCF
Montreal, P.Q.	VFN
Resolute, N.W.T.	VFR4
Sydney, N.S.	VFS
Vancouver, B.C.	VFU
Winnipeg, Man.	VFW5

SCHEDULE F

General Terminal Charges
(section 6)

1. Charge for each unit of five seats seating capacity, calculated to the nearest unit of five seats, of an aircraft on a

(a)	domestic flight	$1.00
(b)	non-domestic flight	2.00

2. Minimum charge regardless of seating capacity for an aircraft on a

(a)	domestic flight	2.00
(b)	non-domestic flight	4.00

SCHEDULE G

Aircraft Parking Charges Elsewhere Than in a Hangar
(section 7)

1. For each 10 square foot unit of area or portion thereof

(a)	Per day	$ .01
(b)	Per week	.06
(c)	Per month	.20
(d)	Per year	1.20

2. Minimum parking charge per day or any part thereof in excess of six hours $1.00

3. Where an owner of an aircraft elects to pay the monthly charge with respect to the overnight lay-overs of a scheduled flight, only one aircraft of the same type or a smaller type may be over-nighted for each monthly charge paid. Where an aircraft larger than the one for which a monthly charge has been paid is over-nighted at the airport, it shall be charged the daily rate for that type of aircraft.

SCHEDULE G (Cont'd)

4. Airports at which free parking privileges are available for the first twenty-four hours to an owner of a private aircraft weighing not over five thousand pounds are

Calgary International	North Bay
Cartierville	Ottawa International
Edmonton International	Quebec
Fredericton	Saint John, N.B.
Frobisher	Saskatoon
Gander International	Sept-Iles
Goose Bay	Sydney
Halifax International	Toronto International
Lakehead	Vancouver International
London	Victoria International
Moncton	Windsor
Montreal International	Winnipeg International

SCHEDULE H

Hangar Storage Charges
(section 8)

		Per day or Portion thereof
1.	For each 10 square foot unit of area or portion thereof occupied by an aircraft	
(a)	For heated hangars	$ .041
(b)	For unheated hangars at Frobisher	.038
(c)	For unheated hangars at airports other than Frobisher	.0223
2.	Minimum charge for storage in a heated hangar during the winter season (November 15 to April 15)	$5.00

SCHEDULE I

Goods Storage Charges
(section 9)

		Per day or Portion thereof
1.	For each 10 square foot unit of area or portion thereof	
(a)	In a hangar	$ .0164
(b)	In a building other than a hangar	.01
(c)	Elsewhere than in a building	.0033

SCHEDULE J

Training Landings
(section 4 (3))

1. Air carriers wishing to carry out training flights must apply to the appropriate Regional Director.

2. A flying training flight is a familiarization flight conducted exclusively for the purpose of improving the skill and knowledge of the aircrew.

3. Subject to paragraphs 4 and 5 training landings will be charged for at 20% of domestic landing fees.

4. Air carriers who prior to July 1, 1969 paid a fixed annual amount for flying training landings at Montreal, Toronto, Winnipeg, Vancouver, Ottawa and Edmonton International Airports and Abbotsford Airport will be charged for training landings at the following rates at those Airports.

Year	Rate
July 1, 1969 - March 31, 1970	10% of Domestic Landing Fees
April 1, 1970 - March 31, 1971	12% of Domestic Landing Fees
April 1, 1971 - March 31, 1972	14% of Domestic Landing Fees
April 1, 1972 - March 31, 1973	16% of Domestic Landing Fees
April 1, 1973 - March 31, 1974	18% of Domestic Landing Fees
April 1, 1974 - March 31, 1975 (and thereafter)	20% of Domestic Landing Fees

5. The special rate for flying training landings is applicable to Canadian carriers only. Non-Canadian carriers wishing to carry out flying training landings at departmental airports will be charged the appropriate international or trans-oceanic landing fee upon arrival at an airport, and for each flying training landing thereafter the full domestic landing fee, except that the trans-oceanic landing fee will apply to the last landing prior to a trans-oceanic flight upon departure from Canada.

(a) Schedule B for each landing of the aircraft that concludes

(i) a domestic flight, or
(ii) a planned trans-oceanic flight that was discontinued at an airport in Canada following the commencement of the flight at another airport in Canada;

(b) Schedule C for each landing of the aircraft

(i) for a technical purpose at Goose Bay Airport, Gander International Airport or Ottawa International Airport while on a trans-oceanic flight; and
(ii) that concludes an international flight;

(c) Schedule D for each landing of the aircraft, other than a landing described in paragraph (b) at an airport that is

(i) the last point of landing prior to a trans-oceanic flight, or
(ii) the first point of landing after a trans-oceanic flight.

(3) Notwithstanding subsections (1) and (2), every air carrier licensed under subsection (1) of Section 15 of the <u>Aeronautics Act</u> shall pay the fee set out in Schedule J for the landing of an aircraft engaged in the training of aircrew personnel of that air carrier.

<u>Telecommunication Service Fee</u>

5. (1) Every owner of an aircraft shall pay a fee of thirty dollars for each flight of the aircraft where the aircraft is engaged on a flight that requires and uses international frequencies and services provided by aeronautical stations listed in Schedule E.

(2) For the purposes of this section, a flight means the whole of a journey of an aircraft regardless of the number of intermediate stops.

<u>General Terminal Charge</u>

6. (1) Subject to subsection (2), every owner of an aircraft that uses the air terminal building at an airport to which this section applies for the purpose of embarking or disembarking passengers shall pay, on each embarkation or disembarkation of passengers, the terminal charge set out in Schedule F.

(2) Where a terminal charge is payable pursuant to subsection (1) for disembarking passengers at an air terminal building, a terminal charge is not payable pursuant to that subsection

(a) for embarking passengers on the aircraft from the terminal building on a through flight of that aircraft;

(b) for embarking passengers on the aircraft from the terminal building for the turn-around flight of that aircraft, irrespective of the flight number, where the aircraft does not have a scheduled lay-over of more than three hours; or

(c) for embarking passengers on the aircraft from the terminal building for the onward flight of that aircraft, irrespective of the flight number, if it completes a domestic flight and commences a non-domestic flight or completes a non-domestic flight and commences a domestic flight, where the aircraft does not have a scheduled lay-over of more than three hours.

(3) This section applies to Calgary, Edmonton, Montreal, Toronto, Winnipeg and Vancouver International Airports.

(4) For the purposes of this section, a "through flight" means a flight by an aircraft that arrives at and departs from an airport under the same flight number as part of the continuous journey of that aircraft.

<u>Aircraft Parking Charge</u>

7. (1) Subject to subsection (2), where an aircraft is parked on any part of an airport elsewhere than in a hangar for more than six hours, the owner of the aircraft shall pay to the officer in charge of the airport the parking charge set out in Schedule G.

(2) No parking charge is payable, in respect of a private aircraft weighing five thousand pounds or less,

(a) for the first twenty-four hour period during which the aircraft is parked at an airport listed in Schedule G; or

(b) for parking at an airport not listed in Schedule G when the aircraft is parked in an area set aside and marked by the officer in charge of the airport as a free parking area.

(3) The total parking charges for any aircraft parking at an airport shall not exceed

(a) in any week, the weekly charge determined in accordance with Schedule G; and

(b) in any month, the monthly charge determined in accordance with Schedule G.

(4) An owner of an aircraft may, by notifying in writing the officer in charge of an airport, elect to pay

(a) for the purpose of schedule flight overnight lay-overs the monthly parking charge set out in Schedule G; and

(b) for a private aircraft having a weight of five thousand pounds or less, based at an airport where parking charges are payable in respect of the aircraft, the annual parking charge set out in Schedule G.

(5) For the purpose of this section

(a) any period of more than six hours but not more than twenty-four hours shall be counted as one day; and

(b) the area occupied by an aircraft is deemed to be the area obtained by multiplying the overall length of the aircraft by the overall width, including wings, rotors and undercarriage.

Hangar Storage Charge

8. (1) Where an aircraft is placed in a hangar, the owner of the aircraft shall pay to the officer in charge of the airport the hangar storage charge set out in Schedule H.

(2) Where arrangements are made with the officer in charge of an airport for storage of an aircraft in a hangar for a continuous period of not less than two months and the aircraft remains in the hangar for such period, the storage charge set out in Schedule H shall be reduced by twenty-five per cent.

(3) For the purpose of Schedule H, the area occupied by an aircraft is deemed to be the area obtained by multiplying the overall length of the aircraft by the overall width, including wings, rotors and undercarriage.

Goods Storage Charge

9. (1) Where goods, other than an aircraft, are placed on any part of an airport, the owner or the person causing the goods to be placed on the airport shall pay to the officer in charge of the airport the storage charge set out in Schedule I.

(2) Where goods are stored in a hangar and occupy less than one-quarter of the floor space of the hangar, the storage charge set out in Schedule I shall be increased by twenty-five per cent.

Payment of Fees and Charges

10. All fees and charges shall be computed to the nearest five cents.

11. (1) Fees and charges shall be paid at the place and in the manner prescribed by the Assistant Deputy Minister, Air.

(2) Notwithstanding subsection (1), the owner of a private aircraft who elects to pay the annual parking charge prescribed by paragraph 7 (4) (b), shall pay the charge annually in advance to the officer in charge of the airport.

Removal of Aircraft or Goods

12. The officer in charge of an airport may cause any aircraft or goods in respect of which any charge under section 7, 8 or 9 remains unpaid for three months to be removed at the expense and risk of the owner to any place on the airport where they will not interfere with the operation or maintenance of the airport and from the time of that removal no further charge is payable in respect of that aircraft or those goods.

Exemptions

13. Notwithstanding anything in these Regulations, no fee or charge is payable

(a) under section 4 in respect of the landing at an airport, other than at Toronto, Vancouver or Montreal International Airports, of

(i) an aircraft that is not based at the airport and that is owned and operated by a flying club or commercial flying school, if the owner of the aircraft notifies the officer in charge of the airport that the aircraft is engaged in flying training, or

(ii) a private aircraft weighing not over five thousand pounds;

(b) under paragraph 4 (2) (a) or 4 (2) (b), in respect of the forced landing at any airport of an aircraft in distress when engaged on a domestic or international flight;

(c) under paragraph 4 (2) (b) or 4 (2) (c), in respect of the landing of an aircraft at any airport after the discontinuance of a trans-oceanic flight that commenced at another airport in Canada;

(d) under subsection 4 (2), in respect of the landing of an aircraft at the airport from which it took off on a trans-oceanic flight after the discontinuance of the flight; or

(e) in respect of state aircraft

(i) under sections 4 and 5, for any landing or flight
(ii) under section 6, for general terminal charges if the aircraft is stationed in a location designated by the officer in charge of the airport,
(iii) under section 7, for the first thirty days that the aircraft remains parked in a location designated by the officer in charge of the airport, and
(iv) under section 8, for the first forty-eight hours that the aircraft remains in a hangar.

APPENDIX "B"

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GLOSSARY

"A" airport: An airport where aircraft Classes A and B are greater than ten percent of population -- principally used by air carriers.

Airspace: Defined for use in computing capacity for "A" airports. If unlimited airspace exists around an airport, departures can be sequenced, one behind the other, at short intervals (low-service times). A slow aircraft, ahead of a fast aircraft, can be turned away from the airport very quickly in any direction allowing the fast aircraft to be released in a short time. However, in a highly restricted airspace situation where noise abatement is a problem and other airports are nearby, each departure may have to follow others along the same path for some distance. This will result in long-service times, with a corresponding decrease in departure capacity.

The graphs used in capactiy computations allow for:

1. Highly restricted airspace: Defined as one common path out of an airport where aircraft must follow each other from 1-to-5 miles. This type of airspace is commonly found at busy airports where noise abatement is a problem and when other busy airports are within a ten-mile radius. Also, mountains can cause similar conditions.

2. Normal airspace: Where aircraft can be 'fanned' out over three basic directions. Some noise restrictions may be present, but are not severe, and the closest busy airport is more than ten miles away.

3. "Unrestricted" airspace: Self-explanatory, and implies no noise, other busy airport, or any geographical restrictions nearby.

ANDE: The ANnual DElay to arrival and departures totaled over a one-year period.

Annual capacity: The Practical ANnual CAPacity (PANCAP) of an airport is reached when the delay to operations over a one-year period reaches the criteria level.

Arrival capacity: The hourly arrival movement rate at which an average delay of four minutes occurs. Also, abbreviated as HAC -- hourly arrival capacity.

Capacity: The operating level, expressed as the rate of aircraft movements, which results in a given level of delay.

Computer sequencing: A future technique to be used by air traffic control to sequence arrivals and departures with the aid of computers. Also called TIC -- terminal interval computer.

Crosswind criteria: The allowable crosswind for routine landing and takeoff operations. Suggested as 15 knots for PANCAP and ANDE calculations.

Departure capacity: The departure movement rate at which an average delay of four minutes occurs. Also abbreviated as HDC -- hourly departure capacity.

"G" airport: An airport where aircraft Classes A and B are less than or equal to ten percent of the population -- principally used by general aviation.

HAC: Hourly arrival capacity.

HDC: Hourly departure capacity.

Hourly capacity: The movement rate per minute at a selected delay level usually four minutes more often called Practical HOurly CAPacity -- PHOCAP.

HTC: Hourly total capacity -- used as a working term in PHOCAP and PANCAP computations.

IAW: Instrument airport weather -- see "Weather conditions".

IAW approach: An instrument approach using ILS, VOR, or other aids during IAW-type weather.

IAW control: Air-traffic-control procedures used during IAW-type weather and is based on either radar or non-radar control.

Intersection ratio: In the case of two intersecting or open-V runways, the relationship between the total runway lengths and the intersection distances must be expressed as a ratio.

Lateral separation of parallel runways: For IAW conditions in 1968-75 and both IAW and VAW in 1975, you will be required to know the separation between the two parallel runways. If it is 3,500 feet or less, and the runway thresholds are offset from eachother, a correction factor will be required.

MTB: An acronym used to identify a parallel runway configuration when the main terminal is between the runways.

MTO: An acronym used to identify a parallel runway configuration where the main terminal is outside the runways.

Off-peak use: A term used to describe the spreading of aircraft movements outside the peak hour periods. Generally occurs at airports where PANCAP is exceeded as a means of reducing delay. Used in PANCAP computations.

PANCAP: See annual capacity.

PHOCAP: Practical HOurly CAPacity -- an abbreviation frequently used as it is a key to many capacity computations. It is the movement rate which results in a selected average delay (usually four minutes). Since it is delay-related, PHOCAP can be exceeded but at the price of a higher average delay.

Population: For capacity analysis, the population is defined as the actual mixture of aircraft classes making up a movement rate.

The mixture of aircraft classes will greatly affect capacity and delays. For a given runway configuration, a population of light aircraft will produce a much higher capacity than a population of heavy aircraft, including jets.

To use the graphs for determining capacity, it is necessary to state the population in terms of percentages of classes of aircraft.

Practical HOurly CAPacity: Commonly used as PHOCAP. It is the movement rate which results in a selected average delay (usually four minutes).

Public desire: Used herein to describe the hourly distribution of traffic when it reacts to the public desire for transportation. This normally results in a major peak period in the afternoon and a lesser peak in the morning. Typical of the distribution at an airport operating well below PANCAP.

Radar control: Used herein to describe terminal air traffic control by use of radar, generally an ASR type.

Ratio of arrivals to departures: This term is used only in conjunction with "A" airports.

For capacity analysis, ratio is defined as the number of landings per hour divided by the number of takeoffs per hour at a given airport or configuration, where

λ_L = number of landings or arrivals per hour for a given airport or configuration

λ_T = number of takeoffs or departures per hour for a given airport or configuration

λ_S = total number of movements per hour for a given airport or configuration

For the same airport or configuration,

$$\lambda_S = \lambda_L + \lambda_T$$

$$\text{Ratio} = \frac{\lambda_L}{\lambda_T}$$

When calculating airport capacity, it is usual to express capacity in terms of movements per -- λ_S. If ratio is 1.0, then $\lambda_L = \lambda_T$. Thus at a S of 40 movements per hour and ratio of 1.0, $\lambda_L = 20$. However, if ratio is not 1.0, then

$$\lambda_L = \lambda_S \frac{\text{Ratio}}{1 + \text{Ratio}} = 40 \frac{1}{1 + 1} = 20$$

$$\lambda_T = \lambda_S \frac{1}{1 + \text{Ratio}}$$

<u>Runway characteristic</u>: In capacity analysis, certain runway characteristics must be determined for accurate capacity analysis.

For each runway that is used for landings on any configuration, the following information is required:

1. Usable runway length in feet
2. Number of turnoffs that can be used on each runway
3. Type of turnoffs to be used
4. Location of turnoffs along the runway

Usable runway length is measured from the runway threshold to the end of the runway.

A runway often has turnoffs on either side of the runway. The use of turnoffs by landing aircraft is determined by the ultimate destination of the arrivals on the airport. Therefore, the number of turnoffs must be listed by "left" and "right" with some notation to indicate the location of the air carrier and general aviation terminals.

For this analysis, there are three basic types of turnoffs:

1. Right angle
2. Angled
3. High speed

Runway configuration: A runway configuration is a layout or design of a runway, or runways, where operations are mutually dependent on the particular runway or runways being used at one given time.

Thus, two widely spaced parallel runways, with arrivals and departures on both runways, may be considered a two single runway configurations (with mixed operations on each) at an "A" airport.

However, two very close parallel runways in bad weather are considered as one runway configuration, since arrivals on one of the two will affect departures on the other.

Exact details of various configurations are given with PHOCAP computation instructions.

Runway ratings: Defined as the average runway occupancy time for a given population of landing aircraft on a given runway.

As each arrival lands, it occupies a runway for a certain time. The occupancy time depends on:

1. Aircraft type or class
2. Physical properties of runway

If departures are using the same runway for takeoff, long arrival occupancy times will give rise to longer departure delays.

To simplify the analysis, one final average occupancy time is calculated for each arrival population by runway. This is called the runway rating (R_R).

It is emphasized that the value of R_R calculated for any runway can change if:

1. Population is changed
2. Runway is altered (length, type of turnoffs, etc.)

Runway use: For capacity analysis, "runway use" is the function of a runway or configuration, with respect to arrivals and departures. That is:

1. Mixed operations (arrivals and departures)
2. Arrivals only, or
3. Departures only

Thus, a single runway, whether by itself or as one of a pair parallel runways, can be used for mixed operations; or, in the case of two parallel runways, one can be used for landings only, and the other can be used for takeoffs only.

Two intersecting runways may differ in their use. One such configuration may have landings only on one runway, and takeoffs only on the other runway. Another similar configuration may have mixed operations on both runways. There are many variations of runway use for the numerous airport configurations. Proper selection of runway use is vital to capacity calculations.

Service times: That time required to complete an operation on a runway before another aircraft can perform an operation on that runway.

T and G: An abbreviation for touch and go.

Terminal interval computer: A subsystem for precise terminal air traffic control. Expected to come into use in 1975 and beyond. Will assist in more efficient sequencing of arrivals and departures to maximize capacity. The availability of this aid is presumed in the 1975+ capacity calculations.

TIC: An abbreviation for terminal interval computer.

Touch and go: Training operations wherein the pilot approaches the runway, touches his wheels and goes on for another aerial circuit.

Traffic priority: The relative priority given arrivals and departures. Since arrivals are currently usually given priority, departure delays are usually greater than arrival delays and are therefore important to capacity calculations. The PHOCAP computations are based on normal usage.

VAW: Visual airport weather.

Weather conditions: For capacity calculations, it is necessary to define special weather categories. The two categories used throughout the handbook (in place of VFR and IFR) are:

VAW - visual airport weather

IAW = instrument airport weather

They are defined as follows:

"G" Airport: VAW exists when the ceiling and visibility are greater than 1000 feet and three miles. IAW exists when the ceiling and/or visibility are equal to, or less than, 1000 feet and three miles.

"A" Airport: VAW, ceiling, and visibility are greater than 700 feet and two miles. IAW, ceiling, and/or visibility are equal to, or less than 700 feet and two miles.