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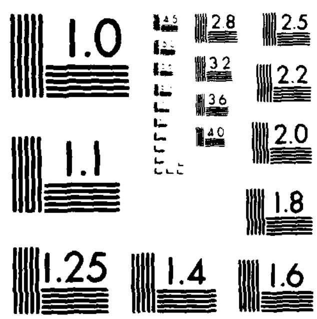

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Volume I

The Allocation of Runway Slots by Auction

U.S. Department of Transportation
Federal Aviation Administration

Office of Aviation Policy
Washington, D.C. 20590

Executive Summary

FAA-AVP-80-3

April 1980
Final Report

M.L. Balinski
F.M. Sand

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16. Abstract

The allocation of runway slots at the high-density airports by means of an auction is studied. Previous approaches to slot auctions have not allowed for the interdependency of slot values to the air carriers--a single slot for a landing of an aircraft is likely to be of little value without a corresponding slot for a subsequent take-off of that aircraft. A Slot Exchange Auction is designed, its theoretical properties and practical implementation discussed. It is shown to allow the slot market to reach an efficient equilibrium under competitive conditions. The Airline Management Game is used to create a simulation test of the Slot Exchange Auction and its associated continuous market, the slot exchange.

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SUMMARY

To comply with the Airline Deregulation Act of 1978, equitable and efficient means by which to allocate scarce slots among air carriers at congested airports must be determined. There is a mounting pressure to make this policy decision soon.

This report reviews the problem, outlines and evaluates the possible approaches to its solution, makes specific recommendations, argues their merit and indicates the further steps necessary to perfect them and to implement them.

The major findings are these:

1. Slots should be six-month options vesting in their holders the right to schedule operations, with prices dependent only on time-of-day and airport.

2. Slots should be allocated in a Slot Exchange Auction.

Each air carrier prepares sealed bids--stating the number of slots it requires and the prices it is willing to pay for each--for every "market," that is, for every time period at each quota airport. The bids are aggregated into a total demand for slots at every market. If a market has a quota of q slots, the q highest bidders are tentatively awarded the slots at the price of the lowest of these q bids. (If there are fewer than q bids, all bidders are tentatively awarded the slots at no cost.) Every carrier is shown the aggregate demand in every market.

If the carriers are satisfied, the tentative allocations and prices become the permanent allocations and prices. If not, a new round of bidding takes place. Every round reveals to the participants a more complete picture of the total market prices, and so a better understanding of the values of the slots to the industry as a whole. In this manner the Slot Exchange Auction approaches an

economic equilibrium and so the economically efficient allocation of slots to carriers.

3. The Slot Exchange Auction has been subjected to two initial tests in the environment of the Airline Management Game. Time limitations curtailed the extent of experimentation, cutting short the number of auction rounds. Nevertheless, the convergence to a set of stable slot allocations was encouraging.

Further experimentation to refine and perfect the practical efficacy of the approach should be done.

4. A continuous slot exchange should be maintained after the auction establishes an initial allocation. It would permit the carriers to buy and sell slot options during the entire six-month period to account for changes in the air transport market, changes in general economic conditions and changes in airline marketing strategies. It would also permit air carriers to adjust to any marginally unbalanced allocations of slots resulting from the auction.

ORGANIZATION OF REPORT

The Report is organized as three volumes. Volume I, Executive Summary, presents the main ideas, recommendations and results. Volume II, The Airline Management Game and Slot Auction Testing, presents the game scenario and detailed results and analysis of the tests of the Slot Exchange Auction which were conducted in the environment of Flight Transportation Associates' computerized airline scheduling game. Some theoretical and historical aspects of auctions and their use by the federal government are presented in Volume III, Theory and Technical Issues for Implementation. The busy reader need only be concerned with Volume I; readers wishing a more thorough acquaintance with the testing and theory of the auction should also read Volumes II and III.

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I. BACKGROUND

The Airline Deregulation Act became law on October 24, 1978. Its spirit is to open the industry--albeit gradually--to the usual market forces by encouraging price competition and allowing both free entry and exit from the market; that is, permitting carriers and commuters to open or to close service on any route. The Act specifically declares as policy:

- "the placement of maximum reliance on competitive market prices..."
- "(reliance) on actual and potential competition to provide efficiency, innovation and low prices, and to determine the variety, quality and price of air transportation services..."
- "the encouragement of entry into air transportation markets by new air carriers...(and) additional...markets by existing carriers..."
- "...the desirability of a variety of price and service options such as peak and off-peak pricing or other pricing mechanisms to improve economic efficiency and provide low-cost air service..."
- "...the desirability of allowing an air carrier to determine prices in response to particular competitive market conditions on the basis of such air carrier's individual costs..."

These goals are to be met in the face of the fixed and limited capacities of existing airports. Airports are and cannot but be of fixed capacities over any yearly period and four major ones among them are and have been congested. To control congestion and its attendant delays, the FAA imposed "quotas"[1] in June 1969, formally restricting the number of scheduled air carrier operations, or "slots," to stated maximum numbers. These are today: 40 at Washington National, 80 or 70 (dependent upon time of day) at New York JFK, 48 at New York LaGuardia and 115 at Chicago O'Hare. These quotas are allocated twice yearly by scheduling committees administrated by the Air Transport Association and made up of air carrier representatives, one day (or more) being devoted to each of the four airports. FAA projections[2] show as many as 40 airports experiencing congestion by 1985.

The scheduling committees--permitted by a CAB sanctioned antitrust exemption--have been criticized for not being a competitive mechanism for allocation of airport operations in congested airports which are subject to FAA hourly quotas. Accordingly, a competitive, economically efficient allocation procedure is being investigated herein.

This report presents an approach to the slot allocation problem which is based on a competitive procedure--the auction. We present a brief review of auctions, their theory, how they are used by the federal government and how they might also be used for runway slot allocation. We describe a particular form of auction--the Slot Exchange Auction*--which we consider best suited to the airline scheduling environment. We give an explanation why this form is preferable to other proposed methods. Experiments have been conducted in the use of the Slot Exchange Auction for slot allocation in conjunction with simulated airline scheduling of flights subject to the quota-restricted slot allocation. We describe these experiments and analyze the results. Finally, we make recommendations for the further testing and development of the Slot Exchange Auction, and its associated continuous market, the Slot Exchange.

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*Also known in recent reports and discussions connected with this work as The Trading Post Auction.

2. STATEMENT OF THE PROBLEM

The problem of the allocation of slots is fundamentally rooted in the equitable and efficient operation of an airport. An early paper concluded,[3] "...the existing price system for airport services fails to allocate the existing capacity so as to maximize its 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." The need for a comprehensive airport pricing system[4] that adequately reflects the multi-attributes of airport capacities including runways and their type, pollution, access, terminals and the like, and also reflects user characteristics such as type of plane, weight, time of day or other, is clear. However, the development of a universal system needs careful analysis and time. As a practical matter, a substitute for the scheduling committee is needed soon. In any case, no static system would do; the allocation of slots must respond to changing market demands and economic efficiencies. A landing fee partly dependent upon time of day could make economic sense, but how should such fees be determined? If set too low, congestion results; if set too high, underutilization results.

Therefore, whatever pricing system is ultimately adopted, the price for the reservation of a scheduled operation, a slot, at a particular time of day should be unbundled from the remaining costs of an operation. Landing fees independent of time but dependent on type of aircraft can continue to be imposed for the recovery of certain operations costs by airports while time dependent slot prices are imposed when necessary for slot allocation under the quota system.

Theoretically, this may not be perfect. The number of slots per hour consistent with safety and the control of congestion is surely a function of the mix of type of aircraft which operate in the given hour. Indeed, the timed-sequence of operations affects actual usage rates. Nevertheless, slot pricing virtually necessitates that a slot in any given hour should be considered a homogenous good. This is consistent with current practice and imperative in the absence of a definition of slots differentiated by type of user. In contrast, the landing fees, while not necessarily equal to the variable airport costs dependent upon the different user types, should nevertheless reflect these costs.

In summary, the cost of a scheduled operation should be composed of two components: one based on the variable costs of the actual physical operation alone, the other based on the slot as a function of time alone. The actual physical operation cost could be determined via an accounting imputation,[5] marginal cost principles[6] or other means for determining published rates. The cost of a slot needs to be determined by an economically efficient market mechanism.

To devise a market mechanism, the "good" which is to be sold and/or traded must be defined. Current usage has it that twice a year the Airline Scheduling Committees meet to distribute slots for the congested airports. Slots are committed to air carriers for a stated period of six months. Each slot becomes, in effect, an <u>option</u> giving the holder the right to schedule an operation at a given hour and airport for the six month period. The complex environment of airline scheduling requires that these rights should be vested for sufficiently long periods of time. Slots are used to schedule flights, flights represent the markets in which air carriers sell their services, these services require investments in support facilities, advertisement and the like which cannot be altered in the very short run. We therefore consider a slot to be an option vesting its owner with the right to schedule an operation at a given time and place for a period of six months. An efficient market mechanism is necessary to allot these in anticipation of each six month period. In addition, since the demand for air travel, the financial positions of individual carriers, the general state of the industry and the condition of the economy as a whole may change, the holders of slot options should be allowed to trade--to buy and/or sell--their options. A carrier having used some options to schedule a particular flight might decide, after two months of service, to drop that service and sell the four months options which remain to other parties. Restrictions on the prices charged may be necessary to prevent speculation in slots by air carriers.

The problem at hand is the design of these two linked competitive mechanisms to first allot then facilitate the trade of slots.

This problem is treated for the slots intended for use by air carriers. Excluded from direct discussion are commuters and general aviation. The same procedures could be applied directly to the allocation of slots to commuters since the quotas for commuters are set separately from those for carriers and could continue to be so set. The information produced by the procedures should shed important light and help to guide the decision as to how quotas should be distributed between carriers and commuters.

3. REVIEW OF APPROACHES

Various approaches to the initial allocation of slots to carriers have been proposed, if only in embryonic form.[7]

Broadly conceived, they may be classified in two categories. The first are the administered or noncompetitively determined allocation schemes. The second are nonadministered or competitively determined.

The first includes: the current scheduling committees: first-come first-served; proportional allotments by priority guidelines (depending upon such factors as historic shares of operations, potential public service provided); lotteries (with win probabilities a function of historic shares, estimated future enplaned and deplaned passengers or on the basis of purchased lots); solutions of mathematical programming problems purporting to maximize the total "value" of all scheduled flights and time- differentiated landing fees. Some of these schemes are in conflict with the stated aims of the Airline Deregulation Act.

The scheduling committees have been the object of a recent study[8] which convincingly shows the economic inefficiency of their outcomes. The committees, in effect, arrive at unanimous decisions, giving every participant (notably the least viable economically) the power of veto; thus, the threat of throwing the decision to the airport or FAA on a first-come first-served basis. The observed consequence is that noneconomic factors determine outcomes.

A mathematical program which maximizes the total "value" of all scheduled flights has been suggested in the past.[4] The difficulty with this approach is the appropriate determination of value. An airline itself is hard-put to come forth with a number which represents the "value" to the airline of a flight. In fact, the basic planning units of airlines are not flights but cycles of equipment over many days. Even if precise values could be determined, no airline would or should agree to divulge this essential information. Were "values" demanded, they would be inexact at best, strategically manipulated and the "optimal" solutions could indeed be found unacceptable and abhorent to the carriers. In a word, this approach is contrary to the goals of the Deregulation Act, makes unrealistic informational demands and would involve the government in a detailed regulatory activity potentially leading to inefficient solutions.

Time-differentiated landing fees are an attractive economic alternative. They have been used by the British Airports Authority (BAA). They were applied, in limited form, by the Port Authority of New York beginning in 1968 to relieve congestion at the New York airports, caused by aircraft having fewer than 25 seats. Such fees make good economic sense. Regretably,* it is impossible in practice to set such fees correctly; that is, to determine equilibrium prices which will result in a balance between supply and demand. If prices are too low, excess demand results and the allocation problem remains. If prices are too high, excess supply results and the airport becomes underutilized, contrary to the public welfare. If some prices are too high and some too low, both conditions obtain. Information to determine equilibrium prices does not exist, and cannot, so any attempt would depend upon sheer conjecture at best. The only safe course would be to incorporate modest time-differentiated fees for landing which would be sure to avoid causing underutilization, and then to rely on another, competitive mechanism for resolving the allocation problem; but this would unduly complicate the entire landing fee and slot allocation process and is not recommended.

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*As BAA has discovered.

The second broad category is the nonadministered or competitively determined allocation schemes. This connotes auctions and/or market mechanisms. If auctions, what type? If markets, how are trades effected? There are a host of specialized auction rules, each apparently tailored to the needs and institutional environment of the industry where they are used.[9] The English auction begins with low bids to buy and goes up, the last (highest) bidder winning. The Dutch auction begins with high offers to sell and goes down, the first bidder winning. Should bids be open (e.g., oral) or sealed? How should many homogenous goods (36 slots per hour at Washington National) be auctioned as versus one specified item (e.g., a painting)? For example, it has been suggested[10] that for the problem of a flight overbooked with passengers, each passenger should indicate on a sealed "bid" that amount of money he or she would be willing to accept for not flying; the passengers making the highest bids would be given seats, the remainder would receive compensation set at the price stated by the first rejected bid. This is a competitive sealed bid auction in that all bids are filled at one price. Should the auction be discriminative sealed-bid, with bids filled at the different full-bid prices? In an exchange market, should offers to buy and offers to sell be anonymous in the market place? Should direct negotiation be allowed between participants?

There are many choices to be made. Essentially, all of these will satisfy the demands of the Airline Deregulation Act. A choice of one method is needed. On the one hand, varying proposals will have varying properties which are independent of the type of "good" whch is to be allocated and traded. These are the "abstract" properties. On the other hand, it is evident that an allocation method and exchange market is needed which is tailored to the particular institutional environment and needs of the airline industry.

4. INTERDEPENDENCY IN THE VALUE OF SLOTS TO AIR CARRIERS

Each airline is periodically confronted with an extremely complex scheduling process. In response to its perceived market opportunities--which in the era of regulation effectively allowed only marginal changes--an air carrier schedules each aircraft in its fleet in set cycles through airports to provide transportation and assure periodic maintenance. For example, each of United Airlines' DC-10s has its own 37 day cycle of about 410 hours of flying, which includes San Francisco at least once for an overnight stay to perform maintenance. Crew routing is fitted to this basic schedule. The slots which air carriers seek are determined by this basic schedule. Of course, the current scheduling committee allocation system encourages strategic posturing, with airlines exaggerating their initial requests in order to give way during the committee negotiations to end up with their true goals. This planning environment explains the role and importance of "sliding," whereby air carriers give up slots in one hourly period to gain slots in nearby periods, thus not upsetting the essential integrity of their basic schedules.

The planning process makes evident the fact that slots per se are not the objects of interest: flights, indeed cycles of aircraft, are the objects of central interest. An 0800 slot at Washington National is of no interest whatsoever if it is destined for a flight due to take off from Washington and land at New York LaGuardia in the 0900 period, if no corresponding slot can be obtained at 0900 at LaGuardia. Another aspect of the interdependency problem is that a particular slot has no identifiable (monetary) value to an air carrier; rather, an air carrier values flights--since these are what they offer the public--and if it is ready to purchase the slots necessary to accomodate a flight for $1000, it does not care whether the first necessary slot costs $800, the second $100 and the last two $50, as versus the first two $25, the third nothing and the last $950. This interdependency in the values of slots is one of the essential characteristics which must be accounted for in the design of an adequate mechanism.

ECON's initial approach at overcoming this problem was to suggest a completely new type of auction, the "first-choice" auction. In barest terms, this mechanism proceeds as follows: at any stage an ordinary auction (say, of the English variety) is held with the winner having the right to choose any slot at any airport which is still available. Thus, the first winner chooses any slot option; the second, any;...; the 500th winner, any slot at any airport for which the time period's quota has not been reached. The interdependency difficulty appears to be at least in part accommodated: the bidders can acquire in sequence the slots necessary to complete flights or indeed cycles. The solution is freely competitive. It is not, however, efficient. The 36 slot option holders at 1700-Washington National may well have paid widely varying prices for the same "good." There is no set of equilibrium prices in the face of which the industry would purchase slots, each carrier maximizing its perceived goals, with each slot market or exchange in supply-demand balance. For these reasons the approach has been discarded.

5. A "ONE-TIME" AUCTION AND AFTERMARKET

A recent report[11] proposes a "one-time" auction similar to that suggested by Vickrey[12] for resolving overbooking problems. The basic mechanism has each airline interested in acquiring slots in some particular "market," viz., the 1700 period Washington National market, making sealed bids for each of the slots it desires. Thus, if it wishes three slots in this market, it names three bids, say, $250, $100 and $100. The sealed bids are collected and the 36 highest bids are awarded the 36 available slots at the price of the lowest of those 36 bids. In general, in a market with a quota q (q = 36 for Washington National), the q highest bids win at the price of the lowest of the q bids. If the total number of bids is lower than q, then all are awarded at no cost (there is excess supply in the market).

This is, in many ways, a reasonable approach. However, it fails to take into account the institutional background faced by the industry.

Assume, for the purposes of concrete discussion, that a situation approximating that of today obtains: four congested airports have hourly quotas and each only permits scheduled operations in certain hourly periods. This means there are roughly 42 slot-markets. Either the 42 auctions operate simultaneously or they operate sequentially (no specific recommendation appears to have been made).

Suppose the auctions are conducted simultaneously. Then each of the participating airlines must place values on each of the slots it desires over the entire network and at all times. What strategy should an airline follow? Assume an airline knows what slots it wishes and knows the values it attaches to flights. How should the airline allocate the values it has on flights to the prices it bids for slots desired to realize those flights? The report answers: "This particular market organization has the feature that the optimum bidding strategy is for each buyer to bid the maximum that he/she is willing to pay" (Ref. 8, p.VI-3). For a flight needing only one slot, this is quite true. But for a flight needing two slots (or more) there are many ways in which he/she could distribute the maximum amount over the two (or more) slots. Where it should bid more or less depends entirely upon the total demand pressure in each of the hour-airport markets. The market organization provides no information concerning this pressure: the airlines are obliged to bid in ignorance, in the dark. The intertemporal and network dependencies so crucial to the industry's environment are unaccounted for.

Nothing remotely resembling an efficient economic equilibrium is likely to be produced: the bids cannot but be pure guesses.

Suppose, then, that the auctions are conducted sequentially. Then the first auction, say 0700 Washington National, is carried out "in the dark;" the second, say 0800 Washington National, is carried out with the outcome of the first known;...the 42nd, say 1900 at Chicago O'Hare, is carried out with the outcomes of all 41 prior auctions known. The strategy of each participant may be increasingly clarified; but early mistakes cannot be recouped and the later bids, and so outcomes, must depend upon the earlier results. As is well known to auctioneers and to readers of the auction literature, "...both the allocations determined by auctions and the final vector of prices associated with these allocations are very sensitive to the sequence in which the goods are brought up for sale."[13] Thus, beginning with Washington National and going on to Chicago O'Hare may yield very different results than vice versa, and beginning with the morning hours and going on to the afternoon hours may give different prices and allocations than beginning with afternoon periods and proceeding to earlier and earlier hours of the day. This fact hints that economically efficient allocations cannot result from these sequential auctions either.

Indeed, sequential auctions open the play to contingent statements wherein the bidders issue threats about their future bids. If irrational threats come from several sides, it is quite possible for each of the bidders to be "locked into" highly inefficient strategies which lead to uneconomic outcomes. Examples can be given which show this possibility (see Volume III). Each player is "locked into" a course of action because no player can deviate to more rational behavior alone: doing so would only worsen his situation. This is the well-known "prisoner's dilemma" wherein Nash equilibria are inefficient. Of course, declared threats can simply be outlawed as a rule of procedure; but the fact that such a possibility is admitted by the sequential approach points to an additional theoretical weakness.

In either case--simultaneous or sequential--abhorrent allocations can result. The proposed remedy is that, "The sealed-bid auctions can be applied to only one airport at a time. In order to facilitate coordination between airports, an aftermarket is proposed. In this market carriers will be able to acquire or sell slots in order to optimize their operations among airports" (Ref. 8, VI-4, 8). "Mistakes by carriers are inevitable but, by participating in an aftermarket, they can be corrected" (Ref. 8, VI-12). In fact, even <u>within</u> one airport, coordination is necessary: an airline acquiring a slot for a planned landing of flight No. 104 must acquire one in a following period for a planned takeoff for the same aircraft, otherwise it would be immobilized and useless. In any case, the potential unbalanced endowments of slots resulting from the initial "one-time" auctions are to be corrected in an aftermarket of the NASDAQ "open-book" type. These markets do indeed converge to competitive equilibrium prices: but the competitive prices and trades which occur are directly <u>dependent upon the initial endowments</u>

which the traders bring witn them...and these initial endowments are the result of the previous rounds of auctions.

To summarize,two mechanisms have been recommended: 1) "one-time" auctions which have the function of producing an initial endowment of "goods," which are numbers of slots at certain hours and airports not surpassing in total the quota restrictions; and 2) an aftermarket which has the function of producing feasible allocations of slots for the airlines which take into account the institutional interdependencies. The auctioning mechanism, in which airlines bid "in the dark," totally unaware of the demand pressures in one or another market, can lead to almost any outcome. Indeed there is no guarantee that the bidders reveal their "true" demands in the auction procedure: strategic misrepresentation may well be engaged in to achieve an advantageous initial endowment for the second market mechanism. Even with no attempt at strategic posturing in the second round, airlines may achieve severely unbalanced outcomes in which one wins perchance a virtual strangle hold on one airport, another an unhoped for abundance of slots in excess of need, still another an alarming dearth of slots which puts it at a great competitive disadvantage for trading in the aftermarkets. Strategic behavior may enhance this possibility. It would therefore do as well, if not better, to impose a lottery on the first round instead of auctions to obtain initial endowments for airlines to subsequently exchange in the aftermarkets.

The question to be posed is this: does the two-stage mechanism produce competitive equilibria? The first alone produces nothing of the kind. The second alone produces a competitive equilibrium based upon the initial slot allocation. What of the joint outcome? It will not, in general, be an efficient competitive equilibrium. The essential random outcomes of the auctions may so distort initial distributions that the aftermarkets are unable to achieve competitive equilibria efficient for the final allocation of slots. Examples suggest that this may indeed occur (see Volume III). The phenomenon which occurs in that example, and which would be likely to occur in practice, may be qualitatively described. In the auction process each airline bids prices on slots whose totals equal or approximate the values of the corresponding flights it wishes to schedule. But, being ignorant of the remaining airlines' demands and prices, it receives only some of the necessary slots. It--and the other airlines--enter the aftermarket to both acquire needed slots and dispose of slots for which the prices of the mates they would need to complete a flight are too high (the total value of the flight would be surpassed). Economic self-interest results in some trades, but not in sufficient trades to drive certain flights out which should not belong to a competitive, efficient solution. The prices and allocations of the initial auction inhibit the aftermarket from producing a competitive equilibrium. This outcome makes no assumptions concerning potential strategic behavior; it depends only on the ignorance of total demands which exists in the "one-time" auction procedure and on the facts of the two-stage procedure.

In summary, the two-stage "one-time" auctions and aftermarkets are not appropriate to the allocation of slots for three major reasons.

- First, the carriers can have no natural strategies to follow in bidding for slots in the primary auctions--they are condemned to "bid in the dark."
- Second, the outcome of the primary auctions can be seriously distorted, yet the outcome determines each airline's initial endowment of slots and, hence, the solution reached in the aftermarkets.
- Third, the final allocation of slots determined by the two-stage process will typically not be an efficient economic allocation or competitive equilibrium for the problem.

6. SLOT EXCHANGE AUCTIONS: A NEW APPROACH

The "one-time" auction suffers from several drawbacks. The procedure we recommend represents an attempt to overcome these defects. We generalize and improve upon the Polinomics plan by introducing a "repeated" auction to create the carriers' initial endowments of slot options. Our "repeated" auction replaces their "one-time" auction. This is done to permit airlines to iteratively learn of the demand pressures which exist in each slot market and so to enable them to allocate their bids for slots intelligently: to enable them to develop informed and rational strategies in view of the demands and the interdependencies; and to obtain auction allocations which are at least close to efficient competitive equilibria. The approach rests upon a theoretical model[15] whose equilibrium solutions are particularly robust. We also recommend an aftermarket, "the slot exchange," not only designed to permit trade in slots throughout the real time period of 6 months in which the options are valid, but also to permit the minor marginal adjustments which may be necessary to adjust the initial allocation reached by the repeated auction.

We call our approach a "slot exchange": it consists of a "slot exchange auction" followed by a continuously operating "slot exchange." The name is intended to invoke the continuous and repeated nature of the offers which are typically found in stock and commodity exchanges and which serve to generate the information which collectively determines competitive equilibria there. In what follows we first explain the procedures in conceptual terms; second, we describe its theoretical underpinnings and argue its merits; third, we remark upon operational and other details that make the procedure practical.

Each airline comes to the initial round of the slot exchange auction with its desired schedules in hand and some appreciation for the total expenditure (the "value") it is prepared to make to realize a flight or cycle. Each airline is requested to prepare sealed bids for the slots that it requires. This means that for each hour at each congested airport--at each what we will call "trading post"--it prepares bids for those slots it desires. Assuming, as we did earlier, 4 congested airports each permitting scheduled operations in 16 hourly periods, there are 64 trading posts which make up the slot exchange. These first bids are made "in the dark," just as is the case in the "one-time" auction. The airlines should bid any prices for slots realizing a flight whose totals do not surpass the value it attaches to the flight. One can imagine that an airline makes its bids at the 42 trading posts by filing prices on forms, one page containing the trading posts of each congested airport, as in Figure 6.1. An airline wishing to make 6 bids at trading post Washington National 0700-0759, 3 at $150, 1 at $100, 1 at $50, and 1 at $0 would complete the corresponding line as in Figure 6.2. A bid of $0 expresses the desire to acquire a slot at $0; a blank expresses no additional demand. So, each airline expresses its individual demand for slots--the quantity it desires and the prices it is willing to pay--at each of the 42 trading posts. The individual demand curve of the airline of Figure 6.2 is given on the left of Figure 6.3. Accumulating the individual demands at each of the 42 trading posts then yields the aggregate demand of the carriers at each post. A typical aggregate demand curve is given on the right of Figure 6.3.

The slot exchange commissioner determines the aggregate demands at each trading post. Either--as on the left of Figure 6.4--the total demand is less than the quota of that trading post, or--as on the right of Figure 6.4--the total demand is at least as great as the quota. The dotted line in effect expresses the supply

WASHINGTON NATIONAL TRADING POSTS								
		SLOT NO.						
TRADING POST	PERIOD	1	2	3	4	5	...	15
W. NATL. 1	0600-0659							
W. NATL. 2	0700-0759							
.	.							
.	.							
.	.							
W. NATL. 16	2100-2159							

FIGURE 6.1 POSSIBLE FORM FOR AIRLINES' BIDS

		SLOT NO.						
TRADING POST	PERIOD	1	2	3	4	5	6	7
W. NATL.	0700-0759	150	150	150	100	50	0	

FIGURE 6.2 AIRLINES' BID AT ONE TRADING POST

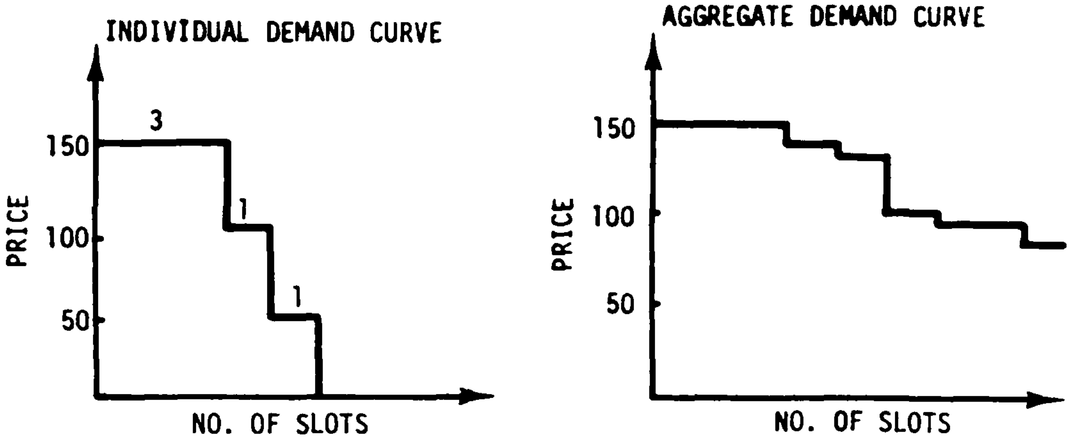

FIGURE 6.3 INDIVIDUAL AND AGGREGATE DEMAND AT ONE TRADING POST

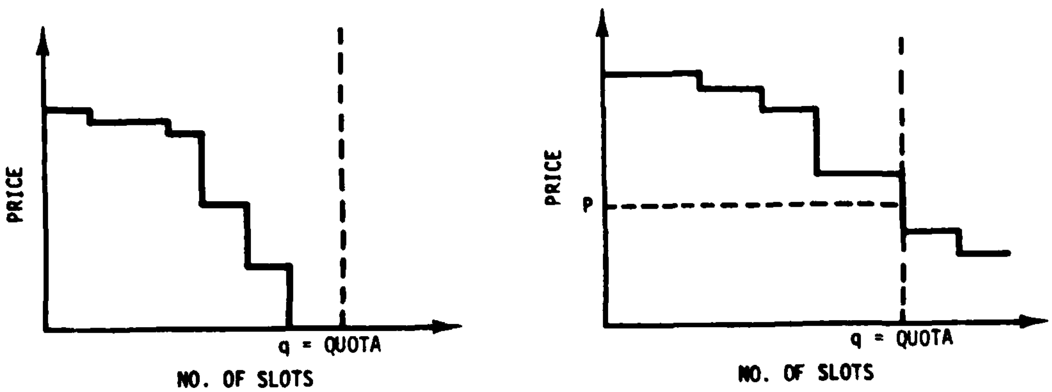

FIGURE 6.4 AGGREGATE DEMAND AT ONE TRADING POST AND PRICE FORMATION

curve, so the trading post price should be determined by where demand and supply intersect. In the case of excess supply (left Figure 6.4) the price should be \$0; in the case of excess demand (right Figure 6.4) the price should lie in the interval comprised between the price of the q^{th} highest bid and the $(q+1)^{st}$ highest bid. It may be that an aggregate demand curve is as in Figure 6.5, showing that there are several bids at the trading post price.

At this point the slot exchange commissioner reveals to all airlines the aggregate demand at each of the trading posts. Moreover, if these aggregate demands truly expressed the demands of the airlines then each of those airlines having made bids at or above the trading post price p (determined to make supply equal to demand) would receive slots for those bids, each of those having made bids lower than p would not. In the case of Figure 6.5, where more than one bid is made at the trading post price p but the quota is such that not all bids at that price or higher can be awarded, then some random allocation among those bidding p would

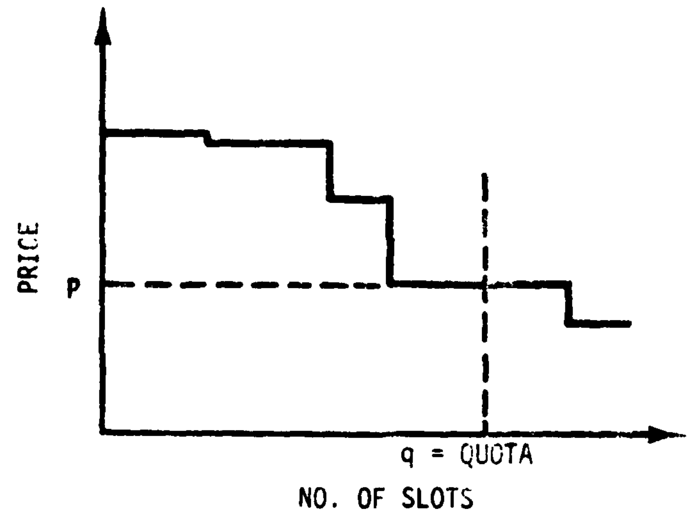

FIGURE 6.5 AGGREGATE DEMAND AT ONE TRADING POST: NEED FOR RANDOM ALLOCATION

be made. The commissioner would announce these conditional allocations and the trading post prices. Were this to be the final slot exchange auction, then each airline winning a slot at a trading post would pay \$p, the price at that post.

If the conditional allocations and trading post prices are agreeable to all airlines then an efficient, competitive equilibrium allocation has been found. Typically--and certainly after the first round of bidding--many airlines will be dissatisfied with the conditional solution. The results of the first round are precisely equivalent to what is produced by the "one-time" auction and so its defects are known.

This is why the commissioner announces conditional allocations and trading post prices, and the current expression of total demand at each trading post. The first round gives each bidder information concerning the demand pressures which exist at each trading post. On the basis of these, and of each airline's individual needs, each airline prepares new bids in a second round of the slot exchange auction. The commissioner accumulates the sealed, secret individual bids, and by the same procedure, announces new conditional allocations, trading prices and total demands. The process is iterated so that instead of a one-time auction there are repeated auctions. Each step increases the information available to the airline, each adds to the airlines' insight into the demand pressure over all trading posts. If, at any step, no airline announces the wish to change its bid, then the process terminates at an equilibrium solution. The temporal and network interdependencies are accounted for directly in the process of the simultaneously repeated auctions.

One of the paramount outcomes of the repeated auctions would be the trading post prices. These would reflect the marginal values of slots at each hour and each congested airport. Comparison between airports would reveal where the demand pressure is greatest, where measures to alleviate congestion are the most pressing. Demand for slots is, in fact, driven by the demand of passangers to fly to and from certain airports at certain times of day. Therefore, airlines should ultimately pass on the extra costs of purchasing slots to passengers, increasing the price of flights which land or take-off at congested hours. The trading post prices would both guide and provide the rationale for determining passenger ticket prices differentiated over time. Ultimately, the expression of passenger demand for flights using congested hours--as estimated by the airlines--will determine the bids of the airlines and so the final trading post prices. It may be quite true that today the airlines will be loathe to engage in this estimation exercise, for detailed information concerning the demand for peak-hour travel is not known; but, in the new era of deregulation, the airlines will have to require the necessary knowledge. The costs of slots will not, and should not, be borne by the airlines and taken from their profits: they must be absorbed by the traveling public which puts priority on peak-hour arrivals and departures.

A by-product of the trading post prices, were the same procedure used to allocate slots between commuters, would be an economic evaluation of the worth of an extra slot to commuters as versus carriers. For example, if the air carriers' slot price at same market were $500 and the commuters' were $100 this would indicate that the commuters were being subsidized through the setting of the respective systems. In this situation, economic efficiency would require far more slots for the carriers, fewer for the commuters.

In summary, the slot exchange auction is this: (1) Airlines prepare their bids privately and submit them sealed. (2) Airlines bid for as many slots as they wish at all trading posts simultaneously. (3) The slot exchange commissioner announces, after every round of bidding, the conditional allocations, trading post prices and total demands. (4) When the commissioner closes the slot exchange auction--when the conditional solution is announced to be the final solution--the airlines must accept the slots awarded them and the obligations of payment at the final trading post prices. (5) If more than one bid is made at the trading post price p and not all can be awarded without exceeding the quota, then the commissioner uses a random device to determine the winners among those bidding p. (6) The commissioner may, at any stage, declare a conditional solution to be final on the basis of a pre-established convention or stopping rule.

The outcome of the slot exchange auction is that each airline is endowed with the ownership of a collection of slot options. Typically, the auction procedure will not result in a perfect equilibrium: some airlines will wish to acquire several slots, some to dispose of several. And, as the six-month period of vested rights elapses, the desire to acquire more slots or to dispose of more, may develop. Therefore, a NASDAQ "open book" slot exchange (of precisely the same type as recommended in the Polinomics report) is maintained continuously until the expiration of the six month period. An airline is free at any time to express its willingness to offer slots for sale at stated prices or to bid to purchase slots at stated prices at each of the 42 trading posts. The global slot exchange is operated by the commissioner who announces every two weeks--to maintain the periodicity of schedule changes--the accumulated supply and demand curves of each trading post, the trading post prices determined by the intersection of supply and demand and the trades which take place. The bids are prepared in precisely the same form as the auctions, except that offers to sell are made in addition to offers to buy. The identities of the bidders are not revealed until the exchanges and prices are determined. Each trading post will have a total demand curve and total supply curve S which may be in any one of four essentially different qualitative forms pictured in Figure 6.6. In

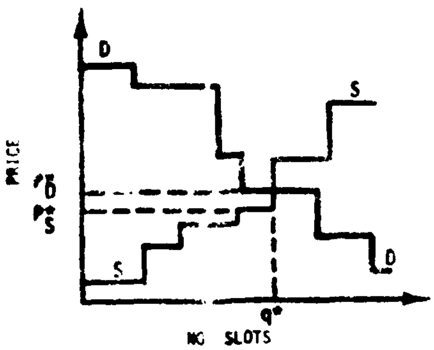

FIGURE 6.6(a)

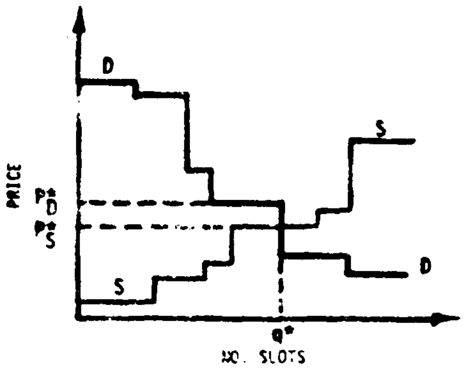

FIGURE 6.6(b)

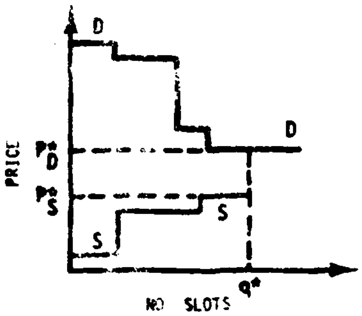

FIGURE 6.6(c)

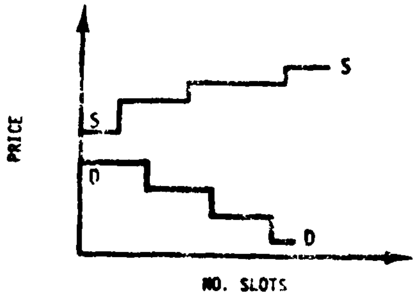

FIGURE 6.6(d)

FIGURE 6.6 FOUR QUALITATIVE FORMS

case (d) the offers to sell are all at prices above the offers to buy, so no exchanges take place. Otherwise, in cases (a), (b) and (c), q^* slots are bought and sold at some trading post price p* which lies between p_D^* and p_S^*, $p_S^* \leq p^* \leq p_D^*$ (e.g., half way between). In these cases all sellers who announce a price higher than p^* sell nothing. All buyers who quote a lower price buy nothing. If there is excess demand at p^* (case (a) with say $p^* = p_D^* = p_S^*$) or excess supply at p^* (case (b) with say $p^* = p_S^* = p_D^*$) then those who bid p^* are rationed by lottery.

It must be noted that the slot exchange auction and continuous slot exchange which operates afterwards, embody precisely the same economic mechanism: the law of supply and demand determines the equilibrium solutions in both cases with the price and number of slots accorded or exchanged determined simultaneously.

Thus, the same arguments sustain the relevance of both mechanisms. In fact, there is little controversy over the open-book NASDAQ type slot exchange: this is a well practiced form of market.

7. INITIAL TESTS OF THE SLOT EXCHANGE AUCTION

The experimental testing of the Slot Exchange Auction poses a number of difficult problems. Foremost among these is the need to have bidding which is related to airline network scheduling in a meaningful way. If the structure of slot interdependence, which we have repeatedly emphasized in this report, is not present in the experiment, the prices attached to slots will have no relationship to the airlines' valuation of slots. Since the real airline scheduling problem is immense and complex, there is a need for a simplified structure in the experiment. The Airline Management Game (AMG), developed and tested by Antonio Elias of M.I.T. and Flight Transportation Associates, is a vehicle for providing a simplified structure of the air transportation network. It is a combination "game" and computer simulation in which the "players" make realistic airline management decisions. These decisions are fed into a computer along with CAB air traffic data, airline operations cost parameters, and air transportation block times and distances. The computer simulation allocates the passenger demand among the competing air carrier services offered by the competing "players," which in practice are teams rather than individuals. It also prints profit and loss, balance sheets, OAG-type schedules, and network and operating statistics for the game. The "players" have a chance to read the computer output, evaluate their performance in the competitive transportation scenario and revise their decisions. After some number of iterations, the results can be regarded as final.

Two experimental tests were conducted using the Airline Management Game, one in December 1979 at the Flight Transportation Laboratory of M.I.T., the second at FAA headquarters in Washington in February 1980. An air transportation scenario for simulating airline decisions was created by FTA.

There were five airlines competing in this network: Blue (BL), Gold (GL), Green (GR), Red (RD) and White (WT). Each of these airlines had, during the past, a traditional pattern of service, which is reflected in the given initial schedule. Under deregulation they were free to serve any market, subject to the limitations of their available equipment. For purposes of this exercise, fares for all airlines were limited to a simple tariff of $23.40 plus 10 cents per nautical mile (8.68 cents per statute mile).

The participants' fleets included three types of aircraft: DC9, 727 and 707. The technical and economic characteristics of each of these aircraft are summarized in Volume II. The composition of each participant's fleet was fixed as follows:

Blue: ten 727s and six 707s

Gold: eight 727s and six DC9s

Green: nine 727s and six DC9s

Red: four 727s and three DC9s

White: six DC9s.

A system route map (Figure 7.1) and an initial marketing plan was provided to the participants before the game commenced. The players were told to maximize short-term profits subject to hourly quotas at three of the 17 airports of the scenario. They were given a wide range of choice for marketing strategies within the limitations of their fixed fleets.

At the first test, which was conducted by ECON and FTA, the results were only of technical interest, on account of the game development requirements. The second test enjoyed the participation of several airlines as players on the five

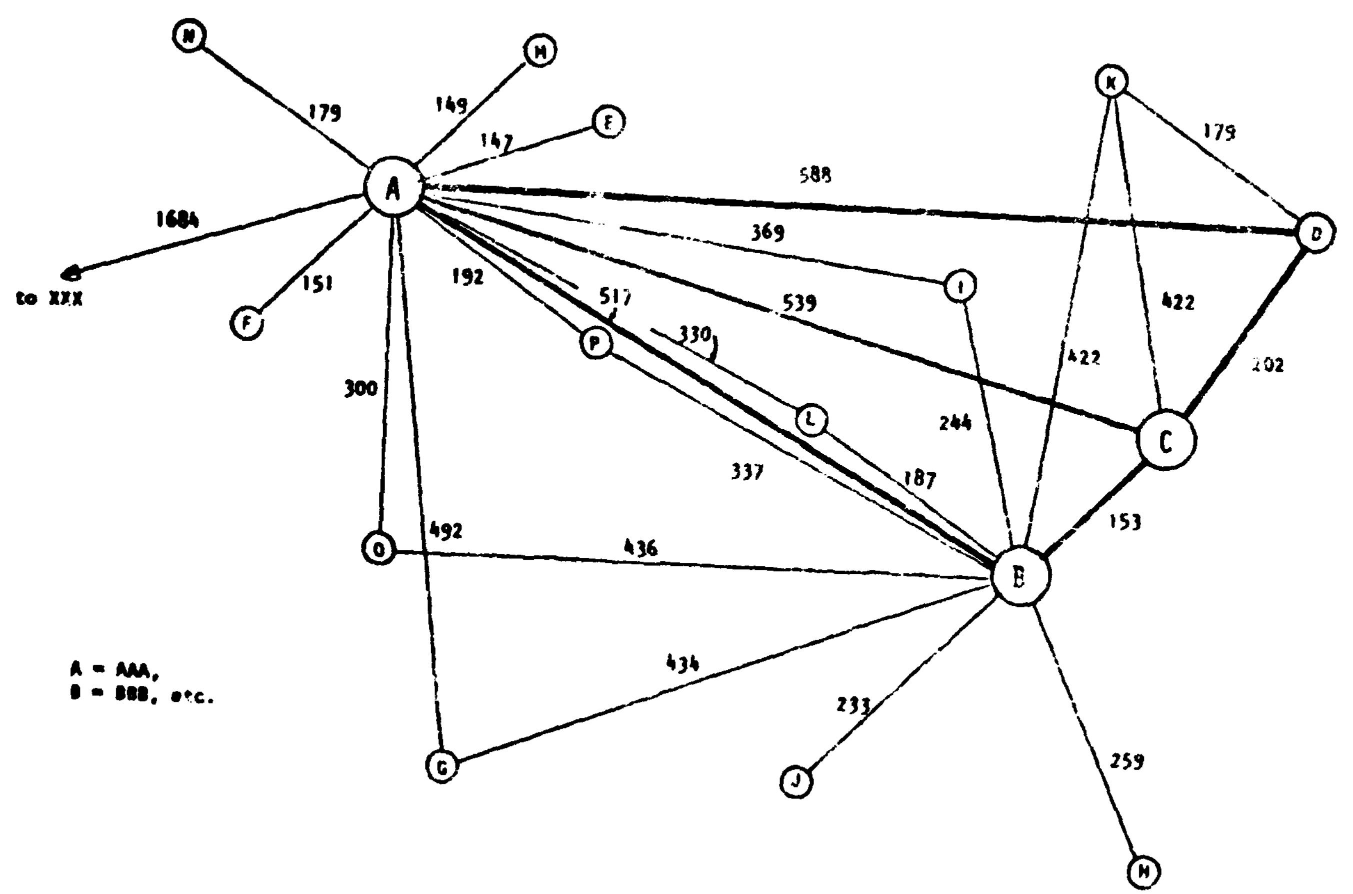

FIGURE 7.1 SYSTEM ROUTE MAP (DISTANCES IN NAUTICAL MILES)

teams. While time limitations curtailed the testing of several key features of the Slot Exchange Auction interesting results were obtained. Three rounds of bidding in a Slot Exchange Auction were held for two separate simulated periods of six months each. The prices and slot allocations were more stable in the second than in the first period, indicating learning of the part of the players. Price convergence was not obtained within the three rounds of bidding--more would have been required.

There was remarkable convergence in slot awards. Figures 7.2 and 7.3 show it. Figure 7.2A plots, by each airline and each trading post, the number of slots awarded in round 1 (horizontal axis) as against the number awarded in round 2 (vertical axis) in Auction 1; Figure 7.2B, the number of slots awarded in round 2 as against round 3 in Auction 1. Perfect convergence in the awards would yield the 45 degree line. It almost does. Figures 7.3A and 7.3B give the corresponding data for Auction 2. The convergence is even better. Comparing figures 7.2A and 7.3A shows the extent to which "learning" in Auction 1 has influenced the behavior of the participants and so the outcomes in Auction 2. These strong positive findings may be termpered by the fact that the participants must have realized that (due to time constraints) the third rounds of bidding would be the last; however, in a real slot exchange auction there would have to be a final round as well.

The results of the Washington test, which are detailed in Volume II, are summarized in Tables 7.1 through 7.3. In spite of high slot payments, all five airline teams were profitable with the exception of the Blue team in Period 1. Surprisingly, the airline "industry" (all five teams) did slightly better after paying $7,303,000 for slots in Period 2 than they had done with no slot payments in the Base Period. This effect is attributed to the increasing degree of optimization of

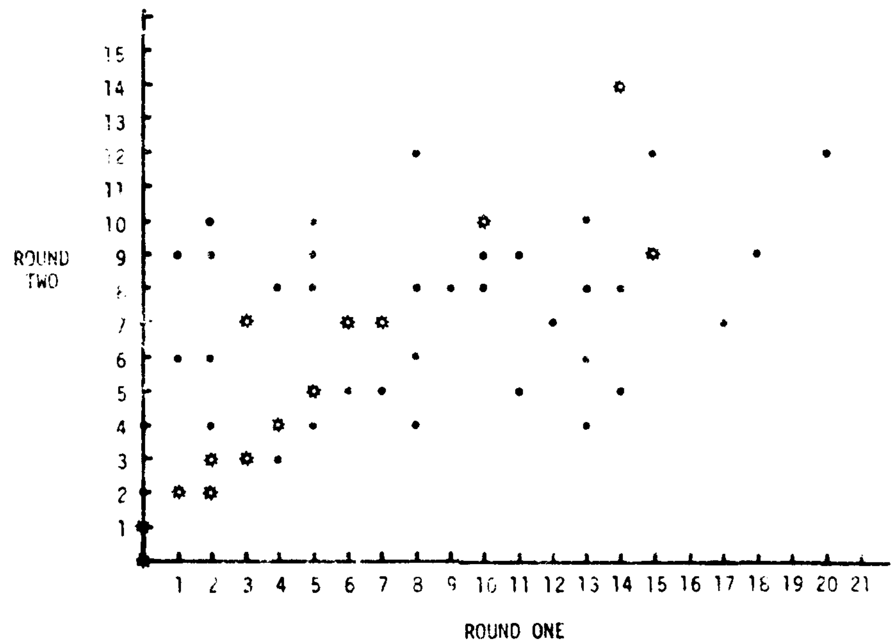

FIGURE 7.2A COMPOSITION OF AIRLINES TOTAL AWARD BY HOUR
ROUND ONE VS. ROUND TWO AUCTION ONE

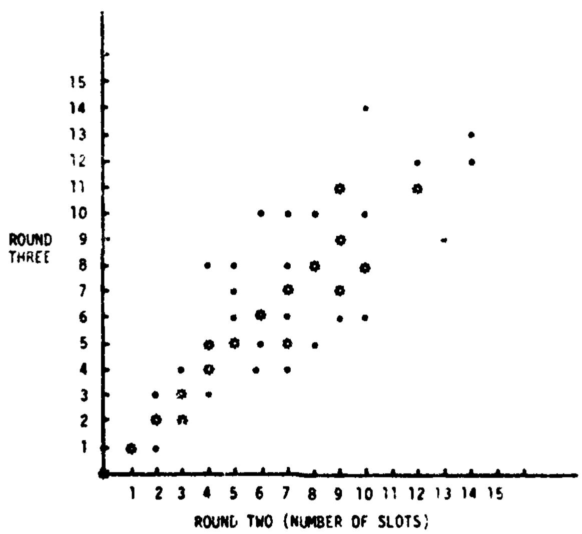

FIGURE 7.2B COMPOSITION OF AIRLINES TOTAL AWARD BY HOUR
ROUND TWO VS. ROUND THREE AUCTION ONE

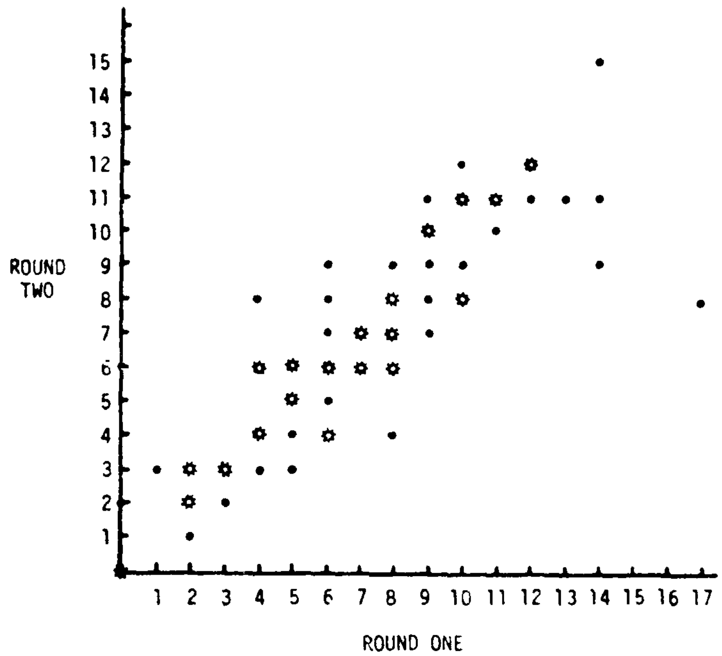

FIGURE 7.3A COMPOSITION OF AIRLINES TOTAL AWARDS BY HOUR
ROUND ONE VS. ROUND TWO AUCTION TWO

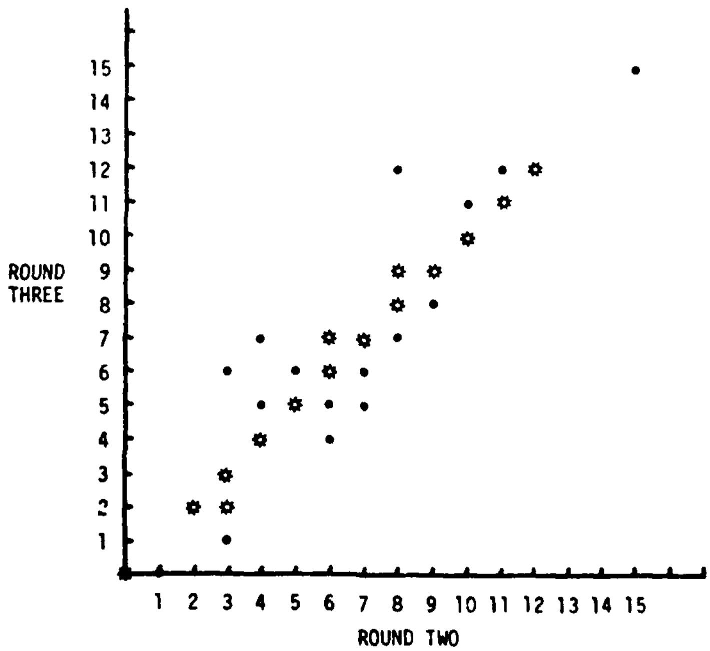

FIGURE 7.3B COMPOSITION OF AIRLINES TOTAL AWARDS BY HOUR
ROUND TWO VS. ROUND THREE AUCTION TWO

AIRLINE	BASE*	PERIOD 1	PERIOD 2
BLUE	-0.22	-2.11	3.00
GOLD	3.8[illegible]	10.[illegible]	[illegible]
GREEN	3.8[illegible]	7.25	7.66
RED	1.11	2.48	3.17
WHITE	4.02	9.07	8.2[illegible]
ALL	12.57	26.84	29.26

TABLE 7.1 NET EARNINGS BEFORE TAXES OR SLOT PAYMENTS (IN MILLIONS OF DOLLARS PER HALF-YEAR SEASON)

*THERE WERE NO SLOT RESTRICTIONS IN THIS INITIAL ITERATION.

TABLE 7.2 POTENTIAL SLOT PAYMENTS AFTER EACH BIDDING ROUND (MILLIONS OF DOLLARS PER HALF-YEAR)

AIRLINE	PERIOD AND ROUND 1.1	1.2	1.3	2.1	2.2	2.3
BLUE	[illegible].843	3.574	5.971	0.921	0.641	1.773
GOLD	0.158	2.079	3.047	0.843	0.959	2.410
GREEN	1.823	2.135	3.617	0.395	0.725	2.034
RED	0.034	0.889	1.019	0.371	0.318	0.185
WHITE	0.703	1.372	2.104	0.436	0.397	0.886
ALL	4.561	10.049	15.758	2.966	3.040	7.303

TABLE 7.3 NET EARNINGS AFTER SLOT PAYMENTS, AFTER [illegible] (MILLIONS OF DOLLARS PER HALF-YEAR)

AIRLINE	BASE	PERIOD 1	PERIOD 2
BLUE	-0.220	-7.967	1.349
GOLD	3.817	3.098	3.254
GREEN	3.845	1.634	[illegible].445
RED	1.109	0.485	1.[illegible]26
WHITE	4.018	3.182	3.691
ALL	12.569	0.432	13.165

market strategies and schedules during the test, since the scenario was not changed from one period to the next.

A continuous slot exchange was available after each auction and some slots were traded but overall the level of activity was not very large. The slot exchange, while a necessary adjunct to the Slot Exchange Auction in implementation, did not seem to serve a vital role in the simulation.

A notable feature of the results was the decline in air service to small communities. Table 7.4 indicates this for six minor airports in the scenario; in the case of OOO and PPP, service was discontinued altogether.

In summary, the test provided confidence that the Slot Exchange Auction is a workable idea and that the competition for slots at quota airports will not destroy industry profits. The following points can be made regarding the analysis of the test results:

- The bidding would probably converge quite rapidly, but requires more than three rounds. A stopping rule for the Slot Exchange Auction is required to avoid excessively long auctions. This rule must be chosen carefully to preserve the fairness of the market mechanism.

- Slot prices appear to be quite high at peak hours at the quota airports. This raises an important question: What will be the disposition of the slot revenues? Clearly, the acceptability of the Slot Exchange Auction to the air transportation community hinges on the answer to this question.

- While we cannot find indications that the Slot Exchange Auction favored either large or small airlines, the smaller ones amongst the five simulated airlines (Red and White) seemed to fare better in the evaluation than did the larger ones (Blue and Green).

- On the basis of the test evaluation, service to small communities might suffer unless such service were to be subsidized or exempted from slot payments.

TABLE 7.4 SMALL COMMUNITIES AVERAGE ENPLANEMENTS/DAY				
PERIOD / AIRPORT	BASE	1	2	AA
KKK	500.2	469.6	470.2	536.2
LLL	255.2	78.8	96.8	98.2
MMM	231.8	69.8	219.9	219.8
NNN	273.8	156.7	279.8	278.4
OOO	94.5	--	--	--
PPP	172.6	--	--	--
TOTAL	1528.1	774.9	1066.7	1132.6
REL. CHANGE COMPARED WITH BASE		-49.3%	-30.2%	-25.9%

8. FURTHER TESTING AND IMPLEMENTATION

This approach is new. There is no mathematical guarantee that the tâtonnement process will converge. The circumstantial evidence is very positive, but not completely convincing. The 42 interdependent trading posts of today may well become 142 trading posts tomorrow. Can the airlines cope with this complexity? What are the effects of this complex dependency on the convergence behavior of the repeated slot exchange auction?

These are difficult questions which demand careful study and meticulous experimentation.

When should the auctioning process be stopped? It seems highly unlikely that the procedure will of itself reach a point where no party wishes to change a bid--the sheer dimension of the number of trading posts would seem to admit the wish of at least one airline to change its bid at at least one trading post. A sine qua non is that the conditional outcome of any round of auction be a potential final outcome: this to ensure that each airline reveal its true demands (to the extent it knows them). The threat must exist that, at any time, the hammer may fall.

8.1 Further Testing

The initial tests did not allow enough time for "convergence" of the Slot Exchange Auction to be adequately explored. Recent experiments by Vernon Smith[19] and his colleagues have shown that auctions with repeated bidding converge extremely fast to an equilibrium, but all these experiments have involved much simpler objects than the Slot Exchange. We believe that the competitive equilibrium can be attained in the Slot Exchange Auction in a reasonable number of bidding rounds. It is likely that a stopping rule will be required to prevent prices from "cycling."

In further testing, the experimental controls should be tightened. The comparison between the results of the base period and the two subsequent periods with slot auctions was largely invalidated by the significant learning that was in evidence on the part of the players. This could have been avoided by conducting parallel experiments using different players, one group having quotas, the other no quotas. To complete the design, we would have both groups play both cases, taking care that they did not communicate with each other during the experiment.

Before the financial results are taken as conclusive it would be wise to conduct further testing with different scenarios to discover the extent to which the test results depend on the system network, fleets, number of competing airlines, etc. Additional tests with constraints on each airline's access to capital, interest charges and so on would also be desirable. Further testing should consider fare flexibility; the ability of airlines to pass on slot payment costs to passengers is likely to have significant economic impacts, even if time-of-day pricing is avoided.

8.2 Some Thoughts on Implementation

The convergence and economic efficiency of the Slot Exchange Auction can be satisfactorily established by further testing if this is done with adequate resources and controls. Before it can be implemented, however, there is another problem to be solved: the distribution of the slot revenues. This problem is both politically and economically sensitive, since the amount of slot revenues, even at one quota airport, could be quite substantial. It is not the purpose of this report to solve this problem, but some comments on the alternatives to the Slot Exchange Auction are in order.

A recurrently expressed concern is that any allocation mechanism be "fair" towards "small" as versus "large" carriers. What is meant by "fair" is never made precise. It seems there exists the feeling that the small carriers could not stand up to the big in bidding, for lack of capital funds. This has no bearing on the auctions if the slots that are acquired are paid for during the period of their use and not at the time of auctions. We recommend monthly payments over the months that the slot options are held. In this way only economic efficiency should determine the prices that are charged in the slot exchange auction.

The FAA Administrative Allocation[20] method has been tested recently in the same exercise used for testing the Slot Exchange Auction. This alternative has one significant deficiency: it is not economically efficient. The difficulty becomes more serious in the face of dynamic change in air service over a number of seasons. Air carriers enter new markets, expand service in existing profitable markets or contract service in less profitable markets. How is the Administrative Allocation to encompass change? It seems to offer an inadequate mechanism for allocating slots so as to allow for air service expansion and contraction because it is too slow in response to change. On the other hand, the Slot Exchange Auction is definitely efficient, since it is an open market, and so far as we know also fair, with the already noted exception of the problem of service to small communities.

Are there fair and efficient alternatives for slot allocation which do not involve the transfer of money? The Slot Exchange might be conducted without money if the air carriers were instead given points for slot entitlement--like casino chips--for the purpose of acquiring slots in an auction. The idea is for some form of Administrative Allocation (such as that proposed by the FAA) to be applied to determine each air carrier's total number of slot entitlement points, without specifying the time distributions of the slots. Then, a modified Slot Exchange Auction would be conducted using these points as fixed bidding budgets; air carriers would be free to allocate their points across hours of the day and different quota airports in any way they chose. The modified slot auction with point bidding would be analagous to an ordinary auction in which each bidder had a fixed money budget which he intended to exhaust but could not exceed. This idea neatly solves the problem of avoiding the transfer of funds, but raises serious difficulties regarding economic efficiency.

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