78-5

MIT

THE DEVELOPMENT OF AN OPERATIONAL GAME FOR THE U.S. DOMESTIC AIRLINE INDUSTRY

Antonio L. Elias

DEPARTMENT
OF
AERONAUTICS
&
ASTRONAUTICS

FLIGHT TRANSPORTATION
LABORATORY
Cambridge, Mass. 02139

February 1979
FTL Report R78-5

THE DEVELOPMENT OF AN OPERATIONAL GAME FOR THE U.S. DOMESTIC AIRLINE INDUSTRY

Antonio L. Elias

FTL Report R78-5
February 1979

Flight Transportation Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

Page 3 is a blank. Nothing has been omitted.

TABLE OF CONTENTS

FIGURES AND TABLES

FIGURE

TABLE

CHAPTER I

INTRODUCTION AND OVERVIEW

This chapter presents the motivation, goals and scope of this work, and an overview of the development and current use of games.

1.1 MOTIVATION OF WORK

The use of computer simulations to analyze large complex systems is now a well-established technique. By combining detailed numerical models of each component of the system, the behavior of the entire system can be simulated, observed, and analyzed; some examples of systems that have been successfully designed and analyzed by means of computer simulations are communications networks, the Microwave Landing Systems (MLS) that competed for the ICAO standard, and many aircraft and spacecraft, such as Apollo and the Space Transportation System ("Space Shuttle").

Attempts to simulate systems that involve human decision-making (pricipally economic and economy-related systems) have not been so successful. The difficulty in modeling an individual's decision-making process: leads to the impossibility of fully modeling such systems, short of including a human element in the simulation itself. This is precisely the essence of the gaming approach to system simulation* a number of "players" (properly called "game participants") drive, with their decisions, numerical models of the other components of the system under consideration.

This effort is motivated by the author's belief that research on domestic air transportation may benefit from the use of such a game for the following reasons:

a) There is a significant number of mathematical models developed or in development about elements of its operations, which have not been integrated.

b) The industry is reaching a turning point, namely deregulation, which increases the relative importance of the human decision-making element over a wider range of options.

---

* Traditional microeconomic demand-supply equilibrium models, such as the Cournot solution, do not model the producer decision-making process; they simply postulate a certain behavior, and model the mathematical consequences of that behavior.

The effort undertaken in past years to develop and refine mathematical models for the airline industry, was made possible in part by the wealth of numerical data available. In their unique position between private industry and the public utilities, the airlines have been forced to keep and make public a staggering amount of data. The high technology environment that permeates the industry has enhanced both the quantity and quality of this data gathering effort, and the uses of this data for model-building (and analytical) purposes.

These models are highly interrelated, but in general are used individually by making simple assumptions about other elements of the system. Thus, sophisticated demand models assume simple statistical supply functions, supply models assume non-competitive environments, etc. A computer simulation, such as the one required for this game, seems to be the ideal way of integrating many of these models in a coherent fashion, while the gaming dimension acts as a surrogate for the unmodelable human decision-making component.

One of the consequences of the current trend towards deregulation in the air transportation industry is an increase in the freedom and range of management decisions. This in turn increases the relative importance of the human decision-making element in the total environmental uncertainty in which the industry must operate. The difficulty in modeling the individual decision-making process indicates a gaming approach to systems analysis.

1.2 GOAL AND SCOPE OF THIS WORK

With the above motivation in mind, we define the goal of the present effort as follows:

> To design, build, and test a computer game for U.S. domestic passenger air carriers, based primarily on existing mathematical models of its operations and economics. This game must offer a sufficient degree of quantitative accuracy to analyze effects of managerial and regulatory decisions on an air transportation system. As a secondary goal, the game should also be usable as a training device in the teaching of subjects on air transportation.

We also impose the following limitations:

1.- New models are not built, unless found absolutely indispensable for the simulation's accuracy or completeness. In this context, and in the rest of this work, the word "model" shall be used to denote mathematical models of the various functions that make up the game's environment simulation (e.g. the demand model, the cost of money model).

2.- Similarly, the numerical data (parameters) that the models may require, are not developed. Maximum use is made of existing data, and deficiencies in the data available are pointed out but not corrected.

3.- Only test and demonstration cases are run. The application of the game to the analysis of real-world problems or situations is left as future work to be done.

1.3 APPROACH USED

A computerized game is actually made up of two components:

a) A set of rules and data that define the "game scenario".

b) The computer model of the system under consideration.

The purpose of the game scenario is threefold:

a) To define and limit the decision-making freedom of the participants (e.g. degree of price competition, route structures, etc.)

b) To define the environmental assumptions under which a particular game is run (e.g. types of aircraft, market demand parameters, etc.)

c) To model aspects of the environment for which there are no convenient mathematical models suitable for computer coding (e.g. when and to whom government subsidies are paid).

Throughout the work, the term "environment" or "game environment" will be used to denote the collection of data and processes external to the system but which affect the behavior of the system. In our case, the "system" is made up of a number of airlines, and the environment is made out of elements such as the latitudes and longitudes of airports (physical environment), the speed and fuel consumption of aircraft (technical environment) or the route freedom of the participants (regulatory environment).

The allocation of system and environment models to either the computer simulation or the game scenario is one of the important design decisions to be made. The computer simulation offers greater data-processing capability at the expense of flexibility (every possible case must be pre-programmed). The scenario rules offer greater flexibility, but must not require tedious calculations. In addition, only well-definable models can be mechanized as computer code, whereas the scenario rules may use subjective judgement ("umpiring").

This work has proceeded in the following fashion:

a) The functional structure of the game was defined.

b) The level of detail at which the game was to be implemented was determined.

c) Based on this level of detail, a selection of which components of airline operations to be included was made. These components were then allocated either to the computer simulation or to the scenario rules.

d) The mathematical models for the components of the computer simulation were defined.

e) The models were implemented (coded), along with the additional software required to mechanize the game.

f) The integrated game was tested with simple cases to test the validity of the code.

The next Section reviews the history and development of games, in particular computer games. For readers not familiar with the peculiarities of the airline industry, Appendix A describes briefly the principal aspects of air transportation economics that influence this work. Chapter II describes the game design process, the tradeoffs involved, and the design decisions made (steps a and b, above). Chapter III explains in detail the mathematical models used in the computer simulation. Chapter IV includes a description of the software implementation of the game, a detailed, annotated example illustrating the functioning of the mathematical models used, and a sample of actual use of the game for teaching and analysis purposes. Chapter V discusses a number of extensions and improvements that have been identified during the game's development, as well as some suggestions for possible applications of the game. Chapter VI summarizes the conclusions and recommendations for future work. Appendices B and C contain a detailed development of the demand vs. time-of-day function and the load factor tail-off function respectively. Appendix D contains a full description of the data bases used, along with the conversational commands available to interactively access, modify or update these data bases.

1.4 ORIGIN AND DEVELOPMENT OF SIMULATION GAMES

Games, that is, physical or mental competitions between two or more participants carried out according to a set of rules, are probably as old as mankind; a bas-relief in the palace of Ramses II (1292-1225 B.C.) in Thebes shows the King playing a board game with pieces that bear an astonishing resemblance with those of modern chess. Most intellectual games (as opposed to most physical games, or "sports") mimic more or less accurately a real-world situation; when they do, they are called "simulation" games.

Traditionally, simulation games have been directed towards the warfare-making activity of mankind; they ranged from table-top board games in which tokens idealize, both in shape and in function, various elements of an army to, at the other extreme, full-sized maneuvers in the field complete with mock battles. From the very beginning a tradeoff between cost and realism becomes evident: the more realistic the simulation, the more expensive it is to run ("play") the game.

The original purpose of these games seems invariably to have been that of providing the participants with vicarious experience in the decision-making process of the simulated situation. With the passing of time, the low-cost end of the spectrum evolved into less realistic (and less useful) but more enjoyable forms designed for pleasure, not training. Simultaneously, the high-fidelity end evolved into various forms of military gymnastics (the medieval jousts and tournaments, and the XVIIIth century army drills) with little or no decision-making contents.

It is only in the XVIIIth century, particularly in the central european army staffs and staff schools, that the value of games as decision-making training devices is formally recognized. Prussia's Baron von Reisswitz, and his son Johann, are generally credited by military historians with the development of the first modern war game, or Kriegspiel, around 1811. This game, played on maps or sand-table models of a battleground, was made up of rules determining the outcome of engagements between different types of military units (fusiliers, cavalry, etc.). Its purpose was twofold: to provide officers with simulated field command experience, and to experiment with unconventional combat tactics. For the first time, the game environment is analyzed rationally for the purpose of developing detailed and realistic models, including effect of terrain and weather, casualties inflicted, etc. Again, the realism-cost tradeoff is in evidence: umpires were usually needed to evaluate the results, both in order to reduce the burden on the participants and because some of the models used involved some form of subjective judgement.

Up to this stage in the historical development of gaming, simulation of the real environment is performed by a set of manually-evaluated rules or "models" describing the effects of the participants' actions on the simulated environment. The process of evaluating these rules is traditionally called "scoring". The advent of digital computers radically reduced the cost of scoring to an extent such that the degree of fidelity of the environment simulation is now the availability, applicability, and accuracy of the models themselves. The tradeoff between realism and the cost of gaming to the player still exists, because high model fidelity usually requires a larger number of decisions and more input data from the game players than lower-fidelity games.

The emergence, towards the end of World War II, of the mathematical discipline called "Operations Research" gave impetus to the search of rational, analytical, decision making processes. It was soon found, however, that only a limited number of decision-making situations were solvable by pure analytical techniques. Ellis A. Johnson, head of the Naval Ordnance Laboratory (NOL) Operations Research group approached the problem of selecting mining patterns by playing games between minelaying and minesweeping teams. The mining strategies thus developed actually improved the effectiveness of mining operations agains Japan.

In early 1950, George Gamow, at John Hopkins University Operations Research Office (ORO) developed "TIN SOLDIER", which is recognized as the first game designed specifically as a mathematical model for use in analytical research (Reference 1). The use of stochastic processes in that game lead to the introduction of a computer for scoring via Monte-Carlo techniques (an IBM 650 was expressely installed at ORO to run the game), and by 1952, ORO had the first full-scale computer-scored game. By 1962, it was estimated that 57 organizations in the U.S., 2 in England, and one in Canada, used games for one purpose or another. Of these, 5 were primarily oriented towards training, 16 towards the evaluation of military operations at different levels, and 47 devoted to research and development.

In 1956, an American Management Association (AMA) team, with the cooperation of IBM, was set up to develop a management game following closely the military models. A well-publicized demonstration was set up at the New York headquarters of the Association, with twenty corporation presidents participating in it. Reactions to it ranged from outright enthusiasm to severe skepticism (Reference 2). After this initial attempt, business interest in games dwindled, partly as a consequence of the reaction to the cultural disruption caused by the introduction of computers in general, partly because of the lack of the required analytical and mathematical modeling expertise in the industries themselves.

The academic community, however, soon grasped the potential that such games could have as training tools. In addition, they had the expertise in modeling the various components of the business environment that computer experts lacked. The result was a veritable boom of "Management Games" designed as low-cost, high-realism class exercises for management students. From the first UCLA game, with only 8 decision variables, we now find games with more than 300 possible decision inputs, and practically every management school in the country has at least one game implemented in its computer system (Reference 3).

Some authors define "operational games" as those games where the environment modeling is accurate and realistic enough to allow evaluation of operational decisions, whereas the term "management games" is reserved to games designed with educational objectives in mind. Using this terminology, most military games are operational games. Academic, or management games proper, are usually classified as general purpose games ("general games"), and specific games.

General games are games whose input (decision) variables cover a wide range of managerial disciplines (production, finances, marketing, etc). The main purpose of these games is to show to the student the interrelationships between these various aspects of management (Reference 4).

On the other hand, games can be "specific" in one of two ways, which are sometimes found simultaneously:

- Discipline-specific: one aspect of the management skills spectrum is emphasized (marketing, finance), while the others are eliminated or de-emphasized. Such games are usually designed for use in advanced courses in that subject (Reference 5).

- Industry-specific: the idiosyncrasies of a particular industry (e.g. the Oil industry) are emphasized (Reference 6).

As it turns out, most industry-specific games are also discipline-specific.

In the field of air transportation, there are three gaming efforts known to the author. The first, by Air Canada (Reference 3) models a two-airline, four-market scenario. The decision variables (inputs) include the number of flights (but not their schedule), the aircraft's seating arrangement split (first class/economy class), financial (two alternatives), maintenance procedures, and passenger service, advertising and market research expenditures. The game is designed for training airline personnel, and specifically to show the interrelationships among the various departments of the airline.

The second, at the University of Tennessee College of Business Administration, is non-interactive (a participant's actions do not affect the othr participant's results), and contains some probabilistic elements. As listed in the available literature, this game's decision variables include routes, aircraft type and configuration, arrival times (sic), advertising policy for each city, and market information to be purchased. The training purpose is to "improve the decision-making process, reactions, goal selection, and implementation" (Reference 3).

The third, by H. B. Tyber at McDonnell Douglas (Reference 8) simulates a multi-carrier (up to five participants) airline system at the senior management level. Decision variables are: total number of flights in each one of four regions (e.g. "the North Atlantic"), crew wage levels, short-term borrowing level, and the inevitable advertising and market research expenditures. Certain number of "frills" (e.g. the relative effect of on-board movies vs. that of free drinks) are added in for realism. This game was designed for use in a corporate Market Development Course to "provide airline employees with a review of all the aspects of airline planning on a systems-wide basis".

All three games described are typical business-school marketing-oriented games mechanized in the framework of the air transportation industry. These games, and in particular the level of detail and quantitative accuracy of their environment models, were designed solely for training purposes, and are not suitable for analysis, research, or "operational" uses.

CHAPTER II

GAME DESIGN

This chapter analyzes the overall game design, the allocation of elements of the game to either the computer simulation or the scenario rules, and the different levels of detail at which the environment can be simulated. The decisions made, and the rationale behind these decisions are described.

2.1 OVERALL GAME STRUCTURE

In the most general terms, a game functions in the manner shown schematically in Figure 1. There are N participants ("players"), each representing a competing operational unit (in our case, air carriers). Each participant produces a set of "decision variables". These variables, plus whatever scenario data is applicable, constitute the input to a simulation of a real-world situation, in our case, the operations of domestic air carriers. The output of the simulation is data which can be grouped according to its purpose:

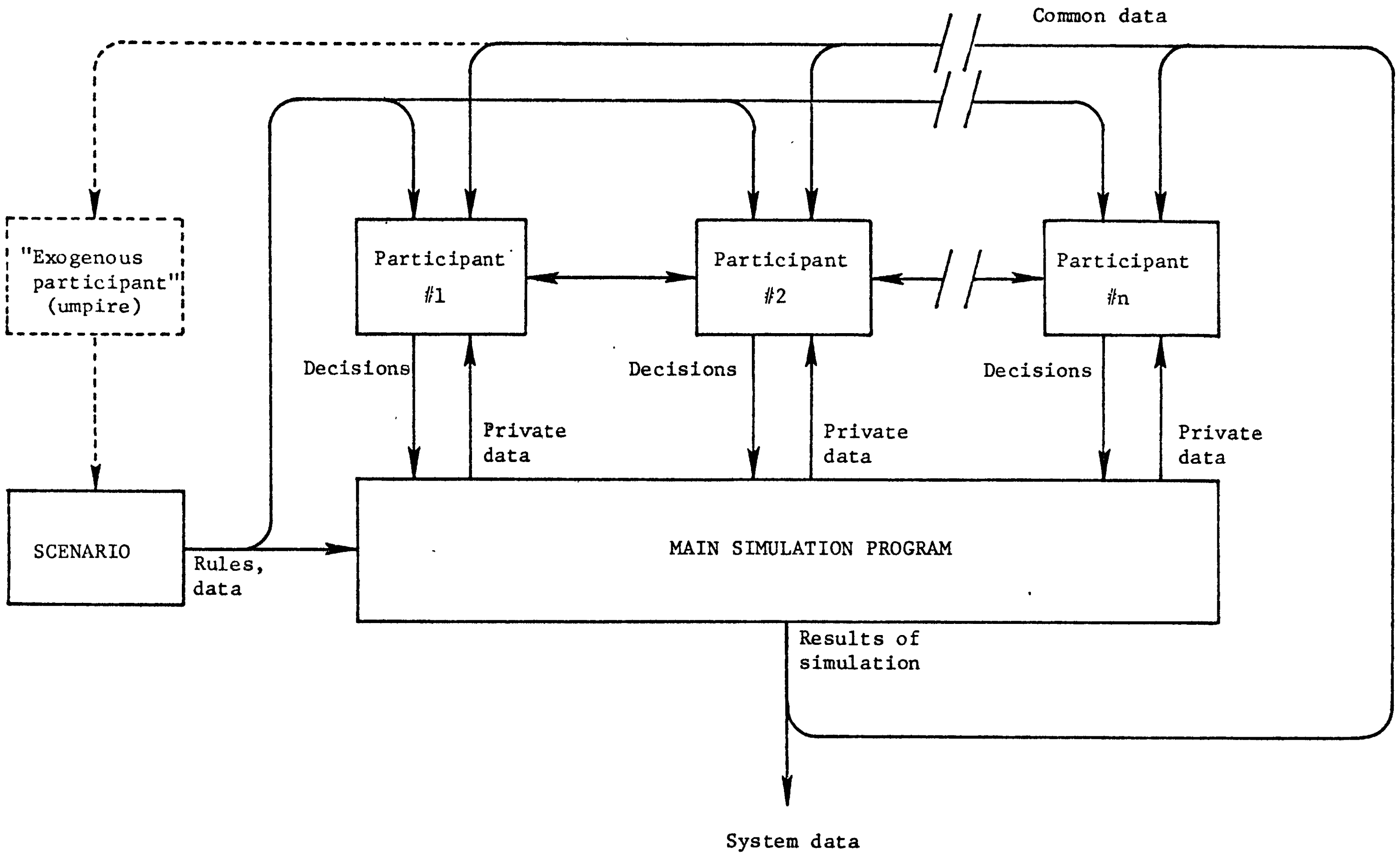


Figure 1.- Generalized game structure

a) Data of interest to the game user for the purpose for which the game is performed. We call this "System Analysis" data.

b) Data which is made available to all participants ("Common" data).

c) Data which is made available to each participant on an individual basis ("Private" data).

The game is carried out as a sequence of plays, or "iterations". Each iteration corresponds to the simulation of a certain amount of real time, such as a month, a quarter, or a year. Thus, the participant's decisions are fixed during that simulated time, and the simulated results represent the average results over that same period of time. Participants are allowed to change their inputs (and examine the data made available to them) between iterations. Data available to the participants include the above-mentioned "Common" and "Private" data, scenario data, and, if allowed by the scenario rules, communications between participants.

The scenario, which includes both rules and all the models and data not internal to the computer simulation, may be static or change from iteration to iteration ("dynamic scenario"). In particular, the scenario changes may be keyed to the results of the simulation via some feedback data. If human decision-making is part of this feedback, then we have in effect an (N+1)th player (the "exogenous participant"), or an umpire.

Of particular interest is the start-up (first iteration) problem, since the only data available to the participants is the scenario data. There are several ways in which the game may be initiated. Two possibilities are:

a) The scenario may depict a real-world startup situation (e.g. the creation of a new carrier operating in a new market).

b) The scenario data may include simulated past-operations Common and Private data.

Figure 2 shows, in schematic form, a model for an air carrier, in terms of the flow of processes and data that link operational results to the management decisions. The central process in this flow is the determination of total demand and the allocation of this demand among competing carriers (and

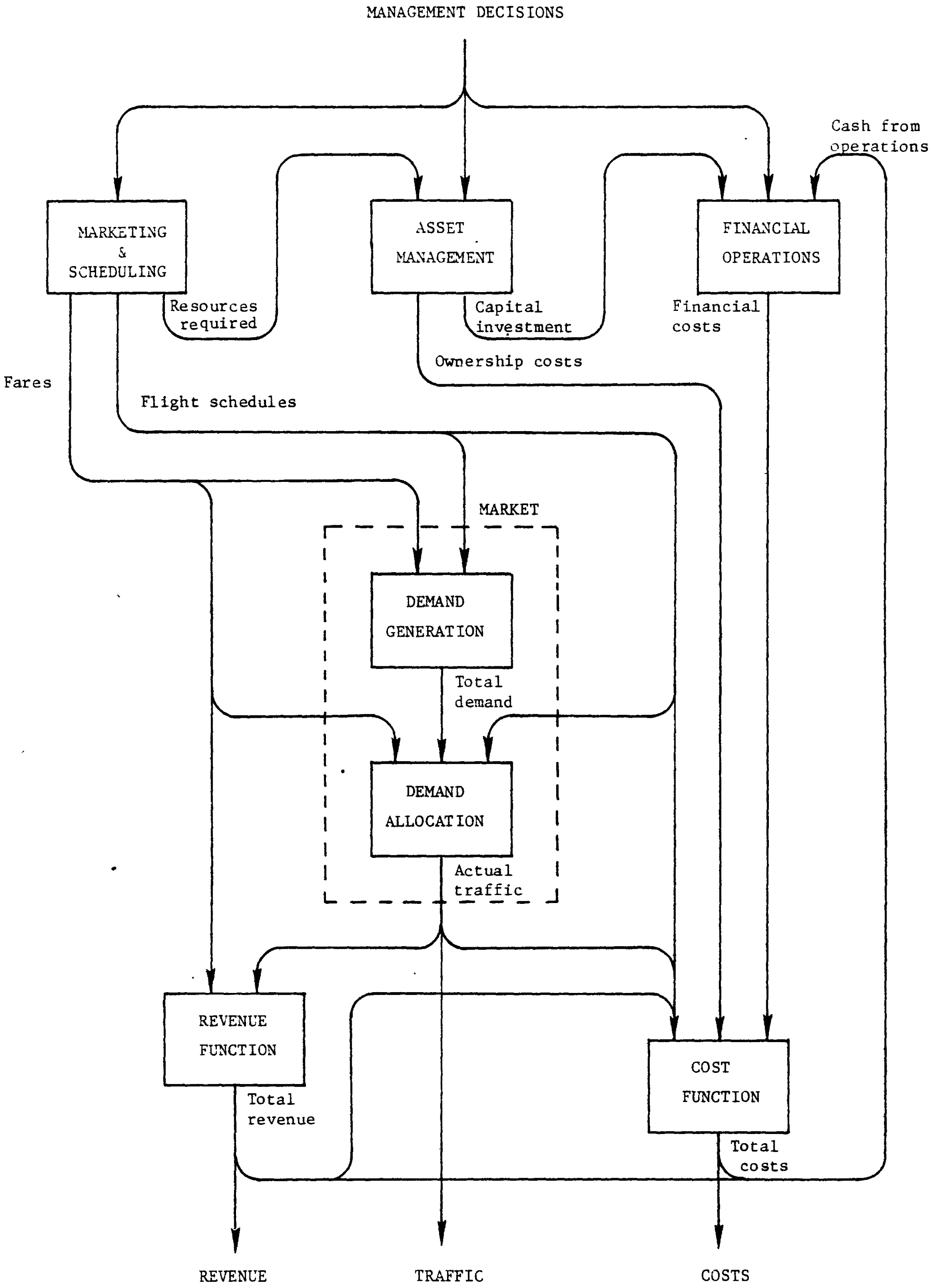


Figure 2.- Air carrier operations functional flow model.

among a carrier's different flights). Total demand and its allocation are influenced by management's decision of the level of service offered by the flight schedule the price of this service. The level of service (schedule) also determines the resources (aircraft, ground facilities, flight crews, etc.) required to provide these services.

The resources required then determine the cash flow required (investment). These financial requirements have a certain cost associated with them; costs are also associated with the maintenance and use of the resources, as well as other operational requirements of providing the level of service determined by the management. Costs combine then with the revenues (intenal and external) to yeld the carrier's net income. This net income (positive or negative) in turn affects the financial cash flow.

2.2 DESIGN DECISIONS AND TRADEOFFS

The three games described in Section 1.1 do not meet the level of detail and numerical accuracy required of an operational game for two reasons: first, they do not attempt to model in detail the actual operations of airlines; second, the range of operating conditions that they are capable of simulating is limited to the "usual" conditions that have prevailed in the industry during the past two decades.

Previous efforts at modeling in detail the operation of airlines (mostly directed towards operational analysis, not gaming) also have made use of this historical limited operational freedom. For example, the McDonnell-Douglas ASPEM (Airline Schedule Planning and Evaluation Model, References 9 and 10) and the Boeing SSFX (Reference 11) assume a fixed demand and a fixed market share (per market) irregardless of the simulated carrier's operations. This assumption may have been acceptable during the CAB-regulated market years, but is certainly not valid in a deregulated competitive scenario. The same observation applies to the traditional "Market Share=Frequency Share" model. In view of the limitations of these previous efforts, design of the game has to be started from scratch.

In order to design the structure of the game and its simulation, three basic decisions must be made:

a) The level of of detail (or aggregation) at which operations will be simulated

b) Which elements of operations to include in the game, and which to ignore or simplify.

c) Which elements to mechanize as computer code and which to be considered part of the scenario rules.

These decisions interrelate, e.g. whether to include a model for certain operational element depends on whether the level of aggregation used makes that element irrelevant, optional, or necessary for the rest of the simulation.

These decisions were also affected by limits on the resources available to the author for implementing of the game. Elements or models excluded or simplified for cost reasons are identified as such, and suggestions for their incorporation or improvement given the necessary resources, are included as recommendations for future work.

2.3 ALTERNATIVE LEVELS OF AGGREGATION

We can identify three broad levels of aggregation at which the game and its environment simulation can be implemented. These levels of aggregation are examined as they affect the modeling of demand, supply, market share allocation, and costs. We also identify the costs and benefits of each level of aggregation on these components.

2.3.1 System-wide aggregation

At this, the topmost level of aggregation, supply and demand are determined as aggregates over an entire market area, such as "the North Atlantic" or "the transcontinental markets". Supply is determined by the number of flights offered in that market, while demand is a function of the total supply, and perhaps an average fare level. Market share is determined from the flight share (a proxy for frequency share, since the average number of flight hours per flight is the same for all the carriers in the area), with perhaps some provision for differential area-wide fare levels.

The operating costs, at this level of aggregation, are usually assumed to be proportional to the number of flights, based on average costs, with perhaps some provision for economies (or diseconomies) of scale. With this crude structure, the efficiency of each carrier in the use of resources cannot be determined from the participant's decision variables, and must be set externally (e.g. the same for all participants). In other words, costs are determined solely by the aggregate level of service offered.

The advantage of this level of aggregation is the simplicity of the participant's decision variables required to model the carrier's management. Indeed, at this level, it would be feasible to construct a mathematical model for these decisions, thus eliminating the human element and converting the game into a numerically-solved, closed form analysis model.

System-wide aggregation has been used, and is very appropriate to management training games, where fidelity in modeling the operational aspects of the industry is secondary to the goal of offering the participants a subjective "feel" for what it is like to be the Chief Executive Officer of an airline. An example of this level of modeling is the McDonnell Douglas (Reference 8) game already mentioned.

2.3.2 Market-level disaggregation

At this level, each individual market (i.e. origin-destination demand area pairs) is modeled. This requires the modeling of individual flight itineraries if any network effects are to be observable. In addition, the user may assign individual aircraft types to individual routes. This in turn allows estimation of flight-dependent direct operating costs. Since the timetable of departures is not modeled, there is no way of determining either the exact number of aircraft required to fly the entire network, or the relative desirability of otherwise identical flights. Rough approximations to the number of aircraft needed can be obtained by dividing the total number of flight-hours implied by the itineraries by an average utilization. Since different aircraft types can be assigned to each itinerary, the fleet requirements and ownership costs can be evaluated by aircraft type.

Now it is possible to model both regulatory restrictions on routes, and the effect of differential fares. The number of decision variables that the user must now input is significant (flight itineraries, aircraft used on each itinerary, fares). Acquisition, sale, and lease of individual aircraft types can be modeled at this level, but with limited usefulness, since the exact number required cannot be determined.

The Air Canada and University of Tennessee games mentioned in the previous chapter are examples of this level of detail.

2.3.3 Schedule-level disaggregation

At this level, the schedule (time of day) of departure for each flight is also specified. This allows aircraft flow to be modeled, and hence the exact size of the fleet required can be determined. This in turns allows the use of a detailed model of aircraft acquisitions and transactions, including depreciation costs, tax rebates, etc. On the demand side, the time-of-day variation of demand (and flight preference) must be modeled. The added demand generated by connecting services can be included.

Direct and indirect operating costs are modeled in the same way as in the previous level; maintenance and crew costs must be averaged over the flight-hour.

The cost of this additional level of detail is, of course, the need for a full-fledged scheduling job on the part of the participant, at least until an acceptable computer model of the scheduling function of an airline can be designed.

These three levels of aggregation, also referred to as "Level I", "Level II", and "Level III", and their effect on some of the components of the system are summarized in Figure 3.

The highest level of aggregation, systemwide, was not deemed acceptable for the type of gaming that was sought. Although usable for training purposes, it does not model reality with any degree of precision required to perform any useful experimentation.

The next level, dissagregation by market, is detailed enough to perform some experimentation, e.g. differential fares, deregulation of routes, elimination of cross-subsidization, etc. It was originally thought to be the ideal level to start this simulation project, since it has a very simple user interface (flight itineraries and equipment only). However, it lacks the capability of accounting for the financial aspects of aircraft transactions.

Component	Level I	Level II	Level III
Operations	Regional total # of flights	Individual flight itineraries	Individual flight schedules
Demand	Global, over entire area	By individual region pairs	By region pair time of day.
Market share	Flight hours share	Frequency share, by market	Relative desirability of each flight
Direct Op. costs.	Estimated from total flight hours	Computed for each individual flight segment - crew and maintenance averaged by type	
Indirect Op. costs.	Estimated from total flight hours	Estimated from seat-miles, passenger-miles, number of enplanements, fleet size	
Fleet required	Estimated from total flight hours	Estimated from flight hours, by type	Computed exactly
Equipment transactions	Not applicable (1)	Estimated for each aircraft type	Exact by a/c type, time in service
Financial transactions	Not applicable (1)	Cash flow requirements only	Annualized accounting

(1) Cannot model the cash flow with sufficient accuracy.

Figure 3.- Possible levels of model aggregation and their effect on several system components.

Financial planning was the reason why the third level, disaggregation by schedules, was selected. Coupled with reasonable scenarios for cost of money and equipment, it allows experiments of a reasonably long time frame (several years), that is, strategic planning, to be carried out.

2.4 SELECTION AND LIMITATION OF COMPONENTS

Real-world air carrier operations have a large amount of variability: airlines carry passengers (in two, now sometimes three service classes), mail, cargo, charging wildly disparate fares, and sometimes generating revenue from non-flying operations, such as leasing out their equipment, or embarking in "peripheral" business, such as training other carrier's flight crews, providing catering services, or running hotel chains.

It is impractical to include in the game every possible operating and revenue-generating activity, cost element, etc. In addition, the structure and level of detail of the game inherently limit the level of detail of the game's components (e.g. the structure of the cost model). In this section, we discuss five elements of the game, namely demand, supply, the asset and financial management function, and the cost and revenue structures. The real-world components of each of these elements, its variability, and the limitations and simplifications that will be used in this game are discussed.

2.4.1 Components of Demand

There are several kinds of "goods" that may require air transportation: passengers, freight, mail. Under certain circumstances these demands do not compete for the available supply (e.g. belly cargo on a passenger flight). In most cases, however, there is a certain degree of interaction (e.g. payload tradeoff between cargo and passengers on a convertible aircraft, or network scheduling conflicts between freight and passenger service). More evident is the competition for services of different "grades" of the same type of demand, such as business passengers and pleasure passengers, which share the same supply of seats.

The simulation of multiple, simultaneous, interactive demands requires separate modeling (each with its own parameters) of each demand. In addition, separate supply parameters must be determined for each demand (e.g. fares, the number of first-class seats vs. number of coach seats or passenger-cargo tradeoffs for each aircraft, etc). This results in a large effort being required both to play the game and to prepare it (the number of market demand parameters and of decision variables is multiplied by the number of different demands that are simulated).

Admittedly, there are problems that can only be analyzed using multiple demand. However, within the scope of this effort, we can obtain useful results from the simulation of a single class of demand, such as a single class of passengers or a single class of freight. Section 5.1 discusses how the game can be extended to the case of multiple interacting demands.

Even for a single class of demand, we still must determine what endogenous and/or external variables will affect this demand. In the real world, total demand changes with time: time of day, day of the week, season of the year. Since we are going to restrict flights to daily frequency, there is no benefit from modeling the day of the week dependence of demand. On the other hand, we will be modeling flight departure and arrival times, so that the time-of-day variation of demand must be modeled. Seasonal variations affect the results if the period simulated per game iteration (iteration period) is of the order of the seasonal variation (around three months). Seasonal variation of demand can thus be modeled by simply changing market demand parameters from one game iteration to the next.

Since one of the objectives of this game is to allow simulation of de-regulated, competitive scenarios, we must include the effect of price on total demand, as well as the effects of competitive services and prices on the allocation of total demand.

2.4.2 Components of Supply

At the level of detail selected, each game participant must specify each flight in his network. The word "flight" is sometimes used to denote two different concepts:

a) The movement of an aircraft through a series of airports ("flight itinerary") carrying fly-through passengers (e.g. "Flight 365" is a flight from BOS to NYC to DCA).

b) The air transportation service offered between two cities (e.g. "Flight 365 between BOS and NYC", "Flight 365 between BOS and DCA" and "Flight 365 between NYC and DCA" for the same BOS-NYC-DCA flight).

In this work we will reserve the word "flight" to signify the first meaning, i.e. "Flight 365". We will use the terms "service" or "service offering" to signify meaning b) above. Thus an N-segment flight (in our meaning) will produce (N+1)N/2 service offerings. Conversely, a service offering may require more than one flight (a connection). Service offerings (not "flights") may be non-stop, n-stop, or connecting. Thus, the Official Airline Guide (OAG) is properly a listing of service offerings, rather than of flights.

Flight itineraries and schedules change, in the real world, in two different periods:

a) The regular, published, day to day variations, such as a flight not offered on Sundays, or a weekly itinerary alteration.

b) The monthly (or discrete) readjustment of the schedule for marketing reasons (e.g. seasonality), which is reflected in a new edition of the OAG.

In order to model weekly schedules, each day of the week must be simulated and processed separately for each game iteration. The simple expedient of multiplying each flight's demand by its relative frequency (e.g. 2/7 for a twice-weekly flight) does not produce valid results at the level of detail that we are using. To illustrate this, consider a market with one daily flight and two twice-a-week flights. All other flight parameters being equal, the simple frequency weighting mentioned above would distribute 63.6% (7/11) of the demand to the daily flight, and 18.2% (2/11) to each of the twice-weekly flights. In reality, this proportion depends on whether the days of the twice-weekly flights coincide or not.

If indeed they do, we have two days of the week with three flights, and five days with a flight each. We would thus expect that the daily flight would get 5/7 of the demand for the five days in which it is the only flight, plus 2/21 for the two days during which it has to share the demand with two other flights, for a total of 80.9% of the market. The two twice-weekly flights would get only 2/21 (9.5%) of the market each.

Thus, in order to simulate the effects of weekly variation of supply, we must simulate each day of the week separately (maybe with varying demand, as mentioned in the previous Subsection), including input data with each flight to allow determination of the exact schedule for each day of the week. We have decided that the complexity of input data and increase in computation time is not cost effective for domestic airlines*.

The second, monthly or seasonal variability, is taken care of, and is limited in frequency by, the simulated length of each game play or iteration. This length is left variable, and is determined by the parameter NDP (Number of Days per Period). Thus, depending on the objectives of the particular game run, weekly, monthly, quarterly or yearly variations can be introduced. We have elected to ignore non-scheduled operations (e.g. individual charters). The extension of an iterative game such as this to include non-repetitive events such as a charter flight is a major challenge.

The process of converting flight itineraries and schedules into a list of service offerings such as the OAG requires two steps:

a) Conversion of multiple-segment flights into a list of individual direct-service offerings.

---

* This may be required for the simulation of long-haul international operations, where weekly rather than daily schedules are the rule.

b) Linking of direct-service offerings into connecting-service offerings.

There is a one-to-one correspondence between single-segment flights and their corresponding direct non-stop service offerings, but multi-segment flights may generate direct service entries in the offerings lists of many airport pairs. Manual conversion from one form to the other would impose an enormous burden to the game users. We thus find it mandatory to have the computer perform this function.

It would also be highly desirable to have the computer perform automatic connection generation. There are several algorithms published that will perform this function (e.g. Reference 10)* . Again, economic limitations have prevented the implementation of an automatic connection generator, and participants are requested to identify all connecting service offerings they wish to supply. Computer code has been provided, however, to aid the user in determining the physical validity of such connections (e.g. sufficient connecting time at the connecting airport).

---

*The problem of how to generalize the allocation of revenue in an interline connection remains to be solved.

Thus, the participant specifies an input list of flight itineraries with scheduled departure times and, in an interactive conversational mode with the computer, gets a listing of direct services by market, from which a list of connecting services can be constructed with computer assistance.

2.4.3 Components of Asset and Financial Management

"Management" of assets and cash involves the determination of the assets (and cash) required to supply the services represented by the participant's schedule, and the determination of the transactions required to secure such assets and cash.

The only non-cash assets that will be modeled explicitly are aircraft. All other resources necessary to run an airline (e.g. ground facilities, reservation system computers, etc.) will not be explicitly modeled. Its costs will have to be aggregated to other measures of activity that somehow reflect the use of these resources, such as number of passengers enplaned or total number of aircraft block-hours (see "components of cost", below).

The minimum flight equipment needs are automaticaly computed from the participant-specified flight schedule. This minimum can then be compared with the equipment available to the participant as a result of his equipment transactions. However, what action to take in case they don't match is left as part of the individual game's scenario rules (e.g. force an automatic lease of the required aircraft). Also, the scenario may require a fixed percentage of spare aircraft of each type.

The number and variety of forms that asset acquisition and disposition may take (e.g. sales, purchases and leases for aircraft, bonds, stocks, notes, for cash) makes it quite impractical to attempt to build a complete computer model that would cover all, or even most, of the real-world possibilities. Modeling of these transactions requires two different types of data processing:

a) The data processing associated with the determination of certain parameters of the transaction, such as the interest at which a participant can borrow money in the short-term or the current selling price of a used aircraft.

b) The accounting of the cash flow consequences of the transactions actually carried out by the game participants.

The amount of data processing required for the first purpose is moderate, and can be carried out manually (e.g. as a table of interest rates vs. the firm's Debt/Equity ratio). The accounting process, however, can be tedious, and since the computer simulation is performing the total accounting for each participant, we have decided to include the cash flow resulting from all transactions in the computer simulaton. This split requires that some data be exchanged between the game scenario rules and the simulation, as shown in the diagram of Figure 1. Chapter IV describes how this communication is mechanized (via the so-called "simulation file").

A restriction curently placed on the financial transactions is that they do not have periodic repayments of principal (e.g. mortgages). This is due to the structure of the communications data between the game scenario and the simulation. This restriction should be removed in subsequent game improvements.

2.4.4 Components of Revenue

In the strict financial accounting sense, all revenue produced by a company under normal circumstances is considered "operating revenue" irregardless of its source. We will, however, use this term to denote the revenue originated by the fare charged to each passenger (or ton of freight) actually carried. Non-operating revenues then include government subsidies (which may in fact depend on the services supplied), the results of resource management (e.g. sale of assets) and the results of other activities, such as crew training or non-flying business.

Without demeaning the importance that income from these peripheral activities may have in real-world air carriers, we find them outside the scope of our interest, (air transportation), and thus will not consider them in the game. Government subsidies will be considered as part of an individual game's scenario as required, since its modeling does not require extensive data processing, and since the great variety of forms they may take defies its being programmed as computer code.

As in the case of financial transactions, the details of specific asset transactions will be modeled by scenario parameters (e.g. market prices of aircraft and short-term interest rate) although its cash flow effect, as with subsidies, will be taken into consideration by the computerized participant financial accounting process.

There is still the basic revenue from fares; in the real world, the fare structure is quite complicated, and, under the current deregulatory trend, is becoming more and more so. Since we are not currently modeling multiple classes of demand (e.g. business vs. pleasure travellers), there is no possibility of including multiple fares based on the class of service (e.g. first, coach) in the game. On the other hand, it would be easy to extend the fare structure based on the time of day of the flight and the type of equipment used. However, we have opted not to include it in this game mechanization, again due to resource limitations. It is our claim that useful results may be obtained even with single fares ("average yield") for each city-pair, as long as each participant may select its own yields*.

---

* The average yield per passenger on a city pair is defined as the total revenue divided by the number of passengers, thus averaging over all types of tariffs (day, night, excursion, APEX, etc.)

2.4.5 Components of Cost

In our generalized model of air carrier operations (Figure 2), we can identify three sources of costs: asset management costs, financial costs, and operational costs.

Asset management costs include the cost of acquiring, keeping, and disposing of non-cash assets, limited in our case to flight equipment. Some examples of this cost are the depreciation of owned flight equipment, the lease payments for leased equipment, and aircraft insurance. This cost may be "negative", such as when an owned aircraft is leased out. Note that the expenditure required to buy an aircraft is not a cost.

Financial costs include the cost of acquiring the cash needed to balance the firm's cash flow requirements. Again, this cost can be negative (as when the interest from the investment of excess cash exceeds the interest of the outstanding debt).

Operations cost is simply "everything else". In our scheme, we make it a function of the schedule, the total traffic, and the total revenue. Our cost structure is directly tied in to the measures of activity that are generated by the simulation: block hours (for each aircraft), departures, passengers carried, etc. This structure is described in detail in Section 3.6. Note that the traditional classification of costs as "direct" and "indirect", while of great analytical significance, is of little use for modeling purposes at this level of detail.

A further element of "cost" are the taxes levied on the participant airlines. The structure of real-world fiscal laws is so complex and ever-changing, that it is not realistic to attempt to model the exact taxation mechanism. We have decided to include in this game three components of taxes:

a) A simple corporate income tax rate.
b) A simple capital gains tax rate.
c) An accumulative credit due to the Investment Tax Credit (ITC), again made up of a simple rate.

The three rates can, of course, change during the game, as part of a dynamic scenario. A problem unique to this particular "cost" is that in the real world it is a function of the net income over a very specific span of time (the "fiscal year"). Unless the simulation period coincides exactly with the fiscal year, we must adopt one of two solutions:

a) Prorate the (annual) tax liability over each simulation period, based on the period's income.

b) Compute this expenditure only on those game iterations coinciding with the end of the fiscal year.

The first approach has the disadvantage of overestimating taxes (profitable and unprofitable periods cannot be averaged out during the year). The second approach complicates the structure and use of the game (more past history must be saved, the results depend on the position in the fiscal cycle of the period being simulated). We have selected the first solution: taxes are computed every game iteration as if the fiscal period was exactly one game period.

CHAPTER III

MODELS USED IN THE COMPUTER SIMULATION

This chapter describes the mathematical models used in the game's computer simulation. These models must perform the following functions during each iteration:

a) Transform the supply data from the participant's format to a format compatible with that of the demand function.

b) Determine total demand by market.

c) Allocate the demand and the revenue it produces among the participant airlines.

d) Determine a number of cash flow elements, such as total revenue, costs, etc. for each participant (accounting function) and collect and summarize system data (performance reporting function).

The software implementation of the computer simulation is overviewed in the next chapter.

3.1 SUPPLY DATA TRANSFORMATION

A most convenient format for the user to specify the supply function is a list of flight itineraries and schedules. In particular, for each flight, he must specify:

a) The type of aircraft used.
b) The itinerary.
c) The schedule of departure times (arrival times can be computed by the program).

The format required by a market-oriented ("Origin- Destination") demand function such as we are using is a list of air transportation services offered between each airport pair, as in the Official Airline Guide (OAG). This list must contain all the characteristics of the service that affect demand or demand allocation (e.g. departure and arrival times, number of stops, etc). The transformation of the supply data from the user format to the market format requires two steps:

a) The determination of block times for each flight segment.

b) The construction of the lists of service offerings for every market.

Segment block times are required to compute flight times (from which costs and equipment needs are computed), and arrival times (which affect schedule feasibility and the "desirability" of the flight). The block time of segment j of flight i is computed as:

$$TB_{i,j} = TS_d + \frac{D_{d,a}}{V_t\,(1 + k\vartheta)} + TS_a \qquad (3.1)$$

where:

$TB_{i,j}$	is the block time
TS_d, TS_a	are the ground and air maneuvering time at the departure and arrival airports, respectively
$D_{d,a}$	is the great-circle distance between the airports
V_t	is aircraft's average cruise speed
k	k is the average fractional reduction in cruising groundspeed due to the average west-to-east wind.
ϑ	is the cosine of the mean course between the two airports.

The reduction in the effective groundspeed due to the average westerly winds is modeled as a fixed percentage of the aircraft's airspeed (10% for k=0.1). This is a reasonable approximation, since slow-flying aircraft also fly at low altitudes, where the wind velocity is low, while fast aircraft fly at altitudes where the effect of the wind is more pronounced. This model must be improved if there is a mix of subsonic and supersonic aircraft, since it overestimates the effect of the wind on supersonic aircraft.

The ground and air maneuvering times are fixed for each airport, and are assumed independent of the type of aircraft used. This assumption is based on the fact that ground taxing speeds are approximately the same for all aircraft, and, in the air, approaches are usually executed on the basis of time, rather than distance, with slower aircraft flying smaller approach patterns. Also, the departure and arrival values are averaged, and a single value is currently used for either a departure or an arrival at a given airport.

Service offering lists for each airport pair contain two types of entries: direct services, and connecting services. Direct service entries are constructed by combining each departure airport in the flight's itinerary with each arrival airport. Thus, an itinerary ABC will generate three entries, one each in the service list of airport pairs AB, AC and BC. A check is made to see whether the departure airport and the arrival airport are the same, to avoid a flight ABA generating an entry AA. No check is currently made in the code against the multiple generation of the same entry (e.g. a flight ABCBA would generate two AB and two BA entries).

Connecting flight entries are not generated automatically, and must be entered by the participants. Each connection is made up of the origin airport, the destination airport, two flights and a connecting airport. Checks are made to ensure that:

a) The connecting airport is served by the first flight after it serves the origin airport.

b) The connecting airport is served by the second flight before it serves the destination airport.

c) The time between the first flight's arrival at the connecting airport and the second flight's departure from it is equal to or greater than a minimum connecting time established for that airport.

Each service list entry contains the departure and arrival times, number of stops, and the identity of the flight(s) involved. In addition, connecting entries include a number representing the fraction of revenue to be allocated to the first flight making up the connection. Currently this number is the ratio of the distance bewteen the origin and the connecting airport and the distance between the connecting airport and the destination airport. All distances used are great-circle distances.

Since Origin-Destination demand is oriented in a region-to-region fashion, we must allow for the fact that a region may have more than one airport. In our mechanization, we merge all the airports within the same region prior to constructing the service lists, so that these lists are indeed region-to-region, rather than airport-to-airport. This is equivalent to the assumption that all the airports within the region are equally desirable from a demand point of view. This may not always be the case, and Chapter V mentions a method of modeling differences in airport desirability within the same region.

3.2 TOTAL DEMAND MODEL

The determination of total demand for air transportation is so essential to almost every aspect of airline operations analysis, that considerable effort has been devoted to designing, calibrating, and verifying demand models. The current state-of-the-art in demand modeling for a city-pair market seems to be represented by the work of Eriksen, Taneja, and Scalea (References 12, 13 and 14). In Reference 12, Eriksen reviews the theoretical (utility theory) economics of air transportation demand, as well as the most recent work done. He then postulates a city-pair demand model which he then proceeds to calibrate and test statistically. We will use a simplified form of his model.

Eriksen's full demand model includes the effects of three parameters:

a) A Socio-Economic index of mutual economic activity between the two cities (actually, regions) that make up a market (e.g. population).

b) A standard fare. In a previous work (Reference 14), Eriksen, Scalea and Taneja had shown that the use of standard coach fare is statistically equivalent to the use of other, more sophisticated, weighted average fares.

c) A "level of service" index, a non-dimensional number that is a measure of the quality of the air transportation service offered in a market, on the basis of a very simple theory of utility of time vs. utility of air transportation (i.e. neglecting passenger aircraft preference, carrier image, on-board amenities and the like).

Fare and level of service are, in our game, endogenous variables. The Socio-Economic index would include all the variables which are external to our scope. Thus we include this parameter as game scenario data, along with the elasticities with respect to the other two parameters. The equation defining the total (unidirectional) demand for market m is:

$$D_m = D_{nom_m} \left(\frac{L_m}{L_{nom_m}} \right)^{e_{L_m}} \left(\frac{F_m}{F_{nom_m}} \right)^{e_{F_m}} \qquad (3.2)$$

where:

D_{nom_m} is the nominal demand for market m.

L_{nom_m}, F_{nom_m} are the nominal level of service and nominal fare that go with the nominal demand.

L_m, F_m are the actual level of service and average fare in the market simulated.

e_L, e_F are the level of service and fare elasticities of demand, respectively.

As an initial approximation, encouraged by the results in Reference 14, we use the simple algebraic mean of the fares offered as the average fare in the market. Future research in demand estimation may indicate the need for a more sophisticated "average" fare, e.g. weighting each carrier's fare by the level of service offered by that carrier.

The level of service index is a measure of how closely the service offered by all carriers in the market approximates a "perfect service" which has a minimum possible flight time (as produced by a non-stop jet service), and a zero waiting time (as would be produced by an extremely large number of departures per hour). The index is computed as:

$$L_m = \int_{t=0}^{t=24} D(t;DT) \frac{T_J}{\min\limits_{(\text{all } s)} (T_s + |t_{D_s} - t|)} dt \quad (3.3)$$

where:

$D(t;DT)$ is the fraction of total demand desiring a departure at time t.

T_J is the non-stop jet flight time.

T_s is service s's flight time.

t_{D_s} is service s's departure time.

DT is the sum of T_J plus the time zone difference between the market's origin and destination airports.

The quantity in the denominator is the lowest total trip time of all services offered in the market, for passengers whishing to depart at time t. This total trip time is made up of the actual flight time, plus the absolute magnitude of the wait time, sometimes called "displacement time". The ratio between the jet time (zero displacement time) and the best trip time available is the level of service index for passengers desiring to depart at time t. The average level of service index is simply the integral of this ratio over the entire day, each time weighted by the fraction of total demand desiring to depart at that time. In our mechanization, we divide the day into 48 half-hour "slices", and the integral is reduced to a simple summation.

In order to compute the level of service, we must know the function D(t;DT), the variation of demand with the time of day. As its notation implies, this function is also dependent on the difference between the local departure time and the local arrival time, DT. That is, the desirability of a departure at local time t is also a function of the correspoinding local arrival time. The local arrival time itself is a function of the flight time and the time zone differences, the sum of which is DT. Thus, a 7:00 P.M. departure from Los Angeles is very desirable in the case of an 8:00 P.M. arrival at San Francisco, but may not be that desirable in the case of a 3:00 A.M local arrival at Boston.

Again, we follow Eriksen's work in the determination of the time-of-day variability of demand. The derivation of this function is shown in Appendix B, along with some representative values for selected DT's.

3.3 DEMAND ALLOCATION

The demand allocation process is the key element in this game's environment simulation. Previous efforts in modeling this process do not seem to be satisfactory for our purposes. Boeing's SSFX program (SSF=Seats, Stops, Frequencies), described in Reference 11, allocates total demand in a market to each service offering proportionally to the factor:

$$W_i = S_a \; P_a \; F_i \; SF_i \tag{3.4}$$

where:

S_a is the seating capacity of the aircraft (type a) used in service i.

P_a is a passenger preference index for aircraft a.

F_i is service i's frequency.

SF_i is an index inversely proportional to the number of stops in service i.

The above model is rather limited from a passenger behavior point of view: a three-stop flight arriving at 6 P.M. may be more desirable than a non-stop flight that arrives at 3 A.M. Similarly, we contend that it is demand that causes carriers to use larger aircraft, and not the use of larger aircraft that causes demand.

McDonnell-Douglas' ASPEM (Airline Planning and Evaluation Model), as described in Reference 10, does try to take into consideration the effect of the flight's departure time. In this case, the demand is allocated proportionally to the factor:

$$W_i = S_a \; P_a \; F_i \; (T_i)^{-x} \; D_{TD_i} \qquad (3.5)$$

where:

S_a is the seating capacity of the aircraft (type a) used (as in the previous model)

P_a is a passenger preference index for aircraft type a (as above).

F_i is service i's frequency (as above).

T_i is service i's flight time.

x is a subjective exponent, ranging from 1 to 6.

D_{TD_i} is a factor measuring the effect of service i's departure time (TD).

This model represents an improvement over SSFX in that it recognizes trip time as a behavioral preference factor in the selection of a flight by a passenger. The use of a variable (and, as it seems, subjective) exponent points to a major difficulty in modeling passenger behavior: if two otherwise identical services differ, in their flight time, by a few minutes, why would anyone bother to take the slower one? The rate at which preference decays with flight time is controlled by the exponent x (for x infinity, nobody would take the slowest flight).

Neither model is sensitive to the influence of actual load on demand allocation, i.e. both allocate all the demand according to the initially-determined weights, and load factors above 100% are not uncommon results. The underlaying assumption is that the model users will then correct this state of affairs, drive the load factors down to around 50%, and the model will be valid again. It is therefore not surprising that both models match quite well "historical experience", even though many cases can be made up where these models produce quite unreasonable results. Since it is one of our requirements that out-of-the-ordinary conditions should be modeled reasonably, we cannot use this simple approach.

The departure time index used by ASPEM is an example of "indifference line" utility modeling. In this approach, a time-of-day variation of demand (such as D(t;DT) used in the previous Section) is assumed. Given N competitive departures throughout the day, ASPEM's index is simply the partition of that demand to each service based on the midpoints between the services' departure times. The pitfalls of this approach (and that of a slightly more sophisticated one where the midpoints are weighted by the demand function) can be illustrated with a simple example.

Assume that the day is divided into four time slices, with the demand distribution shown in Figure 4. Assume furthermore that there are three flights, one at time 2-dt, one at time 2+dt, and one at time 3 (dt being a very small time). Experience indicates that two flights departing very close to each other are perceived as identical services by passengers, and thus should receive approximately the same fraction of the

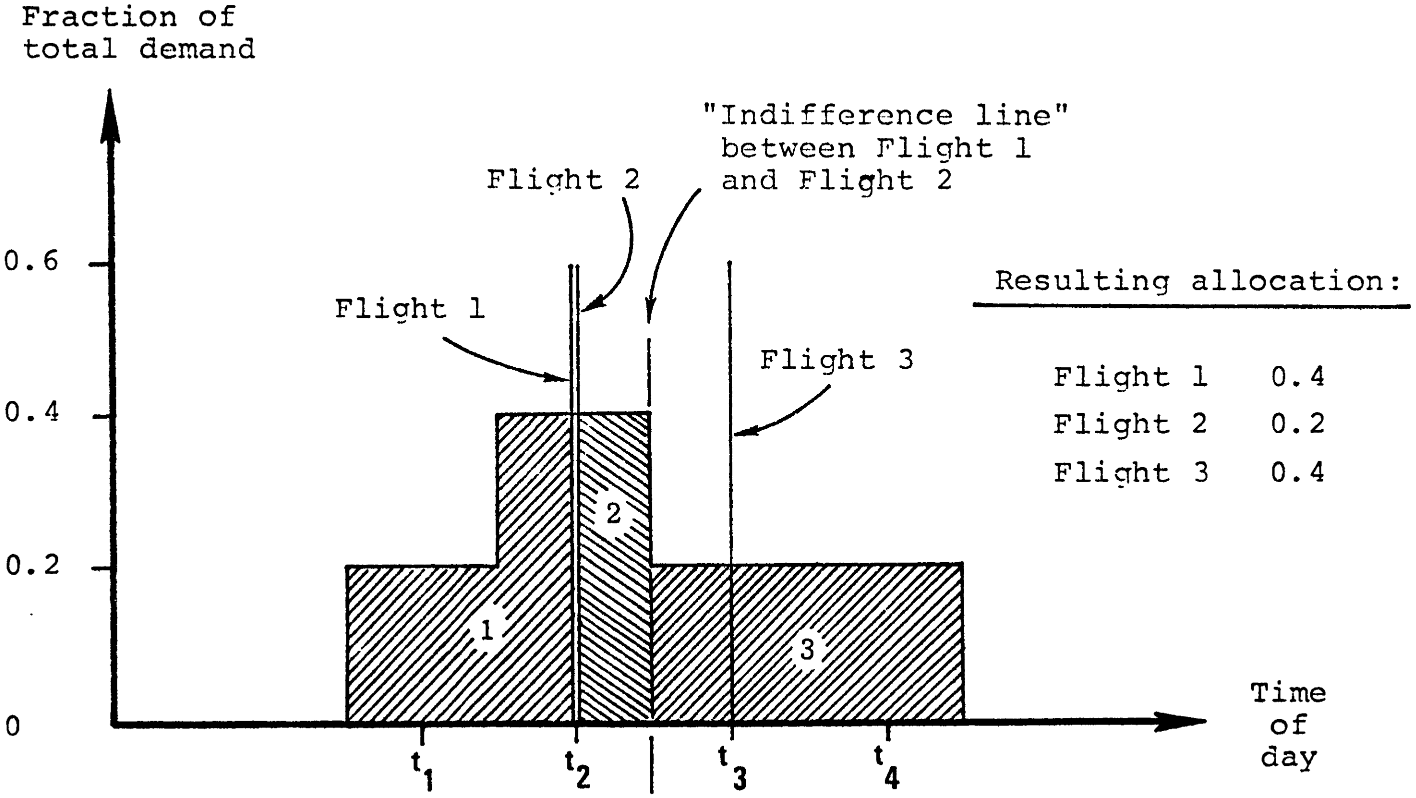


Figure 4.- Illustration of Indifference line demand allocation.

total demand each. ASPEM's algorithm, on the other hand, will divide the day into the intervals shown, allocating 40% of the demand to the first flight, 20% to the second, and 40% to the third.

This approach becomes even more unrealistic if the second flight's fare is lower than the first flight's (none of the above-mentioned programs considers price competition). In this case, it is very likely that some passengers will gladly wait 2dt in order to pay a lower fare (time-money substitution effect).

We recognize that there are two different mechanisms at work in the demand allocation process:

a) The basic ("behavioral") passenger preference for one flight, based on service attributes like trip time, departure time, fare, aircraft type, airline image, etc.

b) The "externally imposed" constraint of not finding space on the preferred flight, thus diverting some passengers to a "second preference" flight ("demand shedding").

It must be pointed out that demand shedding occurs before a 100% average load factor is reached. This is due to the day-to-day statistical variation in demand. Indeed, under certain assumptions, significant demand shedding may occur at average load factors as low as 50%.This will be treated in the next Section.

We therefore divide the load allocation process into two steps:

a) The determination of an initial ("behavioral") desirability for each competitive service offered in the market. This would be the fraction of demand allocated to that entry if supply exceeded demand by such an extent that no demand shedding occured.

b) The incremental allocation of demand, so that segment loads build up gradually, and demand is shed from highly-loaded service offerings to less-loaded service offerings.

3.4 BEHAVIORAL DESIRABILITY PARAMETER

This parameter is determined based on the passeger's utility of time vs. money. Other utilities (e.g. aircraft type, on-board amenities, airline image) are not considered. They may be included by converting them to "equivalent minutes" or "equivalent dollars".

The day is divided into N "slices" of 24/N hours each. For each slice, consider the fraction of the daily demand desiring air transportation during that time. This fraction is obtained from the same D(t;DT) function used to determine Level of Service. These passengers consider all possible services offered throughout the day. Each service has associated with it a total trip time (including the displacement time from the slice under consideration) and a certain price. A price-time substitution function is assumed, and a "behavioral desirability parameter" is computed for each service offering for the passengers of each time slice. The desirability of service i for the passengers from time of day slice t is:

$$D_{i,t} = \left(\frac{T_{min}}{T'_i}\right)^{x\,e_T} \exp\left(x\,e_F\,\frac{\bar{f}}{f_i}\right) \qquad (3.6)$$

where:

T_{min} is the lowest total trip time (flight plus displacement) among all service entries, from the center of the time slice considered.

T'_i is the total trip time of service entry i, corrected for a certain "deadband" (see below).

e_T, e_F are the trip time and fare elasticities.

$\bar{f}$ is the (simple algebraic) mean fare offered.

f_i is the fare associated with service i.

x is an empirical elasticity multiplier.

Once the parameters for all the offerings are computed for a single time-of-day slice, they are normalized (divided by their sum). The total desirability of the i-th service offering is the summation of this parameter over the entire day, weighted by the time-of-day demand function:

$$D_i = \sum_t \frac{D_{i,t} \; D(t;DT)}{\sum_i D_{i,t}} \tag{3.7}$$

The behavioral desirability formula compares the trip time of each service entry with the trip time of the "best" (i.e. lowest trip time) entry. Since each time of day slice has a finite width, we would arbitrarily favor entries whose departure times happen to be close to the slice's midpoints. This is the reason for the "deadband" in the entry's trip time: for all entries, we subtract one-half the width of the time slice, with the provision that no trip time can become smaller than the best trip time. This is expressed mathematically as:

$$T'_i = \min\,(T_{min}\,,\; T_i - 0.5\;(24/N)\;) \tag{3.8}$$

This tends to "crowd-in" flights close to the least displacement time flight, so that all flights within one-half time slice of the best flight are considered equal to the best one. Figure 5 shows, qualitatively, the variation of the behavioral desirability parameter with trip time (including

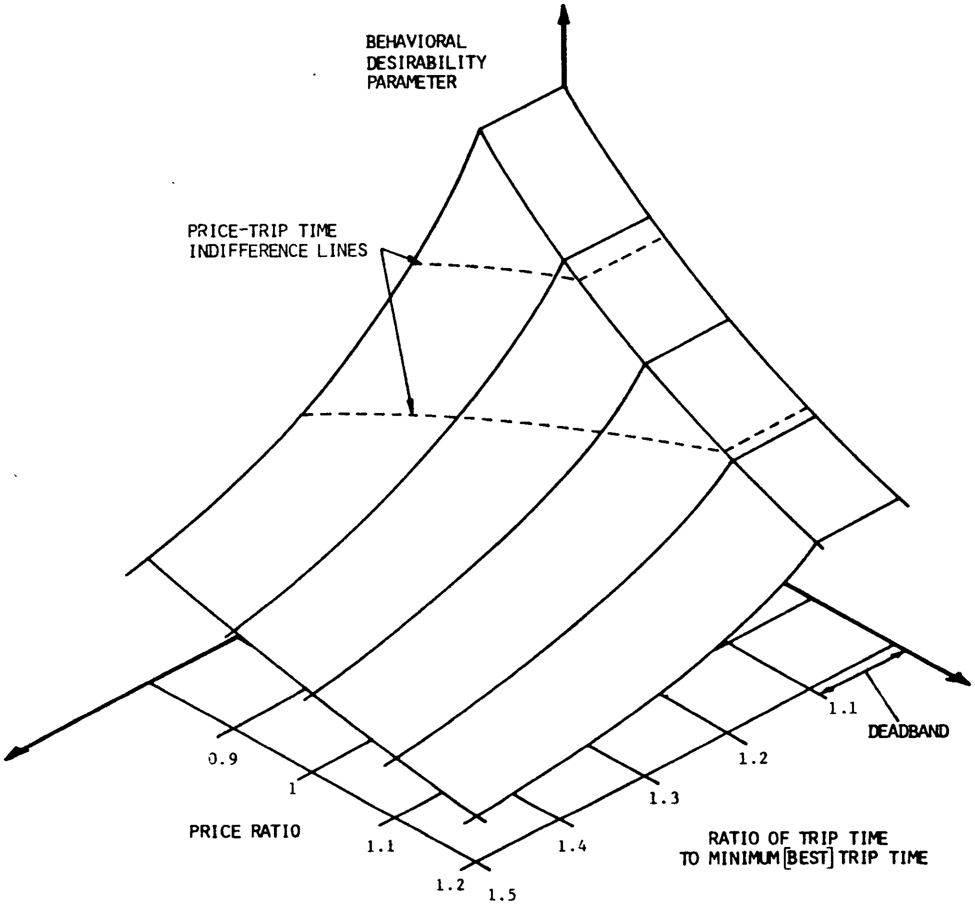


Figure 5.- Behavioral desirability parameter function.

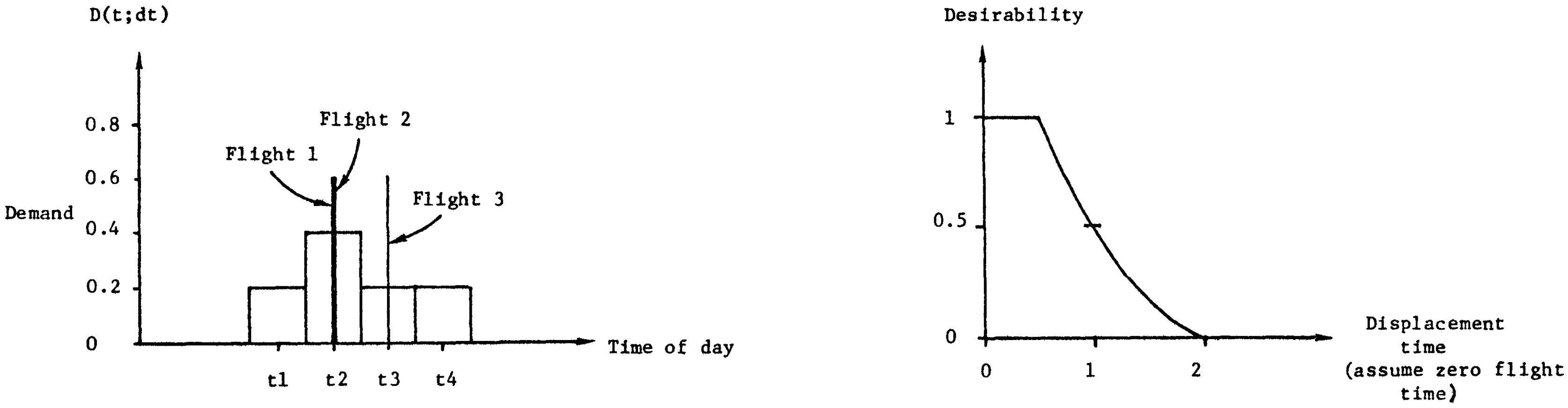
the deadband) and price. As in the case of the ASPEM model, the coefficient x is quite arbitrary. In this case, however, x affects both the time and price desirabilities, so that the ratio (cross-elasticity of time vs. price) remains equal to the ratio of the price and level of service elasticities for the market (regardless of the value of x)*. This allows the use of large values of x (representing the behavioral pattern that the indifference-line approach tried to emulate) while retaining the price-time cross elasticity determined by the ratio of the price elasticity to the trip time elasticity.

The variation of the desirability with respect to fare is exponential, rather than the conventional potential form, to avoid the numerical problems associated with small values of fare. Since "unrealistically" small fares may be sometimes used as strategic competitive weapons, we must allow for the possible occurance of very small fares.

To illustrate the entire behavioral desirability determination process, we compute in Figure 6 the desirability parameter for the sample case used in Figure 4. For clarity, we will use a simple time-desirability function (no price differ-

---

* Note that while the elasticity with respect to trip time is constant, the elasticity with respect to price is proportional to the price ratio; thus the above comment apply to the point elasticities.



Time of day slice	Demand fraction	Demand allocated to 1	2	3
1	0.2	0.1	0.1	0
2	0.4	0.16	0.16	0.08
3	0.2	0.05	0.05	0.1
4	0.2	0	0	0.2
Total:	1.0	0.31	0.31	0.38

Figure 6.- Illustration of behavioral desirability parameter computation.

ences), which takes the discrete values of 1, 0.5 and 0 for time differences of 0, 1, and 2 units respectively. Also for simplicity, we disregard the flight times (i.e. trip time = displacement time).

Passengers desiring departure during the first time slice of Figure 6 have the choice of waiting 1 time unit for flights 1 and 2, or two time units for flight 3. According to our time-desirability function, the relative preferences of these flights for these passengers are, respectively, 0.5, 0.5 and 0. We thus allocate the 20% of the demand that corresponds to the first time slice proportionally to these weights, for a total of 0.1 to each of the two first flights. Similarly, for passengers from the second time slice, the preferences are 1, 1, and 0.5, and the 40% demand corresponding to the slice are allocated as indicated in the table of Figure 6.

After all four time slices have been allocated, we sum the desirabilities of each flight from each time slice, and we get 31% allocated to each of the first two flights, and 38% allocated to the third flight.

Proponents of Indifference-line models may argue that there is no reason for passengers in time slice 2 to prefer anything but flights 1 and 2, and therefore the time-desirability function should exhibit a sharp cutoff, leading to the indifference-line mode (except maybe for the effect of the deadband). In reality, the error induced by "stealing" slice 2 passengers in favor of flight 3 is partially compensated by the stealing of slice 3 passengers from flight 3, in favor of flights 1 and 2. The possible residual error is a small price to pay for the superior behavior of this model in the presence of closely-spaced, "interfering" flights.

In our approach, multi-stop flights are "penalized" with respect to non-stop flights only by their naturally longer trip times (due both to longer flight times and gate times at intermediate airports). It may be argued that the inconvenience of repeated take-offs and landings reduces the utility of a multi-stop flight beyond the mere increase in trip time. On the other hand, it remains to be proved that passengers will actually wait for a non-stop flight in preference to a multi-stop flight that will take them to their destination earlier.

Multi-stop flight penalization could be implemented either by adding to their trip time a "stop penalty time", or by weighting displacement time less than flight time in the computation of total trip time for passenger preference purposes. We do not use either of these approaches for multistop flights, but we do penalize connecting flights with a "connection correction" trip time penalty due to the disutility caused by the finite probability of missing the connection.

3.5 INCREMENTAL LOAD BUILD-UP AND DEMAND SHEDDING

In the real world, the passenger's behavioral preferences are modified by the availability of space. We will not model the airline's "blocking off" practices, i.e. setting away blocks of seats on specified flights for various purposes (e.g. sell to travel agencies). We assume that a single flight segment is saturated on any one day, when the load factor for that day reaches 100%.

The effect of day-to-day statistical variations in total demand is such that the average load factor over any period of time may never reach 100%. For example, consider two days on a market with 100 seats/day capacity. On the first day, demand is 150 passengers but only 100 can be carried[*]. On the sec-

---

[*] It is assumed all 150-100=50 passengers not carried are lost, i.e. none of them show up the next day, namely, daily

ond day, 50 passengers show up, and all are carried. Even though the total demand is 200 passengers (suggesting an average load factor of 100%) actually only 150 passengers are carrier, yielding an average load factor of 75%.

The ratio of the "theoretical" (100% in the example) and the "actual" (75%) load factors depends on the statistical model assumed for the day-to-day variation of demand. We will asume a Gaussian, or Normal, statistical distribution of demand. Appendix C shows how the curves of Figure 7 are derived from the assumption that the standard deviation is one-half the mean. This curve (Figure 7a) shows the theoretical and actual average load factors resulting from a given demand/capacity ratio. Observe how the actual average value diverges from the theoretical value starting at a theoretical load factor of 50%. This effect is called "load factor tail-off". The data of Figure 7a is re-plotted in Figure 7b to show the fraction of demand carried as a function of the same ratio of demand to capacity.

The actual load build-up process cannot be accomplished in a single step. The reason is illustrated with the simple example of Figure 8. Consider two markets, with a total

---

demand is a stochastic random variable.

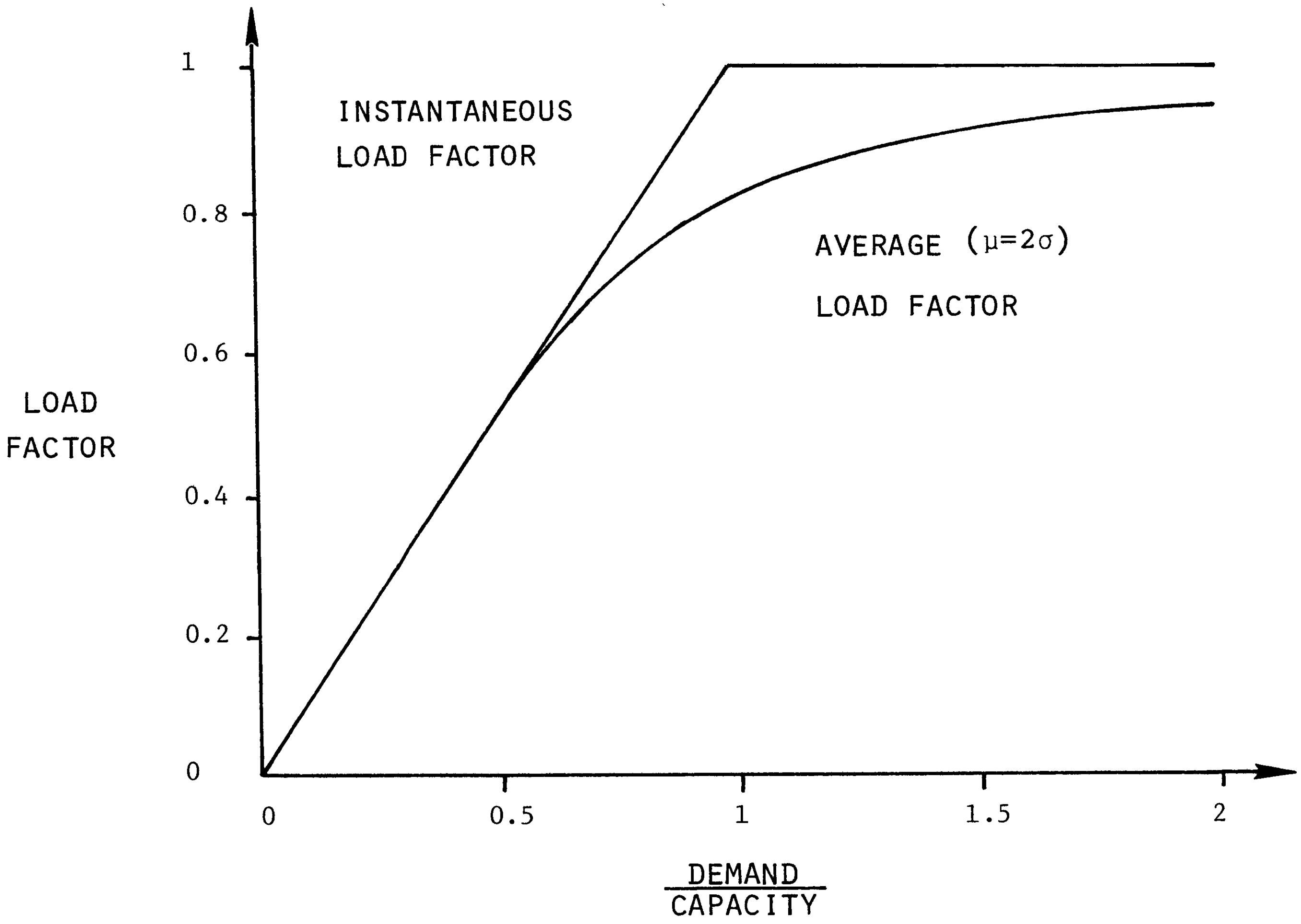


Figure 7a.- Load factor tail-off.

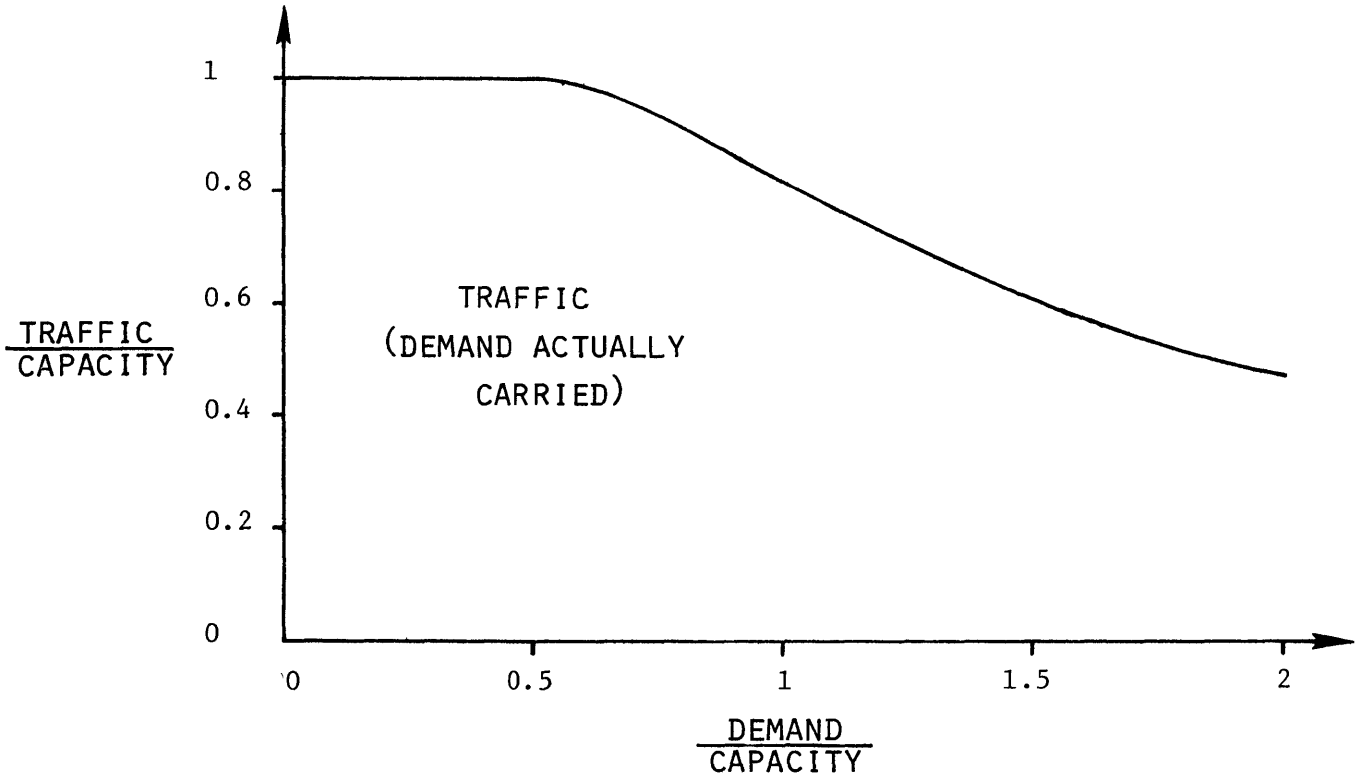


Figure 7b.- Load factor tail-off

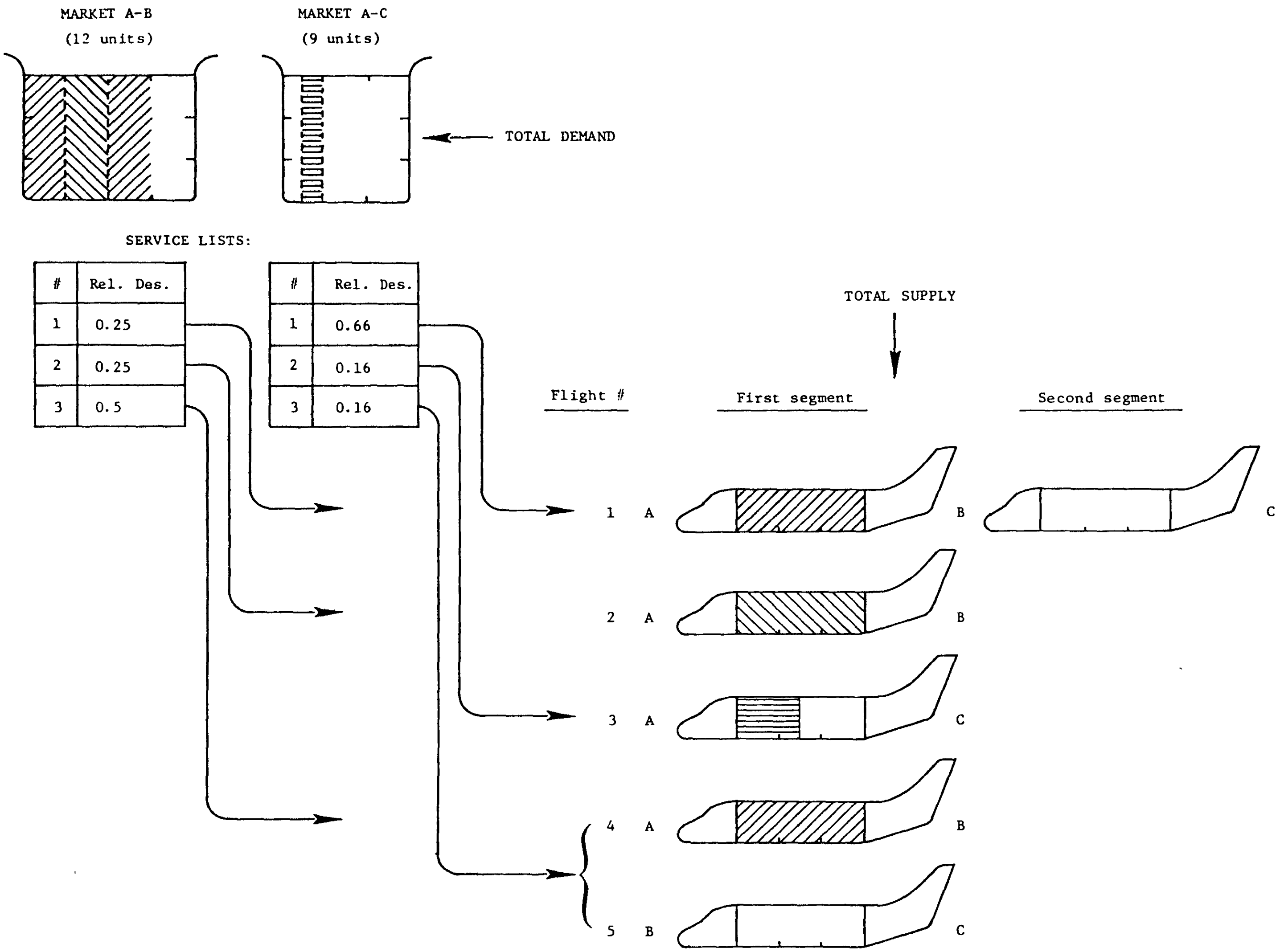
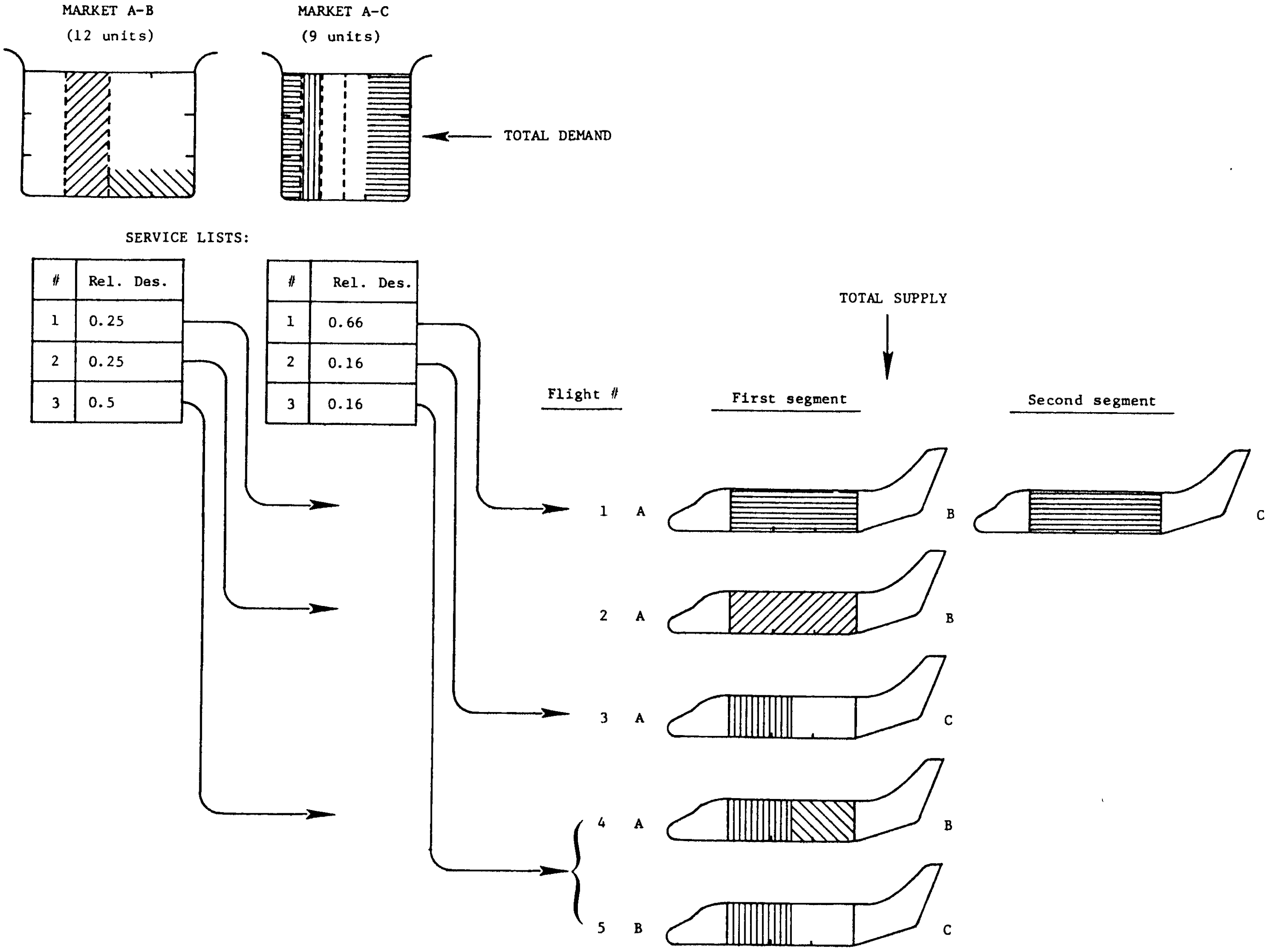


Figure 8a.- Example of non-iterative load buildup: market A-B first



#	Rel. Des.
1	0.25
2	0.25
3	0.5

#	Rel. Des.
1	0.66
2	0.16
3	0.16

Figure 8b.- Example of non-iterative load buildup: market A-C first

demand of 12 and 9 units, respectively. Each market is served by three offerings, made up of non-stop, one-stop and connecting flights. A total of five flights and six flight segments are used to offer these services. Market A-B's service offerings have initial desirability parameters equal to 0.25, 0.25 and 0.5; A-C's entries have values of 0.67, 0.16, and 0.16, respectively. If the demand is allocated in the order shown (market A-B first, then market A-C) we end up with the allocation shown in Figure 8a. One-fourth of the total A-B demand (three units) goes to Flight 1's first segment, and another three units to Flight 2. Since the aircraft capacity is three units, these flights become saturated. Similarly, of the six units of demand that would correspond to Flight 4, only three can be allocated.

When market A-C's turn arrives, it finds two of its three service offerings using flight segments that have already been saturated. Thus, the new desirabilities have the values 0, 1, and 0 respectively. Only three units of market A-C's demand can be allocated (to Flight 3). If the order is inverted, we obtain the allocation shown in Figure 8b. Thus the order in which markets are processed affects the results of the allocation when high load factors are present.

To solve this problem, we divide the process in N steps and allocate 1/N-th of the total demand during each step. Furthermore, we only allocate to each entry a fraction of its share, based on the load of its most loaded segment ("bottleneck" segment) according to the tail-off function of Figure 7. The load allocation iteration stops when all markets are either:

a) Fully allocated, i.e. all the demand has been assigned to one flight or another.

b) Saturated, i.e. all the service entries for that market have reached load factors such that no more than an ϵ of the demand may be allocated in the next step (ϵ being a run parameter).

Going back to the example (Figure 9), we now divide the process in three steps, and will attempt to allocate one third of the total demand (four units for A-B, three units for A-C) during each step. Thus, we allocate one unit of A-B demand (one-quarter of one-third of 12 units), to Flight 1's first segment, one unit to Flight 2, and two units to Flight 4. For sake of simplicity we will ignore the load factor tail-off effect (theoretical load factor = actual load factor).

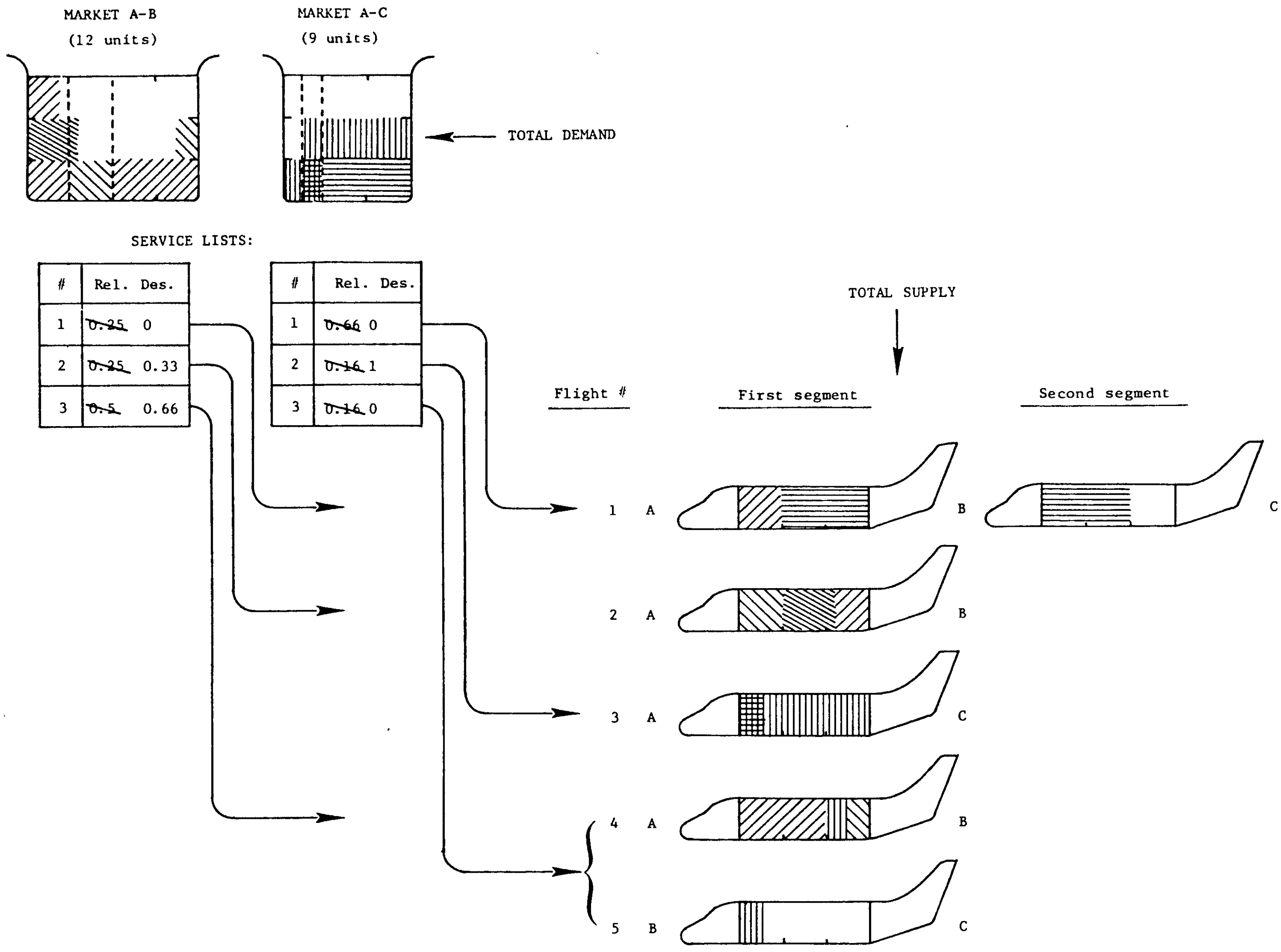


Figure 9.- Example of iterative load buildup process.

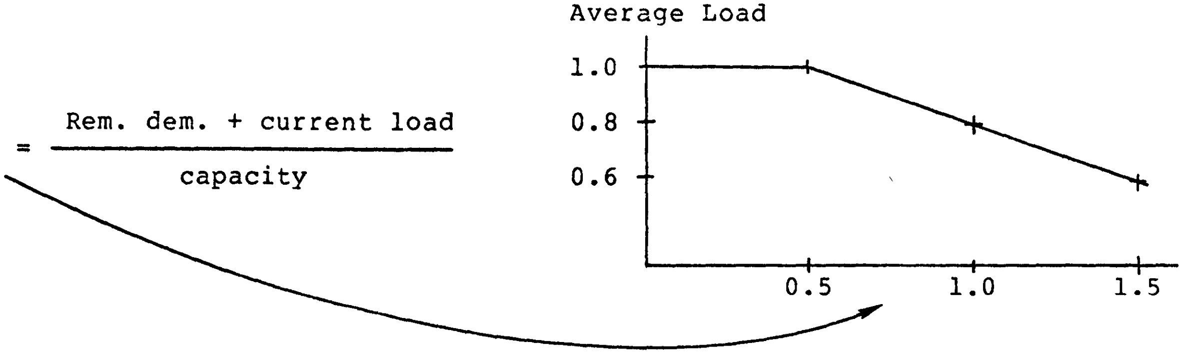
When we allocate market A-C's first third, we find just enough space in Flight 1's first segment to fit in the two units of demand. The allocations for Flights 3 and the 4-5 connection (half a unit each) fit, thus ending the iteration. Before allocating market A-B's second third, we must re-normalize its desirabilities, since the first entry involved Flight 1's first segment, now saturated. The new normalized desirability indices are 0.33 for the first entry, and 0.67 for the second one. This leads us to allocate 1.33 units of demand to Flight 2 and 2.66 to Flight 4, where there is room for only 1 unit. We have thus saturated Flight 4, and we have not been able to allocate all of market A-B's second third.

Back to market A-C, we are left with only one entry, the one pointing to Flight 3. Its re-normalized desirability, therefore, becomes 1. However, of the 3 units of demand that we would like to allocate, Flight 3 has room for only two. This saturates that flight, and therefore the market. The other market (A-B) can only dispose of 2/3 more units of demand (to Flight 2) before its service list is depleted. As it can be seen, the resulting distribution is quite different from those of Figure 8a and Figure 8b.

In the computer code used, this process is modified by the introduction of the load factor tail-off ratio of Figure 7, before a flight's share of demand is allocated. For this purpose, the load of the "critical segment" (most loaded segment in the flight(s)) is compared with the fraction of total demand (all iterations) that would be allocated to this entry based exclusively on the entry's current desirability. This is used as an approximation of what the final load factor in that segment would be (barring load shedding). The theoretical-actual ratio corresponding to this theoretical load factor (Figure 7) is used to reduce the allocated demand so that the resulting critical segment load factor is no greater than the desired (actual) one. As the bottleneck segment load factor approaches its limit value, the demand allocated to it becomes increasingly small. Therefore, the number of iterations needed to allocate the initial demand may be different from the number initially selected to determine the demand slice. The allocation iteration for a flight is terminated when the additional demand added by an iteration becomes smaller than a certain value ϵ.

This process is illustrated by the simple example of Figure 10. In this example, a simple linear tail-off function is assumed; a 100-seat aircraft is used to serve (exclusively)

$$\frac{D}{C} = \frac{\text{Rem. dem. + current load}}{\text{capacity}}$$



	Market A						Market B					
Iter #	Load	Rem. Dem	D/C	Av. L.F.	Demand slice Max	Act	Load	Rem. Dem	D/C	Av. L.F.	Demand slice Max	Act
1	0	20	0.2	0.2	20.0	4	4	80.0	0.84	0.726	68.6	16
2	20	16	0.36	0.36	16.0	4	24	64	0.88	0.756	50.6	16
3	40	12	0.52	0.52	11.6	4	44	48	0.92	0.765	32.5	16
4	60	8	0.68	0.63	3.1	3.1	63.1	32	0.95	0.779	14.8	14.8
5	77.9	4.9	0.83	0.72	0	0	77.9	17.1	0.95	0.779	0	0
Total passengers carried:						15.1						62.8

Figure 10.- Example of load factor tail-off simulation process.

two markets, sharing one ("bottleneck") flight segment. Market A's total demand is 20 passengers/day, that of market B 80 passengers/day. The simple (no tail-off) allocation process described above would fit all 100 passengers in the 100-seat aircraft; however, the load factor tail-off function of Figure 10 indicates that for a Demand/Capacity ratio of 1, only 80% of the demand is carried; we would thus expect to carry only 16 passengers from market A, and 64 from market B.

This process is carried out simultaneously with the incremental loading process described above; assuming that five loading iterations are desired, we would, in our example, allocate 4 and 16 passengers from each market during each iteration. The tail-off process begins with the computation of the current "expected demand/capacity ratio":

$$\left(\frac{D}{C}\right)_{exp} = \frac{D_r + L_s}{c} \tag{3.9}$$

where:

D_r is the remaining demand on the market

L_s is the current aircraft load (on the "bottleneck" segment).

c is the aircraft capacity.

In our example, the initial iteration through market A yields an expected D/C of 0.2. This D/C is then entered in the load factor tail-off function used, (Figure 10 in our example, Figure 7 in the actual game), producing the expected final load factor (0.2 in our example). Thus, it is expected that only 20 seats will be occupied. Since there are no seats curently occupied, the maximum number of seats that can be allocated ("max slice") is 20-0=20, well in excess of the 4 passengers that we would like to allocate during this allocation iteration; thus all 4 passengers are allocated, and no tail-off occurs. Similarly, in Market B, we have an expected D/C of 0.84, corresponding to a final load factor of 0.726, yielding a max slice of 72.6-4=68.6 available seats[*].

---

[*] Note that since we are dealing with with average values, it is proper to use fractional seats and "fractional passengers".

The available seats continue to exceed the demand allocation slice until the fourth iteration, where only 3.1 seats are available in market A. Thus, the demand allocated is reduce from 4 to 3.1. Similarly, market B's slice is reduced from 16 to 14.8 passengers. During the last and fifth iteration, there is no more room (max slice <= 0) for either market, and thus the allocation process is terminated. The total number of passengers carried from each market are 15.1 and 62.8 respectively. This performance was judged satisfactory, although there is some room for improvement.

3.6 INCOME AND COSTS STRUCTURE

There are three possible sources of income in our model structure: revenue from operations, income from asset and financial managements transactions, and external sources. In the case of asset management income, two values of income are kept (following traditional accounting practices), one for financial reporting, one for fiscal reporting (taxes).

Revenue from operations includes the product of the passengers carried on each market by the single fare charged on that market. This revenue is computed during the demand allocation process, and is allocated to the flight carrying the passengers which originated that revenue. The revenue from an interline connecting service is allocated proportionally to the great circle distances between origin and connecting airport, and connecting airport to destination.

Income from asset and financial management includes:

a) Capital gains from the sale of aircraft, modeled as the difference between the sale price (determined by scenario data and rules) and the corresponding book value (straight-line for financial reporting, Double-Declining Balance for fiscal reporting).

b) Income from the lease-out of aircraft. Again, the lease-out rate and terms are determined by scenario data and rules.

c) Interest from the investment of cash on hand. This is modeled as a simple rate (again, from scenario data) applied to the cash on hand at the beginning of a simulation period.

The only source of external revenue considered in this mechanization is government subsidy payments. Again, the rates and terms are to be determined by the scenario data and rules.

As mentioned in 2.4.5, the cost structure must perforce match the endogenous data produced by the simulation. We have grouped the costs modeled into five groups, each containing several cost coefficients; it is the task of the game scenario data to correlate the coefficients with the real-world costs being simulated. Some of these cost elements are computed for the entire simulation period, while others are computed daily. The latter are converted to costs per simulation period by multiplication by the appropriate factor (number of days per simulation period). The five groups are:

Group 1: flight-associated costs. These are costs calculated for each segment of a flight, and are made up of:

- A fixed quantity per segment: DOC/OP
- A term proportional to the block time: DOC/H * BLKTIME
- A quantity for the departure and arrival airports, each composed of a fixed term plus a term proportional to the number of seats: C1 + C2 * SEATS

The parameters C1 and C2 are unique for each airport. The parameters DOC/OP and DOC/H are unique for each aicraft type. The total flight costs per day are the sum of these three components over all the flight segments flown.

Group 2: aircraft fixed costs. These costs are independent of the utilization of the aircraft, and are made up of:

- A fixed quantity for each day the aircraft is available: AC/DAY

- For aircraft owned, the depreciation cost per simulation period. Two depreciation schemes are used, a straight line for finacial reporting, a Double Declining Balance for tax computation.

- For aircraft leased-in, the lease costs per simulation period.

Group 3: Global activity-related costs (all per simulation period):

- A term proportional to the total available seat-miles: C/ASM * ASM.

- A term proportional to the total revenue passenger-miles: C/RPM * RPM.

- A term proportional to the total number of passengers carried (enplanements): C/ENP * ENP.

- A term proportional to the total passenger revenue: C/REV * REV.

The parameters C/ASM, C/RPM, C/ENP and C/REV are unique for each participant.

Group 4: Financial costs. This is simply the sum of the periodic payments per simulation period required by all the debts outstanding for the participant.

Group 5: Taxes. Taxes are made up of a simple rate on corporate income (everything but capital gains), another simple rate on capital gains, and an accumulating ITC (Investment Tax Credit) proportional to the capital expenditures (aircraft acquisition). Two simplifying assumptions are made about the ITC:

a) It can be carried forward indefinitely, but not backwards (retroactive application).

b) It is used as soon as there are any tax liabilities to which it can be applied (i.e. there is no discretion on their use by part of the participant).

These simplifications were made to reduce the number of participant decision variables required. Corporate gain and capital gain are computed using the Double Declining Balance aircraft depreciation expenses and book value.

3.7 PERFORMANCE REPORTING AND ACCOUNTING MODELS

Examples of the printouts produced by the simulation can be found in the next Chapter. These include a number of terms which are defined here. In the case of revenues and costs, this is basically a labelling procedure, and the choice of labels reflects the author's opinion on how real-world costs should be allocated to the terms of the costs structure mentioned in the previous Section. The financial reports include the three standard forms (Statement of Earnings, Balance

Sheet, and Changes in Financial Position), plus a number of analysis-oriented ratios.

The Statement of Earnings (S of E) is made up of the following items:

a) Passenger revenues - as defined in 2.4.4
b) Other revenue - subsidy payments, aircraft lease-out and interest income.
c) Flying expenses - the total Group 1 expenses described in the previous section.
d) Passenger services - the sum of the enplanement and RPM terms in cost Group 3.
e) Reservations and sales - the term proportional to passenger revenue in cost Group 3.
f) General and administration - the sum of the term proportional to ASM in Group 3 plus the first term of the aircraft fixed costs of Group 2.
g) Depreciation and amortization - the aircraft depreciation costs based on straight-line depreciation.
h) Interest expense - the financial costs (Group 4).
i) Lease costs - from Group 2.

j) Earnings before taxes and extraordinary items: a+b-c-d-e-f-g-h-i.

k) Corporate income taxes - as defined above.

l) Investment Tax Credit - as defined above.

m) Extraordinary items - sale of aircraft.

n) Capital gains tax - as defined above.

o) Net earnings (also called "Net after-tax income"): j-k+l+m-n.

The components of the Statement of Changes in Financial Position (SCFP) are as follows:

a) Net after tax income - from the balance sheet (term o).

b) Depreciation expense - term g) above.

c) Book value of aircraft sold - using the straight line depreciation.

d) Other sources - the cash inflow from all financial transactions with a positive initial cash flow (e.g. a loan).

e) Uses of working capital - two components:
   - Equipment aquisitions.
   - Debt redemption (final payment).

f) Change in working capital: a+b+c+d-e.

The Balance Sheet (BS) also conforms to usual accounting practices, and is made up of the following items:

a) Cash and equivalent - the accumulated changes in working capital (item f, above).

b) Flight equipment - the sum of the original purchase price of all owned aircraft.

c) Accumulated depreciation - the difference between the purchase price and the straight-line book value.

d) Current liabilities - the sum of the final cash flow of all financial transactions with a negative final cash flow and a remaining life equal to or less than one year.

e) Other liabilities - two components:

  - The final cash flow of all transactions with a negative cash flow and remaining life greater than one year.
  - The difference between the straight line and Double-Declining Balance book values of aircraft, multiplied by the corporate gain tax rate (deferred taxes).

f) Equity: a+b-c-d-e.

The operating statistics terms are defined as follows:

a) Total seat-miles (ASM) - the sum over all flight segments of the segment length times the aircraft capacity.

b) Revenue passenger-miles (RPM) - the sum over all flight segments of the segment load times the segment length.

c) Total enplanements - the sum over all flights of the number of passengers allocated to each flight.

d) Average daily equipment utilization - the sum over all segments of the segment block time divided by the total number of aircraft usable (owned plus lease-in minus leased-out) by the participant.

e) Average stage length - the sum over all flight segments of the segment length, divided by the number of segments.

f) Average load factor - RPM/ASM.

Items a,b and c represent daily values, and are multiplied by the number of days per simulation period to obtain the total value over that period.

The financial statistics terms are defined as follows:

a) Return on owner's equity - Net after tax income divided by equity.

b) Return on sales - Net after tax income divided by operating revenues (S of E items a+b).

c) Return on assets -

$$\frac{\text{Net earnings} + \text{Interest expense }(1-\text{Corp. Tax rate})}{\text{Cash} + \text{Flight equipment} - \text{Accumulated dep.}}$$

d) Return on invested capital -

$$\frac{\text{Net earnings} + \text{Interest expense }(1-\text{Corp. Tax rate})}{\text{Cash} + \text{Flight eq.} - \text{Accum. dep.} - \text{Current liab.}}$$

e) Investment turnover - Operating revenues (S of E items a+b) divided by invested capital (B.S. items a+b-c-d).

f) Asset turnover - Operating revenues divided by assets (B.S. items a+b-c).

g) Equity turnover - Operating revenues divided by equity (B.S. item f).

h) Current ratio - Cash and equivalent divided by current liabilities.

i) Debt/Equity ratio - Other liabilities minus deferred taxes (first component of B.S. item e), divided by equity.

j) Debt/Asset ratio - Other liabilities minus deferred taxes, divided by assets (B.S. items a+b-c).

k) Times interest coverage - Earnings before taxes and extraordinary items plus interest expense (S of E items j+h), divided by the interest expense (S of E item j).

Items a through g are annualized by multiplying them by the ratio (number of days per simulation period)/365 (days per year).

3.8 ADDITIONAL FUNCTIONS

In addition to the main functions covered in the previous sections, there are a number of additional functions that must be performed to make the game usable. The three most important ones are:

a) Verification of schedule realizability.
b) Aircraft flow balance verification.
c) Aircraft requirements determination.

Schedule realizability implies simply that the departure time for a flight segment cannot be earlier than the arrival time for the previous segment, plus a certain "gate residence time" or gate time. Each participant airline is assigned a fixed minimum intersegment gate residency time for all airports and all aircraft types. The interactive data input program will not accept a flight whose departure schedule violates the minimum intersegment gate time.

The aircraft flow balance and aircraft count procedures are required because game participants enter each flight as an individual item, without assigning them to any particular aircraft ("tail number" assignement), and thus it is non-trivial to determine flow balance and aircraft counts. These two functions are interlaced, and are carried out as follows:

a) For each aircraft type used by the participant, the airports where flights initiate or terminate are identified (intermediate stop airports are ignored).

b) For each of these airports, a flight flow list is created. This is a time-ordered list, from 0000 hours to 2400 hours universal (not local) time*, of the carrier's flight departures and arrivals at that airport.

---

* "Universal" departure or arrival time is the departure or arrival time uncorrected for the airport's time zone.

c) The number of departures and arrivals at each station must balance, or else that airport is labelled as an aircraft "source" or "sink".

d) If the flow does match, a count is started at zero at the beginning of the day, and the flight flow list traversed: for each departure, the count is reduced by one, for each arrival, the count is increased by one.

e) The minimum number (by definition less than or equal to zero) reached by the count is the number of aircraft of the type being counted that stay overnight at that station (e.g. if the count is -3, three aircraft stay overnight).

f) Each flight segment of each flight using that type of aircraft is examined. If the sum of the departure time plus the segment block time is greater than 24 hours (universal time), then that airplane is in flight at midnight.

g) The total number of aircraft of a given type required by the participant is the sum of all the station's overnight stay counts plus all the midnight-flying segments.

The flight arrival times used in the above process are incremented by a "minimum interflight gate time", to simulate the gate time required to turn over a flight. This minimum interflight time is assumed independent of the airport and aircraft type, but is unique to each participant. This time may be different from the intersegment stop time for a multistop flight mentioned above.

CHAPTER IV

IMPLEMENTATION AND SAMPLE USAGE

This chapter describes the current implementation of the game at the Flight Transportation Laboratory of the Department of Aeronautics and Astronautics, Massachusetts Institute of Technology. A very simple example is analyzed in detail to illustrate the concepts of the previous Chapters. The first experience with the game used as a teaching tool at M.I.T. is reviewed.

4.1 SOFTWARE MECHANIZATION

The large number of decisions that the participants must input, and the complexity of the decisions process indicates the convenience of providing participants with conversational, interactive access to the data bases that contain their input decision variables. Conversational access offers the following advantages:

a) It can be made easier to learn and use than fixed-format (e.g. punched cards) methods.

b) Clerical mistakes, such as keypunch errors, can be immediately detected and corrected.

c) Some less trivial mistakes, such as repeated flight numbers, can also be detected at the time the data is entered.

d) Instant and structured access to the entire data base can help in the decision process itself.

e) If programmed to perform some reduction of the data (e.g. computation of segment flight times, aircraft count, etc) the access programs may be used as analysis and decision-making aids.

f) The access programs may detect (and prevent) participant "cheating".

The last three features allow the participants to perform part of their decision-making (i.e. the scheduling part) at the same time that they enter the data at the computer terminal. Thus, a certain amount of interaction is possible; for example, if the resulting aircraft flow is not balanced, the conversational program indicates at which stations the unbalance occurs, and can display the flight flow through that station, so that an appropriate fix may be found.

The resulting overall software structure is presented in Figure 11. The data required to drive the computer-based simulation is divided between three data sets:

a) A "Universe" file, containing data not likely to change from run to run (e.g. airport latitudes and longitudes).

b) A "Simulation run" file, containing data that is unique to the game iteration being run, such as some participant parameters, global demand modifiers, dynamic scenario data, etc.

c) A "Participant" file for each participant in the game, containing both the input decision variables and results from past game iterations that may be required by the simulation ("historical" data).

Each game participant has conversational access to his file via a time-sharing program (the "Participant File Proc-

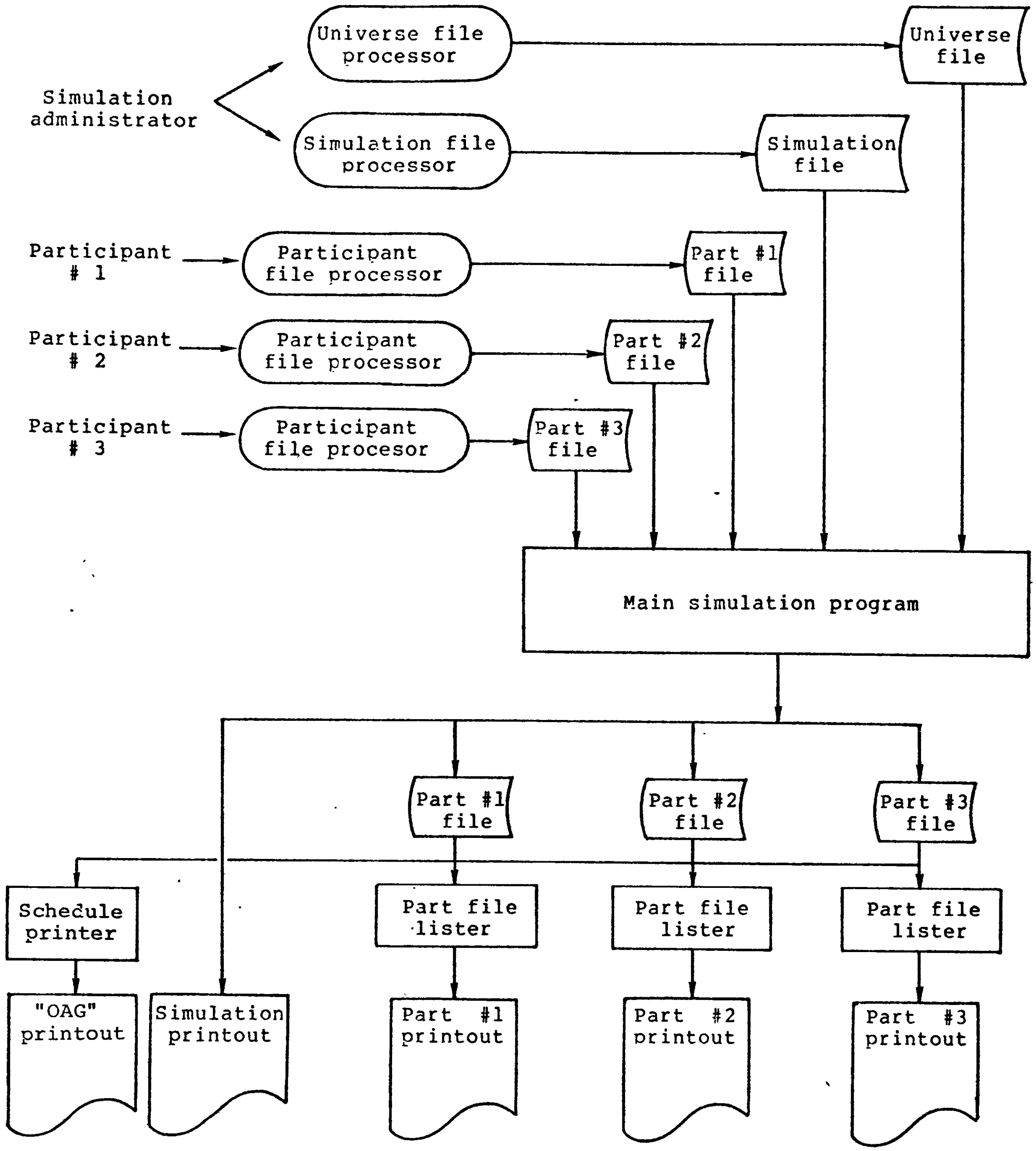


Figure 11.- Structure of game's software mechanization.

essor") and is responsible for entering his decisions on his participant file. The game administrator is responsible for the contents of the Universe and Simulation files. The simulation program itself reads in the Universe, Simulation, and Participant files, and produces a number of printouts, as well as new, modified, copies of the participant files. The new copies of the files can then be updated or changed by the participants and used as inputs in the next game iteration.

The use of separate files for input and output allows the complete history of a game to be saved for future use. This use may be the rerunning of the game with improved environment data (without having to re-enter all the participant's decision variables) or the use of intermediate stages in a game as starting conditions for other games (parallel comparison runs).

Appendix D shows the structure of these data sets, as well as the data contained in them. Table 1 lists the participants' input decision variables. As it can be seen, some of the participant's inputs (the financial and equipment transaction data) are in the Simulation file, rather than in the respective participant's file. The reason is that these decisions are subject to "scenario" rules not mechanized in com-

On the Participant's file:

Flight information:
- Flight number
- Equipment used
- Itinerary
- Schedule of departures

For each city pair:
- Discrete price (tariff)
- Published connections

Tariff-distance formula

On the Simulation file:

Financial transactions:
- Initial cash flow
- Periodic payments
- Length of time
- Final cash flow

Aircraft transaction:
- Aircraft type
- Number of aircraft
- Purchase price or lease cost
- For a lease: length of time
- For a purchase: depreciation data
- For a sale: age of aircraft sold

Table 1.- Participant's decision variables

puter code (see Section 2.4.3). Thus, the conversational programs cannot verify the validity of the inputs: the game administrator must "censor" them (i.e. verify their conformity with the scenario rules). Thus, they are included in the Simulation file, which is under the administrator's control. Also shown in Table 2 are the run parameters that may be changed by the game administrator without modifying the Universe File data.

The following example illustrates the use of a conversational program to access a participant file. Appendix E summarizes the commands available in all three conversational file access programs.

The FTL mechanization is made up of seven software units written in PL/I, totalling 8,800 statements (approximately equivalent to twice as many FORTRAN lines). All the data used is stored in on-line disc devices. Top-down structured programming disciplines were used to keep the programming costs under 2 man-years. Usage costs are illustrated in the following examples.

On universe file:

Airport data:
- Identifier
- City name
- Market identifier
- Latitude, Longitude, Time zone
- Aircraft type restrictions
- Minimum connection time

Market data (for each season):
- Market I.D.
- Nominal demand
- Nominal level-of-service
- Nominal tariff
- Elasticity w.r.t. price
- Elasticity w.r.t. level of service

Aircraft data:
- Identifier
- Capacity (seats)
- Range
- Cruise airspeed
- Cost per block hour
- Cost per operation cycle
- Cost per day
- Airport restriction code

Participant data:
- I.D. and full name
- Cost per passenger enplanes
- Cost per revenue pax-mile
- Cost per available seat-mile
- Cost per dollar of revenue
- Minimum interflight gate time
- Minimum intersegment gate time

On the Simulation file:

- Allocation multiplier ("x")
- Connection penalty time
- Allocation time deadband
- Global demand multiplier
- Implicit price deflator
- Season to be simulated
- Short-term bank deposit rate
- Subsidy paid to each participant
- Corporate income tax rate
- Capital gains tax rate
- Investment tax credit rate

At run submission time:

- Number of days per simulation period
- Iteration termination parameter ("epsilon")
- Fraction of demand allocated per iteration period

Table 2.- Run-time game parameters

4.2 ANNOTATED EXAMPLE

The following example is a single iteration of an extremely simple case, constructed to demonstrate the mathematical models described in the previous Chapter, and to illustrate the current mechanization's input and output formats.

4.2.1 Game Scenario

There are only two participants in this simple case, with the identifiers "ZY" and "ZZ"; there are three market regions: Boston, Hyannis and Nantucket, with one airport each, BOS, HYA and ACK respectively. Thus, there are three possible market area pairs: BOS-HYA, BOS-ACK and HYA-ACK. Three types of aircraft are available to each carrier: CNT, CN4 and PAN (Cessna Titan, Cessna 402B, and Piper Navajo, respectively), with fluctuating market prices.

Figure 12 shows a printout of the Universe file data. Although real geographical names and locations are used for the airports in this example, the market data is completely artificial, with the numerical values selected to demonstrate the operation of the demand allocation mechanism.

```
MITFTL ATIS    FILE ID:UNIV0001    U N I V E R S E   F I L E   P R I N T O U T      LAST MODIFIED 78/07/11 09:56:00.56   PAGE   1

MARKET      DAILY NOM DEMAND         NOMINAL FARE              NOMINAL L.O.S.              FARE ELASTICITY          L.O.S. ELASTICITY
PAIR       1     2     3     4|  1      2      3      4  |  1      2      3      4  |  1      2      3      4  |  1      2      3      4
-------------------------------------------------------------------------------------------------------------------------------------
ACK-BOS   10    15    20    15| 0.00   0.00   0.00   0.00|0.250  0.250  0.250  0.250|-0.90  -1.20  -1.40  -1.00| 0.40   0.40   0.40   0.40
ACK-HYA    7    11    15     0| 0.00   0.00   0.00   0.00|0.250  0.250  0.250  0.250|-0.90  -2.00  -2.00  -1.00| 0.40   0.40   0.40   0.40
BOS-ACK   10    15    20    15| 0.00   0.00   0.00   0.00|0.250  0.250  0.250  0.250|-0.90  -1.20  -1.40  -1.00| 0.40   0.40   0.40   0.40
BOS-HYA   10    15    20    15| 0.00   0.00   0.00   0.00|0.300  0.300  0.300  0.300|-1.00  -1.80  -2.00  -1.00| 0.40   0.40   0.40   0.40
HYA-ACK    7    11    15     0| 0.00   0.00   0.00   0.00|0.250  0.250  0.250  0.250|-0.90  -2.00  -2.00  -1.00| 0.40   0.40   0.40   0.40
HYA-BOS   10    15    20    15| 0.00   0.00   0.00   0.00|0.300  0.300  0.300  0.300|-1.00  -1.80  -2.00  -1.00| 0.40   0.40   0.40   0.40


                                   MARKET  LATITUDE  LONGITUDE TIME  CONN  BASIC BASIC COST/ REST
          ID  CITY NAME            SERVED  DD:MM:SS  DD:MM:SS  ZONE  TIME   TIME  COST  SEAT CODE
          --------------------------------------------------------------------------------------
          ACK NANTUCKET MA          ACK    41:25:22  70:03:33    1     2      3     5  0.00    0
          BOS BOSTON MA             BOS    42:21:52  71:00:17    1    15     10     5  0.25    0
          HYA HYANNIS MA            HYA    41:39:55  70:16:48    1     2      4     5  0.00    0

                                   MARKET  LATITUDE  LONGITUDE TIME  CONN  BASIC BASIC COST/ REST
          ID  CITY NAME            SERVED  DD:MM:SS  DD:MM:SS  ZONE  TIME   TIME  COST  SEAT CODE
          --------------------------------------------------------------------------------------
          BOS BOSTON MA             BOS    42:21:52  71:00:17    1    15     10     5  0.25    0
          HYA HYANNIS MA            HYA    41:39:55  70:16:48    1     2      4     5  0.00    0
          ACK NANTUCKET MA          ACK    41:25:22  70:03:33    1     2      3     5  0.00    0


     PARTICIPANT         PARTICIPANT              MIN STOP      MIN INTERFLIGHT      COST PER:
         ID               FULL NAME                 TIME              TIME     ASM     RPM     ENP    $REV
        ----      ------------------------------    ----              ----    ----------------------------
         ZY       MASSACHUSETTS AIRLINES             2                 2      0.01    0.00    1.25    0.07
         ZZ       TECH AIRWAYS, INC.                 2                 2      0.00    0.00    1.25    0.07


                                   TYPE SEATS RANGE SPEED DOC/H DOC/O
                                   ---------------------------------
                                   CNT     9   800   188    85     5
                                   CN4     6   428   187    70     5
                                   PAN     8   800   188    78     5
```

Figure 12.- Universe file listing for annotated example

The simulation is started from scratch, rather than assuming that the carriers had been operating previously ("going concern"). Each participant is initially allocated $500,000, in the form of $500,000 of initial paid-in capital for ZY, and $250,000 of capital and $250,000 of straight debt for ZZ. Carrier ZY decides to purchase one CN4, at $250,000, while ZZ purchases one PAN at the same price. Thus, both carriers begin the first period of simulation with $250,000 of cash on hand each. Complete freedom of routing and fare-setting is assumed.

The implicit price deflator is set to 1.0 (no inflation), the allocation deadband is set at 15 minutes (all entries within 15 mins. of the minimum-time entry will be treated equally). The allocation time and price elasticities have been set equal to the level of service and price elasticities used for the market's total demand. The x multiplier, which determines the shape of the desirability vs. time curve has been arbitrarily set to four*. The short-term deposit interest rate is 5%.

---

* There is no empirical data from which the value of 4 can be rationalized; however, it is close to the values used in analogous models (Reference 11).

```
Text                                       Comments
-----------------------------------------------------------------------------------------
user zy 0 1                                The user invokes the participant
                                           file processor. File 0 is the input
                                           file, file 1 the output.

ENTER USER ID:                             The system checks the user's i.d.
zy
USER: ZY MASSACHUSETTS AIRLINES            O.K.
ZY>                                        This is the "system ready" prompt.
mt                                         The user asks what the minimum inter-
MINIMUM INTERFLIGHT TIME(MINS): 2.0        flight time is.
ZY>
af 1                                       Add flight nuber 1.
ENTER EQUIPMENT TYPE:
cn4
ENTER ITINERARY:
bos hya ack
ENTER SCHEDULE:
8:00                                       The user has entered the first
                                           departure time only. The processor
                                           will compute the block times,
                                           minimum gate times, and departue
                                           times for the rest of the flight.

AVAILABLE AT 8:46                          The system answers with the
ZY>                                        earliest time at which that aircraft
                                           is again available.

af 2                                       Same for flight 2.
ENTER EQUIPMENT TYPE:
cn4
```

Figure 13 - Sample interactive session with the participant file processor (continues).

```
Text                                        Comments
--------------------------------------------------------------------------------
ENTER ITINERARY:
ack bos
ENTER SCHEDULE:
10:00                                       Same procedure as flight 1.
AVAILABLE AT 10:37
ZY>
lf 1 2                                      To check his input, the user asks
ZY    1 EQ: CN4                             for a printback of the flight
S# FROM TO  DEP T ARR T BLK T DIST  COST    information. Note the flight cost
 1 BOS  HYA  8:00  8:30  0:30   52 51.50    printout. Distances are in nautical
 2 HYA  ACK  8:32  8:44  0:12   17 29.00    miles.
ZY    2 EQ: CN4
S# FROM TO  DEP T ARR T BLK T DIST  COST
 1 ACK  BOS 10:00 10:35  0:35   70 57:33
ZY>
tc 16 0.16                                  The user sets his fare formula to
ZY>                                         $16 plus $0.16 per nautical mile.
lt bos hya                                  Requests the BOS-HYA tariffs.
STANDARD: 23.79  CARRIER: 24.32/
ZY>
mt bos hya 25.00                            The user sets a discretionary $25
ZY>                                         fare for the bos-hya flights.

lt                                          The system "remembers" BOS-HYA.

STANDARD: 28.79 CARRIER:  24.32/ 25.00      In the simulation, the discrete ($25)
ZY>                                         fare will take precedence overthe
                                            formula ($24.32) fare.
```

Figure 13 - (continued)

```
Text                                          Comments
------------------------------------------------------------------------------------------
cs                                            The user requests a flow check.
FLEET REQUIREMENTS (BY TYPE):                 Had the flow not been balanced,
CN4        1                                  the system would have printed out
ZY>                                           the names of the stations at which
                                              the flow did not balance, and the
                                              amount by which it did not.
save new                                      Satisfied with his inputs, the user
SAVED (NEW FILE) AS:                          saves them in the output file. The
USER: ZY MASSACHUSETTS AIRLINES               system responds by typing the new
FILE: TEST0001 78/07/12 10:43:47.74           file's name and creation date and
STAT: 00000000 78/07/11 10:04:37.38           other data.
UNIV: UNIV0001 78/07/11 09:56:00.56
ZY>
end                                           The user logs off.
```

Figure 13 - (concluded).

4.2.2 Conversational Data Input

Figure 13 is a listing of the terminal session used by carrier ZY to enter his decision variables for the first period of simulation. Lowercase text is the participant's typing, uppercase text is the system response. Blank lines have been added to the conversation to allow space for comment lines. This session used less than one second of CPU time on an IBM 370/168 machine operating under the Conversational Monitor Program (CMP) of the Virtual Machine (VM) Operating System. In a more complex game, the segment data provided at the terminal could be used to construct the schedule, or to make incremental modifications to an existing one.

Figure 14 shows the schedule of services resulting from the schedule of flights entered by the two participants. This printout follows closely the data format of the Official Airline Guide, OAG. This is the form in which participants know each other's schedules, and is made available only after each participant has entered his schedule, to avoid "back-and-forth" schedule changes. As it can be seen, Carrier ZZ uses exclusively the standard ("CAB") formula, while ZY uses his own formula ($16 plus $0.16 per mile) for every market except BOS-HYA, where he applies a discretionary $25.00 fare. Of the

```
F L I G H T   I T I N E R A R I E S

 MASSACHUSETTS AIRLINES            |
                                   |
    1 CN4  BOS HYA ACK             |
    2 CN4  ACK BOS                 |
    3 CN4  BOS HYA                 |
    4 CN4  HYA BOS                 |
                                   |
                                   |
 TECH AIRWAYS, INC.                |
                                   |
    2 PAN  ACK HYA BOS             |
   10 PAN  BOS ACK                 |
                                   |
```

```
F L I G H T   S C H E D U L E S

============================== |
TO BOSTON MA             BOS 1 |
============================== |
FR HYANNIS MA            HYA 1 |
          CAB   28.79          |
           ZY   24.32          |
 10:14 10:44   ZZ   2  PAN   0 |
 17:00 17:30   ZY   4  CN4   0 |
                               |
FR NANTUCKET MA          ACK 1 |
          CAB   30.95          |
           ZY   27.20          |
 10:00 10:35   ZY   2  CN4   0 |
 10:00 10:44   ZZ   2  PAN   1 |
============================== |
TO HYANNIS MA            HYA 1 |
============================== |
FR BOSTON MA             BOS 1 |
          CAB   28.79          |
           ZY   25.00          |
  8:00  8:30   ZY   1  CN4   0 |
 15:00 15:30   ZY   3  CN4   0 |
                               |
FR NANTUCKET MA          ACK 1 |
          CAB   24.60          |
           ZY   18.72          |
 10:00 10:12   ZZ   2  PAN   0 |
============================== |
TO NANTUCKET MA          ACK 1 |
============================== |
FR BOSTON MA             BOS 1 |
          CAB   30.95          |
           ZY   27.20          |
  8:00  8:44   ZY   1  CN4   1 |
  8:00  8:35   ZZ  10  PAN   0 |
                               |
FR HYANNIS MA            HYA 1 |
          CAB   24.60          |
           ZY   18.72          |
  8:32  8:44   ZY   1  CN4   0 |
                               |
```

Figure 14.- OAG-type printout of flights offered by participants.

three region-pair markets, two (BOS-ACK in both directions and BOS-HYA in the Hyannis to Boston direction) are competitive. Each carrier has single-segment flights and two-segment flights.

During the first game period, carrier ZZ decides to sell its Navajo (at a substantial profit; presumably the scenario market price for Navajos increased from the original price) and purchase a Cessna. Also, they add a bank loan to their debt. These transactions are carried out to illustrate the financial reports included as part of the "common data" printouts.

4.2.3 Analysis of Simulation Results

Figures 15 through 17 show the "debug" printout which can be invoked by the simulation administrator to print out in detail the demand determination and allocation process. In Page 1 of this printout (Figure 15, top), the total demand determination process is being performed; for each market the printout shows the ideal Jet Time (in minutes), the nominal, standard and average fares charged, nominal and actual levels of service, and the nominal and actual total demand levels.

```
MITFTL ATIS         FIRST QUARTER                    D E B U G  P R I N T O U T                 78/09/18 12:46:18.82     PAGE   1

MARKET->ACK-BOS  JET TIME:   24 FARE:  30.95(CAB)   30.95(NOM)   28.67(AVR) LOS:0.250(NOM) 0.068(ACT) DEMAND:     10(NOM)   6(ACT)
|ZY   2   0.607|ZZ   2   0.393

MARKET->BOS-ACK  JET TIME:   24 FARE:  30.95(CAB)   30.95(NOM)   28.67(AVR) LOS:0.250(NOM) 0.060(ACT) DEMAND:     10(NOM)   6(ACT)
|ZY   1   0.607|ZZ  10   0.393

MARKET->ACK-HYA  JET TIME:   17 FARE:  24.60(CAB)   24.60(NOM)   24.60(AVR) LOS:0.250(NOM) 0.051(ACT) DEMAND:      7(NOM)   4(ACT)
|ZZ   2   1.000

MARKET->HYA-ACK  JET TIME:   17 FARE:  24.60(CAB)   24.60(NOM)   18.72(AVR) LOS:0.250(NOM) 0.046(ACT) DEMAND:      7(NOM)   5(ACT)
|ZY   1   1.000

MARKET->BOS-HYA  JET TIME:   22 FARE:  28.79(CAB)   28.79(NOM)   25.00(AVR) LOS:0.300(NOM) 0.124(ACT) DEMAND:     10(NOM)   8(ACT)
|ZY   1   0.410|ZY   3   0.590

MARKET->HYA-BOS  JET TIME:   22 FARE:  28.79(CAB)   28.79(NOM)   25.68(AVR) LOS:0.300(NOM) 0.142(ACT) DEMAND:     10(NOM)   8(ACT)
|ZY   4   0.695|ZZ   2   0.305
```

Figure 15.- Total demand and initial desirability parameter determination.

```
                                          78/09/18 12:46:18.82       PAGE   2


MITFTL ATIS         FIRST QUARTER                  D E B U G   P R I N T O U T


                                                       ALLOCATION ITERATION NO.  1

MARKET->ACK-BOS D:     6.36|ZY   2    0.77    0.77|ZZ   2    0.50    0.50
MARKET->BOS-ACK D:     6.04|ZY   1    0.73    0.73|ZZ  10    0.48    0.48
MARKET->ACK-HYA D:     3.72|ZZ   2    0.74    0.74
MARKET->HYA-ACK D:     4.57|ZY   1    0.91    0.91
MARKET->BOS-HYA D:     8.11|ZY   1    0.67    0.67|ZY   3    0.96    0.96
MARKET->HYA-BOS D:     8.32|ZY   4    1.16    1.16|ZZ   2    0.51    0.51




                                                       ALLOCATION ITERATION NO.  4

MARKET->ACK-BOS D:     2.54|ZY   2    0.77    0.77|ZZ   2    0.50    0.50
MARKET->BOS-ACK D:     2.42|ZY   1    0.73    0.20|ZZ  10    0.48    0.48
MARKET->ACK-HYA D:     1.49|ZZ   2    0.74    0.74
MARKET->HYA-ACK D:     1.83|ZY   1    0.85    0.16
MARKET->BOS-HYA D:     3.24|ZY   1    0.67    0.50|ZY   3    0.96    0.96
MARKET->HYA-BOS D:     3.33|ZY   4    1.16    1.16|ZZ   2    0.51    0.51




                                                       ALLOCATION ITERATION NO.  6

MARKET->ACK-BOS D:     0.45|ZY   2    0.45    0.16|ZZ   2    0.29    0.00
MARKET->BOS-ACK D:     1.27|ZZ  10    0.48    0.48
MARKET->ACK-HYA D:     0.27|ZZ   2    0.27    0.00
MARKET->BOS-HYA D:     1.12|ZY   3    0.96    0.15
MARKET->HYA-BOS D:     0.99|ZY   4    0.99    0.00|ZZ   2    0.51    0.25
```

Figure 16.- Demand allocation process. (iterations 1-6)

```
                                        78/09/18 12:46:18.82      PAGE   9


MITFTL ATIS        FIRST QUARTER                    D E B U G  P R I N T O U T


                                              ALLOCATION ITERATION NO.  8

MARKET->BOS-ACK D:    0.32|ZZ  10    0.32    0.32
MARKET->HYA-BOS D:    0.59|ZZ   2    0.51    0.09



                                                OUTPUT FOR PARTICIPANT ZY

FLIGHT     1 LOAD:  BOS    4.90 HYA    5.31 ACK
FLIGHT     2 LOAD:  ACK    4.00 BOS
FLIGHT     3 LOAD:  BOS    4.66 HYA
FLIGHT     4 LOAD:  HYA    4.92 BOS



                                                OUTPUT FOR PARTICIPANT ZZ

FLIGHT     2 LOAD:  ACK    5.57 HYA    5.02 BOS
FLIGHT    10 LOAD:  BOS    3.64 ACK
```

Figure 17.- Demand allocation process. (final results)

Taking the ACK-HYA market for example, we see that the average fare is the same as the the nominal fare. Thus, the difference between the nominal and actual demands is due exclusively to the lower level of service actually offered (0.051 vs. 0.250). The return market, HYA-ACK, has a slightly lower level of service (0.046 vs. 0.051). This is due to the earlier (and thus less convenient) time of day of the single departure serving this market (8:32 vs. 10:00 for the ACK-HYA direction). The fare offered, however, is lower ($18.72 vs. $24.60). This causes (due to the high elasticity of demand with respect to fare) an increase in actual demand which more than offsets the reduction due to the lower level of service.

There is always the question as to whether the total demand in a two-way market should be constructed symmetrical to begin with, e.g. by averaging the two fares and levels of service, rather than having, as here, different demands in each direction. Certainly, the demands are not entirely disjoint; a passenger flying from A to B is likely to fly back from B to A. On the other hand, if there are alternate modes of transportation, then large asymmetries in the fare/level of service structure may cause a directional diversion of demand towards other modes. Since we are interested in out-of-the-ordinary supply conditions (such as asymmetric fares) it was decided to take the latter approach.

The two markets that we have been discussing (ACK-HYA and HYA-ACK) are served by a single entry each. The desirability of each single entry is, therefore, unity. On the ACK-BOS market, however, we see two competing entries, ZY 2 and ZZ 2. Looking back to Figure 14 we see that they both depart at 10:00. ZZ 2, though, is both a one-stop flight, and is the more expensive of the two entries (\$30.95 vs. \$27.20). This is reflected by an initial relative desirability of 0.39 for this flight, with 0.61 going to the competition. Barring capacity saturation, this would be the proportion of total demand allocated to each carrier.

The effect of the time-of-day variation of demand is seen in the BOS-HYA market, where both entries are ZY's, at the same fare (\$25). The different initial relative desirability (0.41 vs. 0.59) is entirely due to the difference in departure times (8:00 vs. 15:00): the latter departure time minimizes the displacement time for a larger portion of the daily demand. Similarly, notice the difference in level of service offered in the HYA-BOS and the ACK-BOS markets. Both have the same number of departures (2), but the simultaneous departures in the latter results in a much lower level of service (0.068 vs. 0.142) than in the market with well-spaced departures (BOS-HYA).

Figure 16 shows the initial iterations (1-6) through the demand allocation loop. The first number after the market name indicates the remaining unallocated demand. Thus, the initial total demand in the ACK-BOS market is 6.36 passengers/day. One-fifth of this (1.27) is allocated during this pass, 0.77 to ZY 2, and 0.5 to ZZ 2, according to their initial desirabilities. There is no load limiting process in effect, and therefore the entire 0.77 demand is "accepted" by flight ZZ 2 (second 0.77). This process continues for all the markets, and nothing different happens until the fourth iteration.

In pass number 4, we see that, in the BOS-ACK market, the allocated demand accepted by flight ZY 1 is 0.2, short of the 0.73 allocated. This is caused by saturation of one of this flight's segments (both are needed to go from BOS to ACK). The other flight (ZZ 10) does not benefit from this reduction until the next pass. The total demand for the market, however, is reduced only by 0.68, and not by 1.21 as during the previous passes.

Actually, both segments of ZY 1 seem to be saturated, as can be seen from the load reduction process taking place in that flight's entries in the HYA-ACK and BOS-HYA markets. No other flight is, for the moment, saturating. During the sixth pass, we see that ZY 1 has been dropped entirely from further consideration, its accepted demand having dropped below a certain minimum during the previous pass. ZZ 2 has also saturated and, as a matter of fact, has not accepted any demand in either the ACK-BOS or the ACK-HYA markets during this pass; it will be dropped from further consideration in these markets. ZY 4 is about to suffer the same fate in the HYA-BOS market. ZZ 10 appears to be the only flight without signs of saturation. The HYA-ACK market has dissapeared completely, since its only entry, ZY 1, is saturated.

Now, to Figure 17 for the final (eighth) pass and results. The market served by ZZ 10 (BOS-ACK) has seen its demand totally allocated (0.32 remaining, 0.32 accepted by ZZ 10). Thus, this market will be dropped from further consideration. Since the last entry in the HYA-BOS is also about to saturate, this is the last allocation pass. The total load carried by each segment of each flight is printed next. The relative low loading of ZZ 10 is apparent.

The unsatisfied total demand in a market can be determined from the last allocation printout for that market. For instance, in the HYA-BOS market, we see that the last iteration allocated 0.09 pax/day (to flight ZZ 2), of the 0.59 pax/day left, and thus 0.50 pax/day were not carried at all. This represents 6% of the 8.32 pax/day original demand for that market. This market is served by both ZY 4 and the second segment of ZZ 2. The average load factors for these flights are 82% and 63% respectively, or a traffic-weighted average of 72%. Looking at Figure 7a we see that a 72% average load factor corresponds to a 0.77 demand/capacity ratio, which (Figure 7b) indicates that 0.94 of the total demand is carried. This corresponds quite well with the 6% turn-away ratio observed in the example.

Figure 18 shows the resulting traffic statistics for this simulation pass. The "Table X" data follows the C.A.B. format (10% sample for the period of time involved). These are passengers actually carried, not the demand computed in Figure 15. The period simulated was one quarter (91.25 days).

While demand was being allocated to each flight, the revenue produced by that demand was also allocated. This revenue is reflected in the carrier's private detailed printout. The private printout for carrier ZZ is shown in Figure 19. For each flight flown by the carrier, the printout shows the reve-

```
                                    78/09/18 12:46:18.82            PAGE  10


MITFTL ATIS    FIRST QUARTER                       T A B L E  X  S T A T I S T I C S



FROM ACK TO BOS TOTAL:       56  ->      ZY      36     ZZ       19
FROM BOS TO ACK TOTAL:       55  ->      ZY      22     ZZ       33
FROM ACK TO HYA TOTAL:       32  ->      ZY       0     ZZ       32
FROM HYA TO ACK TOTAL:       27  ->      ZY      27     ZZ        0
FROM BOS TO HYA TOTAL:       65  ->      ZY      65     ZZ        0
FROM HYA TO BOS TOTAL:       71  ->      ZY      45     ZZ       26

                                                   CARRIER  O-D PASSENGER-MILES
                                                   -------  -------------------
                                                     ZY                118240
                                                     ZZ                 64355

                                                    TOTAL:             182595




                         S Y S T E M  S T A T I S T I C S        78/0


                        S Y S T E M  O P E R A T I N G  S T A T I S T I C S
                        ---------------------------------------------------

                       AVAILABLE SEAT-MILES:                          269924
                       REVENUE PASSENGER-MILES:                       182120
                       TOTAL ENPLANEMENTS:                              3057
                       AVERAGE DAILY EQUIPMENT UTILIZATION:             1:47
                       AVERAGE STAGE LENGTH (MILES):                      55
                       AVERAGE LOAD FACTOR:                            0.675
```

Figure 18.- Traffic statistics printout for annotated example.

```
MITFTL ATIS     FILE STATUS: 10000000   P A R T I C I P A N T  F I L E  P R I N T O U T   LAST USE: 78/09/18 12:46:18.82
FILE ID: TEST0001 78/07/11 10:10:13.28                         TECH AIRWAYS, INC.             UNIVERSE: UNIV0001 78/07/11 09:5

FLIGHT    2 EQUIP: PAN   REVENUE:    233.98  COST/ASM: 0.1805   REV/ASM: 0.4878   REV/RPM: 0.7570   NET INCOME:    147.38
            SEGMENT #    DEPARTS @   ARRIVES @      DIST     TIME        COST     PAX*       ASM         RPM      L.F.*
                1        ACK 10:00   HYA 10:12        20     0:12       30.60     5.6        157         109      69.6
                2        HYA 10:14   BOS 10:44        60     0:30       56.00     5.0        479         300      62.7
                                                --------- ------ -----------  ------ ----------  --------- --------
                         TOTALS/AVERAGES:             79     0:42       86.60       5        635         409      64.4

FLIGHT   10 EQUIP: PAN   REVENUE:    112.71  COST/ASM: 0.1284   REV/ASM: 0.2316   REV/RPM: 0.5087   NET INCOME:     50.21
            SEGMENT #    DEPARTS @   ARRIVES @      DIST     TIME        COST     PAX*       ASM         RPM      L.F.*
                1        BOS  8:00   ACK  8:35        81     0:35       62.50     3.6        644         293      45.5
                                                --------- ------ -----------  ------ ----------  --------- --------
                         TOTALS/AVERAGES:             81     0:35       62.50       4        644         293      45.5



                                                                                   STATION FLOW


                 | ===================== |                        |                        |
                 |    STATION: ACK       |                        |                        |
                 |                       |                        |                        |
                 |  A  8:35  PAN     10  |                        |                        |
                 |  D 10:00  PAN      2  |                        |                        |
                 | ===================== |                        |                        |
                 | ===================== |                        |                        |
                 |    STATION: BOS       |                        |                        |
                 |                       |                        |                        |
                 |  D  8:00  PAN     10  |                        |                        |
                 |  A 10:44  PAN      2  |                        |                        |
                 |                       |                        |                        |
                 |   TYPE  NET   OVN     |                        |                        |
                 |   PAN     0     1     |                        |                        |
                 | ===================== |                        |                        |
```

Figure 19.- Carrier private data printout for participant "ZZ".

```
MITFTL ATIS      FILE STATUS: 10000000   P A R T I C I P A N T  F I L E  P R I N T O U T   LAST USE: 78/09/1
FILE ID: TEST0001 78/07/11 10:10:13.28                   TECH AIRWAYS, INC.                UNIVERSE: UNIV00C


                                FINANCIAL TRANSACTIONS ACTIVE

                    DESCRIPTION                                      TIME        FLOW    FINAL FLOW
                   --------------------------------------------------------------------------------
                    INITIAL PAID-IN CAPITAL                            97        0.00          0.00
                    EQUIPMENT-SECURED 10-YEAR 10% LOAN                 38     6750.00    -250000.00
                    10% 1-YEAR LOAN                                     3     2500.00    -100000.00

                                      EQUIPMENT STATUS

                   TYPE   AGE    #      COST     BOOK1     BOOK2  LIFE1 LIFE2  RESIDV1   RESIDV2
                   ----------------------------------------------------------------------------
                   CN4      0    1    260000    260000    260000     40    40    26000     26000

                                  AIRCRAFT SUMMARY (BY TYPE)

                                                AV.       AV.      AV.        AV.            AV.
                     TYPE  NO AV.  NO. REQ. BOOK VAL.    AGE    USE/DAY   STAGE LEN  BLOCK  SPEED
                     ---------------------------------------------------------------------------

                     CN4     1        0     260000.00    0.0     0:00         0           0.0
                     PAN     0        1          0.00    0.0     1:17        53         124.6

                                       USER PARAMETERS
                                       ---------------

                         COST PER ENPLANEMENT                            1.2500
                         COST PER SEAT-MILE:                             0.0010
                         COST PER PASSENGER_MILE:                        0.0050
                         COST PER $ OF REVENUE:                          0.0700
                         MINIMUM STOP TIME:                              2.0000
                         MINIMUM INTERFLIGHT TIME:                       2.0000
                         FARE FORMULA COEFFIENT 1 ($):                   0.0000
                         FARE FORMULA COEFFICIENT 2 ($/NMI)              0.0000
```

Figure 19.- continued.

nue collected during the last simulation period, segment-by-segment direct costs (the Group 1 costs defined in Section 3.6), as well as a "net" income figure (the direct contribution of that flight to the total overhead and profit).

This printout also includes the flow of flights in and out of every airport at which flights initiate and terminate, as well as the number of aircraft (by type) that must "sleep" overnight at that station. This printout is useful in debugging large flight networks. Note that individual flight segments (intermediate stops) are not listed.

Next follows a list of the financial transactions active for the participant, including the number of periods remaining, the periodic cash flow, and the final cash flow implied by the transaction. Aircraft information is contained in two listings; the first one shows the number of aircraft owned or leased by the carrier, grouped by "batches" of identical length of time in service. Shown are the number and type of aircraft, length of time in service (or time remaining in lease for leased aircraft), the cost value (lease paymants for a lease), and the book value, life, and residual values for each of the two depreciation schemes carried. The second listing shows the usage and availability of aircraft by type as well as their operational statistics.

Finally, this printout lists the various cost parameters that are being charged against this participant, some operational time limitations, and the coefficients of the fare formula he is using.

Available to all participants is the financial information for each participant, embodied in four listing: a Statement of Earnings, a Statement of Changes in Financial Position, a Balance Sheet, and a list of operational and financial ratios. Figure 20 shows all this data for participant ZZ ("Tech Airways, Inc."). The definitions of the financial terms may be found in Section 3.7.

4.3 FIRST EXPERIMENTAL USAGE AT M.I.T.

The Flight Transportation Laboratory of the Massachusetts Institute of Technology offers a two-week intensive summer course on the fundamental aspects of air transportation. This graduate-level course is oriented towards industry and government personnel, and comprises sixty hours of formal classes and team participation in a short game. Use of the game is

```
                                S T A T E M E N T   O F   E A R N I N G S
OPERATING REVENUES:
                     PASSENGER                                              31635
                     OTHER                                                   3125
                                                                     ------------

                               TOTAL OPERATING REVENUES                                         34760

OPERATING EXPENSES:
                     FLYING EXPENSES                                        13605
                     PASSENGER SERVICES                                      1382
                     RESERVATIONS AND SALES                                  2214
                     GENERAL AND ADMINISTRATIVE                               101
                     DEPRECIATION AND AMORTIZATION                           4688
                                                                     ------------
                               TOTAL OPERATING EXPENSES                                         21991



NON-OPERATING EXPENSES:
                     INTEREST EXPENSE                                        6750
                     LEASE COSTS                                                0
                                                                     ------------
                               TOTAL NON-OPERATING EXPENSES                                      6750
                                                                                         ------------

EARNINGS BEFORE TAXES AND EXTRAORDINARY ITEMS                                                    6020

CORPORATE INCOME TAXES                                                          0
     MINUS: INVESTMENT TAX CREDIT                                               0
                                                                     ------------

                               TOTAL TAXES                                                          0
                                                                                         ------------

EARNINGS BEFORE EXTRAORDINARY ITEMS                                                              6020

EXTRAORDINARY ITEMS:
                     GAINS ON MAJOR DISPOSITION OF FLIGHT EQUIPMENT         39688
                     MINUS: CAPITAL GAINS TAX                               14013
                                                                     ------------
                               TOTAL EXTRAORDINARY ITEMS                                        25675
                                                                                         ------------

NET EARNINGS                                                                                    31694
                                                                                         ============
```

Figure 20.- Common data printout for participant "ZZ" (continues).

```
MITFTL ATIS    FIRST QUARTER                    TECH AIRWAYS, INC.             78/09/18 12:46:18.82              PAGI
                                          STATEMENT OF CHANGES IN FINANCIAL POSITION


                SOURCES OF WORKING CAPITAL

                  FROM OPERATIONS:

                     NET AFTER TAX INCOME                                 31694
                     ADD: DEFRECIATION EXPENSE                             4688
                     ADD: BOOK VALUE OF AIRCRAFT SOLD                    245313
                                                                   ------------
                              TOTAL FROM OPERATIONS                                          281694

                  OTHER SOURCES:

                     10% 1-YEAR LOAN                                     100000
                                                                   ------------
                              TOTAL FROM OTHER SOURCES                                       100000
                                                                                       ------------
                                                                                             381694
                                                                                       ============


                USES OF WORKING CAPITAL

                     PURCHASE OF 1 CN4                                   260000
                                                                   ------------
                              TOTAL USES OF WORKING CAPITAL                                  260000

                     NET CHANGE IN WORKING CAPITAL                                           121694
                                                                                       ------------
                                                                                             381694
                                                                                       ============
```

Figure 20.- (continued)

```
TL ATIS    FIRST QUARTER                     TECH AIRWAYS, INC.             78/09/18 12:46:18.82              PAGE   7
                                          B A L A N C E   S H E E T

                                                       ASSETS

           CURRENT ASSETS:

                CASH AND EQUIVALENT                                                                 371694

           FIXED ASSETS

                FLIGHT EQUIPMENT                                              260000
                MINUS: ACCUMULATED DEPRECIATION                                    0
                                                                        ------------
                               TOTAL FIXED ASSETS                                                   260000
                                                                                              ------------

                                                                                                    631694
                                                                                              ============


                                                     LIABILITIES

           CURRENT LIABILITIES

                10% 1-YEAR LOAN                                               100000
                                                                        ------------
                               TOTAL CURRENT LIABILITIES                                            100000

           OTHER LIABILITIES

                EQUIPMENT-SECURED 10-YEAR 10% LOAN                            250000
                DEFERRED INCOME TAXES                                           3581
                                                                        ------------
                               TOTAL OTHER LIABILITIES                                              253581


           EQUITY                                                                                   278113
                                                                                              ------------

                                                                                                    631694
                                                                                              ============
```

Figure 20.- (continued)

```
MITFTL ATIS    FIRST QUARTER                        TECH AIRWAYS, INC.            78/09/18 12:46:18.82              PAGI


                                         O P E R A T I N G   S T A T I S T I C S
                                         ---------------------------------------

                                   TOTAL SEAT-MILES:                                     116792
                                   REVENUE PASSENGER-MILES:                               64132
                                   TOTAL ENPLANEMENTS:                                     1105
                                   AVERAGE DAILY EQUIPMENT UTILIZATION:                    1:17
                                   AVERAGE STAGE LENGTH (MILES):                             53
                                   AVERAGE LOAD FACTOR:                                   0.549

                                         F I N A N C I A L   S T A T I S T I C S
                                         ---------------------------------------


                    RETURNS (P.A.):   INCLUDING INTEREST -

                                   RETURN ON OWNER'S EQUITY                               45.6%
                                   RETURN ON SALES                                       100.2%

                                  EXCLUDING BEFORE-TAX INTEREST -

                                   RETURN ON ASSETS                                       22.2%
                                   RETURN ON INVESTED CAPITAL                             26.3%


                    TURNOVERS (P.A.):      INVESTMENT TURNOVER                            0.238
                                   ASSET TURNOVER                                         0.200
                                   EQUITY TURNOVER                                        0.455


                    DEBT RATIOS:           CURRENT RATIO (C. ASSETS/C. LIABILITIES)       3.717
                                   D/E (LONG-TERM DEBT/EQUITY)                            0.899
                                   D/A (LONG-TERM DEBT/ASSETS)                            0.396
                                   TIMES INTEREST COVERAGE                                1.892
```

Figure 20.- (concluded)

introduced in the third day, after the participants have been exposed to some fundamental concepts, particularly in airline economics. Four and one-half classroom hours are devoted to introducing and explaining the game, its objective, rules, scenario, etc. The participants work on their team decisions after regular class hours.

During the 1978 session, there were a total of 32 participants from U.S. and foreign governments, universities, and businesses, including international air carriers, airframe manufacturers, and banks. There were no participants from U.S. air carriers. The participants were divided into nine teams of three or four members each.

4.3.1 Game Scenario

The scenario represented an eight-airport closed market area. Three competing airlines were assumed, with complete freedom of routing, scheduling, and fare-setting. The simulated period of operations was one year, and thus there was no market seasonality. The market was also stable (no growth trend). Four types of aircraft were available to the users. For simplicity, an infinite supply of leases was assumed (infinite fleet flexibility) and negative cash-on-hand levels were allowed (no financial requirements). Table 3 summarizes

Type:	Piper Navajo Chieftain	DHC Twin Otter	Swearinger Metro II	Fairchild/ Fokker F227
Identifier:	PAN	DHT	SWM	FK7
Seats:	8	19	19	40
Average airspeed (kts/mph)	188/216	165/190	231/266	230/265
Direct Op. Costs:				
per block hour:	78	160	180	300
per takeoff/landing cycle:	5	9	15	35
per day (inc. lease costs):	145	348	455	598
Reference price*, $	300,000	755,000	990,000	1,250,000

---

* Lease costs are 16% of the reference price per year.

Table 3.- Aircraft characteristics

the aircraft's assumed characteristics. These characteristics are indicative of real aircraft data, but have been modified so that all four aircraft's costs per seat-mile fall roughly in a straight line when plotted against number of seats*. This was done in order to illustrate simple fleet planning methodology and trade-offs.

The three airlines were assumed to have been operating previously with a disjoint route structure and a fixed fare formula, as if in a regulated environment. The participants were given the results of the operations of their carriers in the previous year. The initial route structure covered most of the possible city-pairs, so that the traffic data was a good indication of market demand. All three airlines were operating close to the break-even point. Figure 21 shows the scenario geography (airports), as well as the assumed initial route maps for the three carriers. Complete routing freedom was granted, but all aircraft had to be based at a certain airport (NYC for carrier NY, Boston for carrier BO, Providence for carrier PV). Participants were explained that the game's model behaved "in a way similar to the real world" but were not given detailed data about the model's operations or its

---

* The DHC Twin Otter is slightly cheaper than the Metro II for stages under 72.5 miles, slightly more expensive for longer stages.

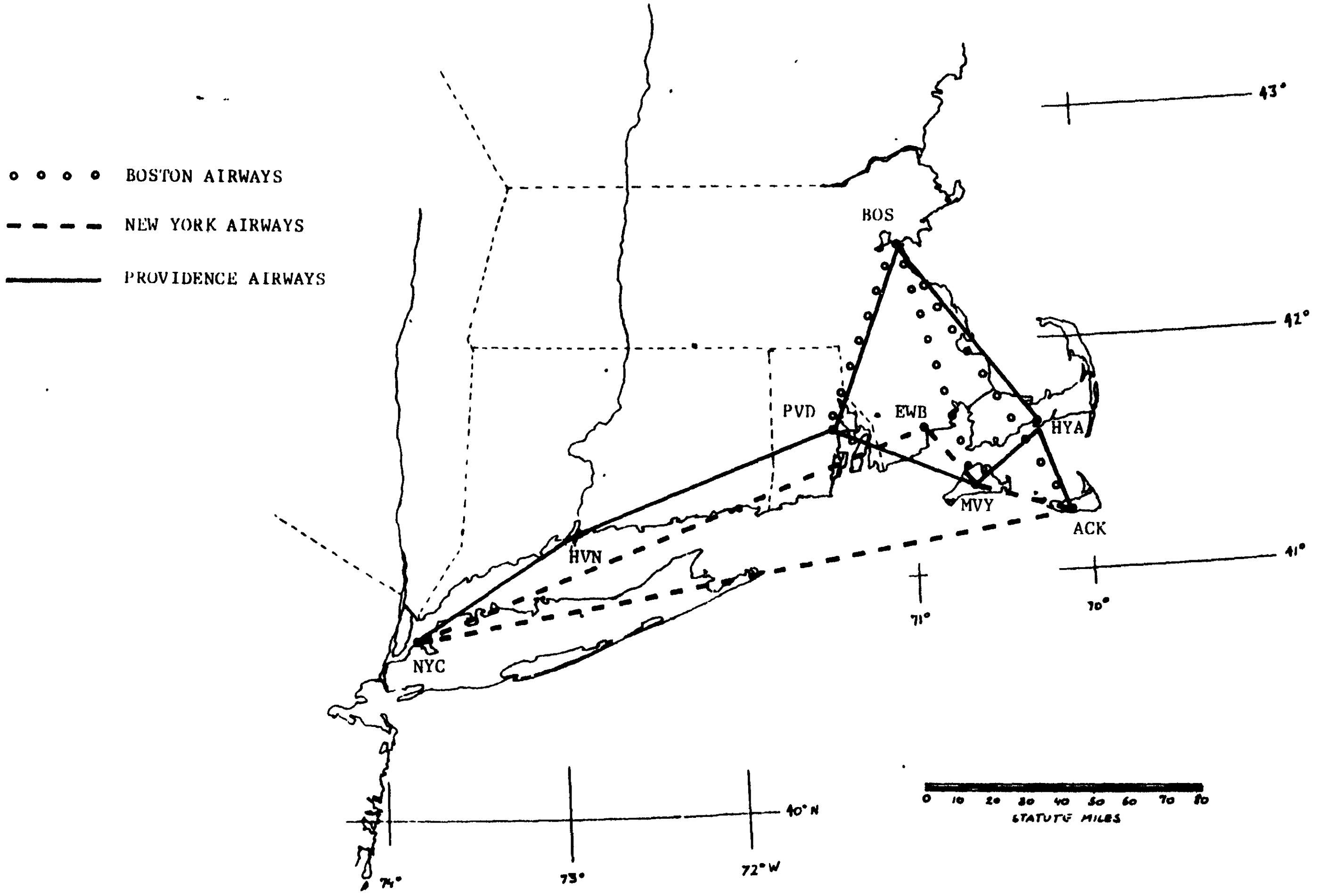


Figure 21.- Game scenario geography and initial route structure for MIT summer 1978 games.

parameters, particularly the elasticities. Average price elasticity over the network ranged from -1.2 to -1.4, while the elasticity with respect to the level of service (and with respect to trip time) was 0.4. The behavioral desirability multiplier (Section 3.4), which determines the rate of decay of the time-desirability function, was again arbitrarily set at 4.

Three parallel games were run simultaneously, and thus there were three BO teams, three NY teams, and three PV teams. These games, or "leagues", were labelled A, B, and C. The purpose of this division was both to reduce the size of the teams without having an unrealistically large number of competitors in the same markets, and to allow parallel comparison of similarly-based airlines (e.g. NY-A vs. NY-B vs. NY-C).

The average terminal session required to input a team's decisions was one hour*, and cost approximately 8 seconds of machine time using an IBM 370/168. The computer simulation for a typical three-participant game iteration required some 6 seconds of machine time, and produced some 3,500 lines of printed output. The total cost (nine game iterations) was approximately 5 minutes of machine time. The cost is expected

---

* In this exercise, participants did not use the terminal as an interactive decisions-making aid.

to be proportional to the product of the number of city-pairs considered and the number of participants.

The game objective given to the participants was to maximize the carriers' after-tax income. The limited time available restricted the number of game iterations to three. Although the iterations are labelled "year 1", "year 2", etc., they are really decoupled from one another, and could be interpreted as three decision iterations for the same year of operations. This decoupling is caused by the static scenario data and the absence of financial and fleet decisions carrying over from one year to the next.

The participants were not professional airline planners and schedulers; therefore, the results cannot be interpreted as indicative of what real airline managers would produce. Nevertheless, this case provides a good example of the level of analysis detail possible using the game, and thus some of this analysis will be carried out to illustrate the capabilities of the game, with all the conclusions subject to the above caveat.

	Original	-------First iteration results------		
		League A	League B	League C
Total seat-miles	56,502,464	137,765,232	105,398,768	113,703,168
Total RPM	26,580,096	32,337,184	35,892,960	35,329,520
Total passengers	284,627	329,605	303,148	420,995
Average Trip miles/pax	93.4	98.1	118.4	83.9
Average segment, miles	63	71	77	62
Av. segmets/pax trip	1.48	1.38	1.54	1.35
Total revenue, $	7,876,007	9,041,278	7,936,134	9,735,732
Average ticket, $	27.67	27.43	26.18	23.12
Average revenue, /rpm	29.6	27.5	22.1	27.6
Total costs, $	7,331,536	14,039,011	11,837,025	14,128,247
Av. cost, /seat-mile	13.0	10.2	11.2	12.4
Breakeven load factor	0.439	0.371	0.508	0.450
Actual load factor	0.470	0.235	0.341	0.311
Ratio (Actual/Breakeven)	1.07	0.63	0.67	0.69
System net income, $	544,471	(-4,997,733)	(-3,900,891)	(-4,392,515)
Aircraft used:				
PAN/DHT/SWM/FK7	3/3/1/1	4/2/3/2	4/3/2/1	7/3/4/0
Reference price, $	5,405,000	8,180,000	6,695,000	8,325,000
Seat-miles per hour	31,668	50,494	38,540	43,142
Efficiency factor*	0.209	0.311	0.313	0.301

---

* see text

Table 4.- Summer 1978 MIT games - system summary, initial state and first iteration.

4.3.2 System-level Game Analysis

System-wide analysis (i.e. all carriers combined) is carried out by observing a number of aggregate data and ratios.

Table 4 shows the system summary for the three leagues' first year (iteration period), along with the results from the supposed previous year (initial state). As it can be seen, the general trend was to increase the level of operations, in an attempt to increase each one's market share by increasing frequency share. This did not work out well, since the competitive markets became service-saturated. Total demand did increase by some 35%, due also to price level reductions of 7% to 25%. A simple regresion analysis, using flight frequency as a measure of level of service yielded a global demand elasticity with respect to price of -1.4 (surprisingly close to the average of the values used on each individual market), while the correlation of demand with flight frequency was practically zero (consistent with the supply saturation situation).

The efficiency with which aircraft are used was measured by means of a "fleet efficiency factor". This factor is the ratio of the total seat-miles actually flown in a given period of time, divided by the theoretical capability of the fleet (total seat-miles in that same period of time). This theoretical capability is simply the sum, for all aircraft, or each aircraft's cruising speed times the number of seats, multiplied by the number of hours in the period under consideration. For example, a 200-mph, 8-seat aircraft can theoretically produce 1,600 seat-miles per hour, or 14,016,000 seat-miles per year. This efficiency factor is a measure of fleet utilization that accounts for the lower productivity of smaller flight segments (two one-hour segments produce less seat-miles than a two-hour segment).

The 90% to 144% increase in Seat-miles was accomplished with a 21% to 60% increase in fleet capacity and an increase in efficiency factor from 0.21 to around 0.3. The increase in operations costs produced by this increase in service caused substantial losses for all participants. Note the reduction in costs per seat-mile with the number of seat-miles flown, suggesting an overall economy of scale.

After the first year results, participants became much more cautious. Table 5 shows the system results for the second game iteration. As it could be predicted from the service-saturated situation of the previous year, the system with the lowest level of operations was the most (the only!) prof-

	------Second iteration results------		
	League A	League B	League C
Total seat-miles	87,277,952	50,951,504	76,988,512
Total RPM	32,802,384	20,513,184	33,772,848
Total passengers	339,972	265,980	368,638
Average Trip miles/pax	96.5	77.1	91.6
Average segment, miles	63	65	64
Av. segmets/pax trip	1.53	1.19	1.43
Total revenue, $	9,128,926	7,318,482	9,163,318
Average ticket, $	26.85	27.52	24.85
Average revenue, /rpm	27.8	35.7	27.1
Total costs, $	10,403,199	6,824,396	10,391,027
Av. cost, /seat-mile	11.9	13.4	13.5
Breakeven load factor	0.429	0.375	0.497
Actual load factor	0.376	0.403	0.439
Ratio (Actual/Breakeven)	0.63	0.67	0.69
System net income, $	(-1,302,273)	494,086	(-1,227,709)
Aircraft used:			
PAN/DHT/SWM/FK7	7/0/2/1	7/0/0/1	7/2/2/0
Reference price, $	4,080,000	3,350,000	5,590,000
Seat-miles per hour	22,204	22,696	29,424
Efficiency factor	0.449	0.256	0.299

Table 5.- Summer 1978 MIT games - system summary, second iteration.

itable one. The results for the third and last iteration (Table 6) are interesting: the League B participants, spurred perhaps by the previous positive results, again fell into the "frequency war" trap, and their profitability tumbled again, while those of Leagues A and C continued the trend towards reduced operations with increased fleet utilization. The final results of game C are particularly noteworthy with a fleet 55% the size *of the original given fleet (as a matter of fact, composed exclusively of the smallest aircraft available) they carried 127% of the original traffic, almost doubling the net system income obtained under the original market monopoly scenario, while the average price level (price per seat-mile) dropped approximately 15%. In the given original schedule, only one out of 22 markets served was "competitive" (the second largest carrier must carry more than 10% of the market). Using the same definition, 10 out of 17 markets were competitively served during game C's last iteration.

4.3.3 Carrier- and Market-level analysis

Since game "C" produced the best final results (with respect to the game objective of maximizing the final net

---

* As measured by the total seat-miles per hour.

	-------Third iteration results------		
	League A	League B	League C
Total seat-miles	69,283,600	78,483,264	50,998,544
Total RPM	32,779,504	20,688,336	33,867,296
Total passengers	349,997	327,658	344,763
Average Trip miles/pax	93.7	93.7	98.2
Average segment, miles	64	65	77
Av. segmets/pax trip	1.46	1.44	1.28
Total revenue, $	9,091,105	8,629,361	8,576,600
Average ticket, $	25.97	26.34	24.88
Average revenue, /rpm	27.7	28.1	25.3
Total costs, $	9,176,709	9,987,937	7,598,295
Av. cost, /seat-mile	13.2	12.7	14.9
Breakeven load factor	0.510	0.483	0.588
Actual load factor	0.473	0.391	0.664
Ratio (Actual/Breakeven)	0.93	0.81	1.13
System net income, $	(-85,604)	(-1,358,576)	978,305
Aircraft used:			
PAN/DHT/SWM/FK7	6/0/3/0	8/3/1/0	10/0/0/0
Reference price, $	4,770,000	5,655,000	3,000,000
Seat-miles per hour	25,530	22,696	17,280
Efficiency factor	0.310	0.302	0.337

Table 6.- Summer 1978 MIT games - system summary, third iteration.

income), we will analyze the peformance of the participants in this game. Table 7 shows the evolution of the traffic carried in the nine largest city-pair markets in the game. These nine markets account for 75% of the activity in the entire game. The first column of Table 7 shows the "nominal" bi-directional daily demand on each market (see Section 3.2 for a description of the demand model). The actual demand is affected by the price level, the level of service, and, in one case, capacity limitations. With the elasticities used (around -1.4 for price, 0.4 for level of service), management decisions significantly affected the total demand.

The evolution of prices is shown in Table 8. As it can be seen, participant PV's prices are consistently below those of its competitors. Notice how, after the initial surge, prices do not fluctuate very much, and can be considered stable by the third and last iteration. The level of services offered in each market can be measured by the level of service index (see Section 3.2). Table 9 shows the level of service indices for the key markets; it must be remembered that the level of service is extremely non-linear with respect to the frequencies offered and, futhermore, it is affected by the time-of-day spacing of the schedules. To illustrate the correlation between this index and the schedule, Figure 22 shows

Market	Nominal	Original	1	2	3
1 BOS-HYA	130	86.4*	210.1	202.3	191.7
2 ACK-BOS	130	134.4	194.3	174.5	156.8
3 BOS-MVY	88	88.7	121.0	120.8	120.8
4 ACK-NYC	64	68.8	71.8	74.8	72.1
5 ACK-HYA	60	60.7	130.1	100.3	92.0
6 MVY-NYC	48	50.1	52.7	54.5	54.4
7 BOS-PVD	46	76.4	94.7	89.0	70.9
8 HYA-MVY	46	47.3	109.0	74.2	59.6
9 EWB-NYC	36	54.4	55.9	57.9	56.7

---

* Capacity saturation resulted in a substantial fraction of demand unsatisfied.

Table 7.- Average trafic (pax/day) in game "C"'s nine largest markets.

				1			2			3	
	Market	Orig.	BO	NY	PV	BO	NY	PV	BO	NY	PV
1	BOS-HYA	28.79	25.24	23.74	17.00	22.00	22.99	20.00	22.00	23.60	20.00
2	ACK-BOS	30.95	30.00	26.86	20.00	28.00	25.98	25.00	28.00	26.91	25.00
3	BOS-MVY	29.75	28.00	24.70	18.00	26.00	23.91	22.00	25.00	24.62	22.00
4	ACK-NYC	43.64		38.50			37.14		38.00	39.22	
5	ACK-HYA	24.60	22.12	20.62	11.00	18.00	19.99	18.00	18.00	20.30	18.00
6	MVY-NYC	40.65		35.62			34.88		38.00	39.22	
7	BOS-PVD	27.59	25.00	22.54	11.00	24.00	21.83	20.00		22.33	20.00
8	HYA-MVY	25.20	18.00	20.14	11.00	18.00	19.53	18.00	18.00	19.79	18.00
9	EWB-NYC	39.57		34.54			33.34			35.03	

All prices in dollars

Table 8.- Prices offered in the 9 largest markets during game"C".

		Original	1	2	3
1	BOS-HYA	0.290	0.487	0.474	0.439
2	ACK-BOS	0.272	0.425	0.413	0.385
3	BOS-MVY	0.256	0.505	0.410	0.420
4	ACK-NYC	0.300	0.292	0.286	0.310
5	ACK-HYA	0.312	0.563	0.531	0.503
6	MVY-NYC	0.280	0.285	0.285	0.329
7	BOS-PVD	0.355	0.473	0.359	0.208
8	HYA-MVY	0.288	0.563	0.500	0.390
9	EWB-NYC	0.279	0.270	0.270	0.290

Table 9.- Levels of service offered on 9 largest markets during game "C".

L.O.S. = 0.208

```
| ============================= |
| TO BOSTON MA            BOS 1 |
| ============================= |
| FR PROVIDENCE RI        PVD 1 |
|             CAB   24.04       |
|              BO   24.00       |
|              NY   22.33       |
|              PV   20.00       |
|  5:57  6:25   PV  20  PAN   0 |
|  6:27  6:55   PV  01  PAN   0 |
|  7:27  7:55   PV  40  PAN   0 |
|  9:00  9:28   NY 302  PAN   0 |
| 13:57 14:25   PV  44  PAN   0 |
| 14:30 14:58   NY 304  PAN   0 |
| 20:00 20:28   NY 306  PAN   0 |
| ============================= |
| TO PROVIDENCE RI        PVD 1 |
| ============================= |
| FR BOSTON MA            BOS 1 |
|             CAB   24.04       |
|              BO   24.00       |
|              NY   22.33       |
|              PV   20.00       |
|  8:14  8:42   NY 301  PAN   0 |
| 12:10 12:38   PV  43  PAN   0 |
| 13:44 14:12   NY 303  PAN   0 |
| 19:14 19:42   NY 305  PAN   0 |
| 22:00 22:28   PV  33  PAN   0 |
| 23:00 23:28   PV  51  PAN   0 |
| 23:08 23:36   PV  14  PAN   0 |
```

L.O.S. = 0.563

```
============================= | ============================= |
TO HYANNIS MA           HYA 1 | TO NANTUCKET MA         ACK 1 |
============================= | ============================= |
FR NANTUCKET MA         ACK 1 | FR HYANNIS MA           HYA 1 |
            CAB   22.12       |             CAB   22.12       |
             NY   20.62       |              NY   20.62       |
             PV   11.00       |              PV   11.00       |
  7:05  7:20  BO 302  PAN   0 |   6:35  6:50  BO 301  PAN   0 |
  7:18  7:34  PV  20  DHT   0 |   7:58  8:14  PV  01  DHT   0 |
  8:07  9:12  NY 401  SWM   1 |   8:15  8:30  BO 303  PAN   0 |
  8:30  8:46  PV  02  DHT   0 |   8:20  8:33  NY 101  SWM   0 |
  8:45  9:00  BO 304  PAN   0 |   9:08  9:24  PV  21  DHT   0 |
  8:50  9:03  NY 102  SWM   0 |   9:30 10:35  NY 402  SWM   1 |
  9:40  9:56  PV  22  DHT   0 |   9:55 10:10  BO 305  PAN   0 |
 10:25 10:40  BO 306  PAN   0 |  10:18 10:34  PV  03  DHT   0 |
 10:50 11:06  PV  04  DHT   0 |  11:28 11:44  PV  23  DHT   0 |
 12:00 12:16  PV  24  DHT   0 |  11:35 11:50  BO 307  PAN   0 |
 12:05 12:20  BO 308  PAN   0 |  12:00 12:13  NY 103  SWM   0 |
 12:30 12:43  NY 104  SWM   0 |  12:38 12:54  PV  05  DHT   0 |
 13:07 14:12  NY 403  SWM   1 |  13:15 13:30  BO 309  PAN   0 |
 13:10 13:26  PV  06  DHT   0 |  13:48 14:04  PV  25  DHT   0 |
 13:45 14:00  BO 310  PAN   0 |  14:30 15:35  NY 404  SWM   1 |
 14:20 14:36  PV  26  DHT   0 |  14:55 15:10  BO 311  PAN   0 |
 15:25 15:40  BO 312  PAN   0 |  14:58 15:14  PV  07  DHT   0 |
 15:30 15:46  PV  08  DHT   0 |  15:40 15:53  NY 105  SWM   0 |
 16:10 16:23  NY 106  SWM   0 |  16:08 16:24  PV  27  DHT   0 |
 16:40 16:56  PV  28  DHT   0 |  16:35 16:50  BO 313  PAN   0 |
 17:05 17:20  BO 314  PAN   0 |  17:18 17:34  PV  09  DHT   0 |
 17:50 18:06  PV  10  DHT   0 |  18:25 18:40  BO 315  PAN   0 |
 18:07 19:12  NY 405  SWM   1 |  18:28 18:44  PV  29  DHT   0 |
 18:55 19:10  BO 316  PAN   0 |  19:20 19:33  NY 107  SWM   0 |
 19:00 19:16  PV  30  DHT   0 |  19:30 20:35  NY 406  SWM   1 |
 19:50 20:03  NY 108  SWM   0 |  19:38 19:54  PV  11  DHT   0 |
 20:10 20:26  PV  12  DHT   0 |  20:05 20:20  BO 317  PAN   0 |
 22:30 22:46  PV  14  DHT   0 |  20:48 21:04  PV  31  DHT   0 |
                                 21:58 22:14  PV  13  DHT   0 |
```

Figure 22.- Schedules corresponding to the lowest and highest values of the level of service index.

the actual schedules of the markets with the lowest (BOS-PVD during iteration 3) and highest (ACK-HYA during iteration 1) levels of service. Notice, in Table 9, the service improvement in the ACK-NYC and MVY-NYC markets during the last iteration, when participant BO enters the markets, and the reduction in the BOS-PVD market when BO leaves it.

The general trend is to increase the level of service in the largest markets, and reduce it in the smaller ones (in the initial state, all major markets were quite uniformly served). This can be seen by plotting (Figure 23) the data of Table 9. In spite of numerous "discrete" events, such as participant BO abandoning market BOS-PVD during the last iteration, or the network-induced level of service increase in the ACK-HYA market*, the trend lines do indicate a settling towards a decreasing level of service with market decreasing importance.

Table 10 shows the evolution of the market shares; as mentioned before, the initial state was essentially monopolistic. Three markets continue to be monopolistic until the last iteration. Carrier PV's market share advantage is clear; however, its market share never exceeds 63% (nor, during the last iteration, is less than 43%). Thus, this carrier's outstand-

---

* This is due to the serving of the ACK-BOS markets via one-stop flights stopping at HYA.

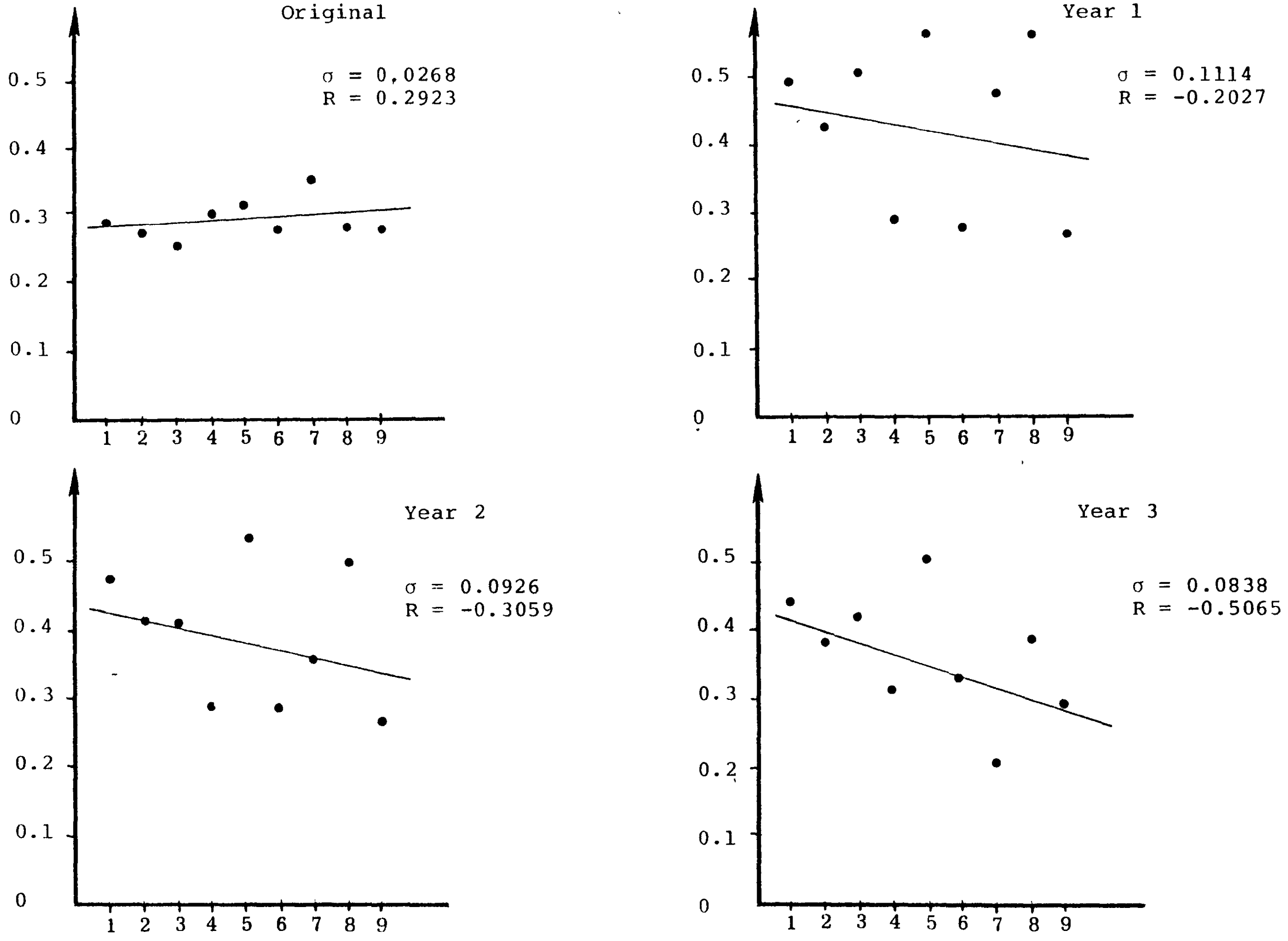


Figure 23.- Variation of level of service index on game "C"'s nine largest markets.

	Original			1			2			3		
Market	BO	NY	PV	BO	NY	PV	BO	NY	PV	BO	NY	PV
1 BOS-HYA	0	0	100	35.8	9.0	55.2	40.0	8.1	51.9	38.2	12.1	49.7
2 ACK-BOS	100	0	0	28.9	19.0	52.1	40.1	22.5	37.1	14.6	33.9	51.5
3 BOS-MVY	100	0	0	64.8	13.4	21.9	41.0	17.5	41.5	34.6	20.2	45.2
4 ACK-NYC	0	100	0	0	100.0	0	0	100.0	0	11.3	88.8	0
5 ACK-HYA	0	0	100	21.6	18.5	59.9	34.0	23.5	42.5	10.4	29.1	60.5
6 MVY-NYC	0	100	0	0	100.0	0	0	100.0	0	11.8	88.2	0
7 BOS-PVD	50.2	0	49.8	38.8	11.5	49.6	27.4	19.9	52.8	0	37.1	62.9
8 HYA-MVY	0	0	100	28.0	11.3	60.6	38.4	17.2	44.4	23.2	33.8	43.1
9 EWB-NYC	0	100	0	0	100.0	0	0	100.0	0	0	10.0	0
Average*	87	100	86	35.3	28.8	50.6	37.8	33.5	45.0	23.5	39.2	51.5

---

* Traffic-weighted average, markets served only.

Table 10.- Market shares in the 9 largest markets during game "C"

		Original	1	2	3
Total seat-miles	BO	17,342,320	33,898,208	15,581,212	9,813,878
	NY	27,141,488	55,747,520	39,110,976	29,381,136
	PV	12,018,640	24,057,440	22,296,320	11,803,541
Revenue Pax-miles	BO	6,867,735	7,018,817	6,395,001	7,346,522
	NY	13,689,638	18,769,824	19,367,360	18,128,880
	PV	6,022,746	9,540,893	8,010,500	8,391,914
Total revenue, $	BO	2,576,976	2,956,561	2,466,039	1,576,262
	NY	2,680,872	4,006,770	4,070,115	4,234,413
	PV	2,618,159	2,772,401	2,627,164	2,765,925
Av. rev. /seat-mile	BO	37.5	42.1	38.6	21.5
	NY	19.6	21.3	21.0	23.4
	PV	43.5	29.1	32.8	33.0
Total costs, $	BO	2,552,360	4,630,846	2,522,734	1,529,393
	NY	2,612,585	5,713,008	4,476,847	4,065,575
	PV	2,444,322	3,784,393	3,391,451	2,502,264
Av. cost, /seat-mile	BO	14.7	13.7	16.2	15.6
	NY	9.6	10.3	11.4	13.8
	PV	20.3	15.8	15.1	21.2
Breakeven load factor	BO	0.392	0.324	0.420	0.725
	NY	0.490	0.481	0.545	0.592
	PV	0.467	0.541	0.464	0.643
Actual load factor	BO	0.396	0.207	0.410	0.749
	NY	0.504	0.337	0.495	0.617
	PV	0.501	0.397	0.359	0.711
Net income, $	BO	24,616	(-1,674,285)	(-56,695)	46,869
	NY	68,287	(-1,706,238)	(-406,732)	168,838
	PV	173,837	(-1,011,922)	(-764,287)	263,661

Table 11.- Game "C" system analysis - revenues and costs.

		Original	1	2	3
Total enplanements	BO	95,466	114,124	105,162	64,652
	NY	75,077	130,557	137,899	142,669
	PV	114,085	176,314	125,576	137,441
Average miles/pax	BO	71.9	61.5	60.8	113.6
	NY	182.3	143.8	140.4	127.1
	PV	52.8	54.1	63.8	61.1
Av. segment, miles	BO	66	58	56	76
	NY	105	96	96	105
	PV	49	40	44	46
Av. segments/pax	BO	1.09	1.06	1.09	1.50
	NY	1.73	1.50	1.46	1.21
	PV	1.08	1.35	1.45	1.33
A/C used (PAN/DHT/SWM/FK7)	BO	0/3/0/0	5/0/0/0	4/0/0/0	2/0/0/0
	NY	0/0/1/1	0/0/4/0	2/0/2/0	5/0/0/0
	PV	3/0/0/0	2/2/0/0	2/3/0/0	3/0/0/0
Reference cost, $	BO	2,265,000	1,500,000	1,200,000	600,000
	NY	2,240,000	3,960,000	2,580,000	1,500,000
	PV	900,000	2,110,000	2,865,000	900,000
Capacity, (seat-miles/hour)	BO	10,830	8,640	6,912	3,456
	NY	15,654	20,216	13,564	8,640
	PV	5,184	10,676	14,286	5,184
Efficiency factor	BO	0.183	0.448	0.257	0.324
	NY	0.198	0.315	0.329	0.388
	PV	0.265	0.257	0.178	0.260

Table 12.- Game "C" analysis - network efficiency

ing performance is obtained with market shares around 50% in all major markets served (six out of the nine largest markets).

Table 11 shows the revenue and cost analysis for the game; note the high load factors during the last and most succesful iteration. The apparent economies of scale are such that the breakeven load factor increases as the level of activity decreases; thus, the increase in actual load factor made possible by using smaller aircraft more than offsets the increased production costs*.

Finally, Table 12 shows the network efficiency analysis for game "C". As expected, the New York-based carrier has the highest segment length and passenger trip averages, in spite of its inroads into the short markets (ACK-BOS, HYA-MVY). The average number of segments per passenger is a measure of the non-stop vs. one-stop mix of flights**. Carrier NY starts with a high percentage of one-stop services, while BO continues with mainly non-stops until the last iteration. Eventually, the most succesful carriers (NY and PV) settle for an average

---

* Note that these costs include global activity-related indirect costs as well as aircraft-related direct operating costs.

** The percentage of non-stop flights is approximately two minus this index. For example, 1.35 average segments/pax is equivalent to 65% non-stop and 35% one-stop flights.

value around 1.4*. This seems to be a reasonable tradeoff between network efficiency and passenger convenience.

Due to the limited time available, the game participants did not have the benefit of such a detailed analysis as the one performed here; rather, they operated on an "incremental" mode with regards to total level of activity and aircraft to be used, while, surpirsingly, major schedule revisions were the rule rather than the exception. It would be interesting to speculate what the decisions would have been had they had time and resources to carry out such a detailed analysis. In particular, would the data of Figure 23 be used to increase the level of service in the under-served markets at the expense of the over-served ones, getting even closer to the trend line?

Some obvious decision mistakes were made, such as NY's weak dabbling in the Boston-based markets (market shares under 20%), or BO's sudden abandoning the BOS-PVD market, or NY's use of the smaller aircraft. At the risk of monday-night quarterbacking, the author could not resist the temptation of running a test iteration using the benefits of the above analysis. By altering the NY and BO schedules, while retaining

---

*The average value for major trunk carriers in also around 1.4.

the PV schedule, a total system net profit of \$1.2 million[*] was obtained, with load factors in the high 70's and low 80's, and a total fleet investment of \$3,390,000.

None of these results can be considered as representative of real-world situations in an absolute sense. However, relative comparisons and trends can very well indicate the presence of similar trends in real life. Improved basic data, and considerable participant decision-preparation effort is required to obtain results valid in a real situation. The above example shows the level of detail and the type of analysis that can be carried out with the present mechanization of the game.

---

[*] BO: \$429869, NY: \$301594, PV: \$449432; notice that PV benefited from the other two carrier's changes.

CHAPTER V

EXTENSIONS AND APPLICATIONS

The application of the game to particular problems is not within the scope of this work. However, this chapter will review some of applications that were considered during the design of the game, and the methodology associated with these uses. It should not be implied that the game, as it has been mechanized, can be directly applied to all the cases mentioned without further work. In most applications, a considerable data gathering effort is required, while some applications actually require modifying elements of the game or even enlarging its scope. Also discussed in this Chapter are a number of improvements, modifications and extensions which have been identified during the development of the present game mechanization. The impact of these improvements range from "cosmetics" to major structural changes. The implementation of these improvements, as well as the use of the game for any of the applications mentioned is left as possible future work to be done.

5.1 IMPROVEMENTS AND EXTENSIONS

The range of improvements and extensions that have been identified during the development of the game range from minor modifications to major structural changes. In the minor modification category, we will only mention, as examples, the inclusions of a periodic-repayment financial transactions option (such as a mortgage). The unique characteristic of this financial transaction is that part of the periodic payment goes to redeem principal, instead of being entirely interest. Another minor change would be to model advertising and "carrier image" passenger preference by the simple expedient of converting that preference (however obtained) to "equivalent dollars" or "equivalent time" to be added to that carriers' service entries.

In the more useful, but also more complex category, we believe the following items deserve further attention:

a) Develop an "Origin-Destination" data structure associated with each flight. This structure would allow the specification of discrete fares for the flight (for passengers from specified Origin-Destination pairs), as well as the accumulation of O-D actual traffic when the simulation is run. This will allow segment data to be compared with that collected in the real world segment load data collected by the C.A.B.

b) Model the gate occupancy time, with the dual goals of increasing the schedule's realism, and modeling gate requirements (and costs). The present flow-checking and aircraft-counting algorithm (Section 3.8) can be used for this purpose; the maximum number of gate positions required at any station is the maximum value of the flight count for that station. As opposed to the current algorithm, the flight flow list used for gate-counting purposes would have to include intermediate segment stops and would aggregate all aircraft types.

c) Non-weekly schedules. As proved in Section 2.4.2, simulation of non-daily frequencies requires the independent modeling of each day of the week. This requires adding an item to the flight description, and effectively performing all the schedule checking functions seven times (one for each day of the week). The simulation itself (demand determination, allocation, etc) would then be executed seven times (with each day's schedule) and the results aggregated. This assumes that demand does not "spill over" from day to day. If it is assumed that demand may shed from one day to another, then an approach similar to the time-of-day allocation scheme must be extended to the entire week (in effect, a 168-hour day).

d) Automatic connection generation. As already mentioned, only economic limitations prevented the mechanization of an automatic connection generator in the current mechanization. There are excellent connection generation algorithms available (Reference 10). Two major problems must be solved: the pricing of an unpublished connection (one possibility: the sum of each individual flight's fares) and, in the case of a reduced-fare connection, the allocation of the revenue between the two flights. This is particularly troublesome if only one of the carriers making up the connection publishes it.

e) "Smart" entry generator. Again, the coding of a more sophisticated service entry generator (one that would not be fooled by an itinerary such as ABCBA) is only a matter of programming resources. A very simple algorithm would be to check for multiple entries, and to select only the one with the shortest flight time.

Other modifications involve a major re-structuring of the game and its simulation. This may be required for the most sophisticated uses postulated in the next Section. Some interesting possibilities are:

a) Different times for passenger preference, cost calculation, and utilization accounting purposes. This major improvement would use three different measures of "flight time" as opposed to the current single one. The time used for demand generation and allocation purposes would include items such as airport access time (which would, by the way, model airport preferences in a multi-airport area); the utilization time would be the sum of the block time and the exactly-computed (as opposed to the current fixed) minimum gate time, while the cost-related time would take into account the different costs of cruising flight, climb, and taxiing.

b) Multiple interacting demands. The reasons for modeling multiple demand are explained in Section 2.4.1. The difficulty involved in modeling multiple demand depends on the degree of interaction between the demands. If the demands are fully non-interacting (e.g. passengers and mail) then separate demand determination and allocation processes are carried out, and the main cost is in incorporating market data for both demands.

If the demands are fully interacting (such as business and pleasure travellers sharing the same aircraft space), then a single demand process must allocate both demands simultaneously; each market is turned into two, effectively competing, markets: market A-B's business passengers compete with market A-B's pleasure passengers in the same way they compete with market A-C passengers that use the same flight segments. Thus, the iterative demand allocation process developed for this game can be naturally extended to fully-interacting demand.

The case of partially-interacting demand (e.g. when the aircraft has a complex passenger-cargo payload tradeoff envelope) cannot be simulated with the present algorithm as expediently as the fully-interacting case. More work is needed in order to design an interacting-demand allocation process.

c) Multiple-grade supply (e.g. first-class vs. coach class seats). This case can be handled by the present algorithm in a way similar to the interacting-demand solution. In this case, each service offering is split into two competing service entries (such as "Flight 365F" and "Flight 365Y"). A price-time equivalence of the advantages of a first-class seat must be included, or else all the demand will be allocated to the cheaper entry. Even without this correction, this method would automatically simulate the spilling of coach passengers to first class when coach space becomes scarce.

5.2 ANALYSIS AND RESEARCH APPLICATIONS

The game can be used as a "test bench" for research and analysis in air transportation in several ways:

a) Testing and Calibration of individual models. As mentioned in the introduction, some sophisticated mathematical models of elements of air transportation operations are used with simple assumptions about other elements of the system. An example would be the total demand model used in this game, which was previously tested (Reference 12) by assuming a simple statistical correlation between level of service and demand, and by assuming a single class of demand. Discrepancies between the results obtained from the model and real-world observations can be attributed either to the model being tested, or to the simplifying assumptions about the elements not modeled. Since, in the game approach, there are less simplifying assumptions, it is easier to calibrate the model than by its "standalone" use. For example, the total demand model could be calibrated by means of an extended, multiple-demand version of this game.

b) Testing of other analysis tools. Due to the high level of detail of the game, it can be used to check the performance of other analysis tools. For example, most fleet planning models are based on Linear Programming techniques. These models do not incorporate effects that are modeled by the game, such as load factor tailoff and load shedding. The ease or difficulty with which the tool can be applied, and comparison of the game results with those expected from the tool's model by itself is an indication of how the tool would perform in a real world situation. For example, an intriguing possibility would be to pit a schedule generated by a schedule optimization program against a hand-generated schedule.

c) Scenario evaluation. Effects of a changing regulatory environment, introduction of new aircraft technology, general economic conditions, etc can be evaluated by means of the game. In addition to the accurate environment simulation, the gaming dimension adds the human decision-making element which is a crucial component of some of these scenarios.

d) General research. There are a number of research activities that can be carried out by experimenting with the game. For example, the effects of different measures of supply (flight frequencies, total asm offered, etc.) in the estimation of market parameters can be compared. The use of the game for this purpose has the advantage over real world observations that the actual model used (e.g. Erikson's level of service index) are known. From the results of these comparisons, some insight may be gained on the merits of different models.

5.3 EDUCATIONAL APPLICATIONS

The traditional use of management games as educational tools focuses on the aspect of "experience". Games are seen as providers of vicarious experience that students may not acquire otherwise. We also see another use for games with detailed, high-fidelity operations models, such as this one.

In this application, the game is used as an "experiment bench" to illustrate abstract concepts and/or methods presented in the classroom, much in the same way physics experiments are carried out in High School. It can be argued that this falls in the general category of "experience", but the difference is that there is a premeditated correlation between the conduct of the game and the structure of the teaching process; whereas, in traditional academic gaming, participants are left more or less "on their own", and herein lays the value of that experience.

The integration of the game with the academic curriculum requires stressing the aspect of operations most relevant with the subject being treated. Two examples are given:

a) Schedule generation and graph theory. For this purpose, the computer simulation does not have to be run (except as an added realism measure). The preparation of the data base itself (i.e. preparation of the schedule) exemplifies the problems and procedures associated with network analysis.

b) Microeconomics and market equilibrium. In this case, the game can be reduced to a single competitive market. The performance of simple market share models (frequency share, S-curve) can be compared. Revenue and cost results can be compared with the result of various microeconomic equilibrium solutions.

Ideally, the game should be used in conjunction with a structured, integrated approach to the teaching of air transportation. Each subject taught uses as examples cases from the commonly-run game. When enough material has been acquired, a full-scale game can be run, while more advanced subject matter is covered in the classroom.

5.4 AIRLINE MANAGEMENT AND PLANNING APPLICATIONS

"Corporate planning" is at the same time an important subject and a very difficult one to define. Functionally, it has been described as the combination of the gathering and evaluation of relevant data ("environment scanning") and the evaluation and selection of objectives and strategies. Reference 15 surveys the many different conceptualizations that planning activity has been subject to, as well as the planning practices of 13 major U.S. carriers. The resulting overall picture is one of great disparity, both in the emphasis given to formal planning activities, and the mechanisms (if any) used in these activities.

Two major difficulties seem to stand against the study of planning activities:

a) There is no way of clearly delimiting which managerial activities should be labelled "planning" and which should not; there is (or should be) an overlap between planning and the daily conduct of business.

b) The planning activity seems to be so situation-dependent that it is outright incorrect to attempt to define universal "formulae" or precise planning methodology applicable to all possible situations. The best that has been achieved is the identification of "frameworks" within which the planning process may fit (Reference 16).

One such framework that can be used to conceptualize the general planning process is that of Vancil and Lorange (Reference 17). This framework is based on two viewpoints of the planning activity:

a) There are two processes in action during the planning cycle: adaptation to changes in the environment, and integration of the planned decisions to produce a coherent single master plan.

b) The planning activity follows a precise path in the company's hierarchical structure, from the top corporate management ("portfolio planning"), to the business-level management ("business planning") and, finally, to the operational level ("functional planning").

In the Vancil and Lorange framework, planning is an iterative process of identifying strategic options and alternatives and a narrowing down of these alternatives to arrive at a final strategic, business, and operational plan. Adaptation to changes is stressed in the first part of the cycle, while integration of components into a unified plan is stressed in the second part.

The same authors recognize the importance of computer models and tools in the planning process (Reference 18); however, they stress the role that computer-based models play at each individual stage of the planning process: macroeconomic analysis programs* at the top, corporate level, industry-oriented market and microeconomic models for the business level** and so-called "pro-forma budget" generators (simple trial accounting programs), and a large number of operations-oriented mathematical models (PERT, Linear Programming, etc.) at the third level.

Indeed, existing airline-oriented computer models (or, more properly, computer-based decision-analysis tools) are designed with explicit purposes in mind, such as Fleet Plan-

---

* e.g. those of Data Resources Incorporated (DRI), or the Wharton School of Finance and Commerce.

**e.g. the PIMS program (Strategic Planning Institute, Cambridge Mass.)

ning (Reference 19), or schedule evaluation (Reference 11). The game described in this work does not have such a specific primary application, and its scope and characteristics differ from those of the above-mentioned programs.

First, the game itself is not a decision-generating program, such as Fleet Planning models which, given the proper data, automaticaly produce an "optimal" schedule of aircraft acquisitions. The game can be used to generate decisions in a closed analysis loop with a human decisions-maker (the participant). An example of this process was shown in the previous Chapter, where the analyzed results of the MIT 1978 Summer Games were used to generate a better set of scheduling decisions than was possible using the raw output from the game.

Second, the game, as opposed to other computer-based tools, is not oriented towards a specific stage in the overall planning process; rather, since it attempts to appear to the participants as a model of an entire airline, its use, ideally, would reouire the exercise of the three levels of planning mentioned above, from strategy-setting, to fleet planning, to detailed scheduling, even if some of these individual aspects may be "turned off" by appropiate scenario rules* .

---

* For example, in the MIT games described in Section 4.3, the fleet planning aspect was eliminated by means of the "infinitely flexible leases".

We will try to visualize how such a game can be incorporated in the overall planning process by means of two examples.

5.4.1 Idealized Use Scenario

Let us assume a hypothetical airline whose top management has been "sold" on the idea of using the game as a planning tool. We will present an admitedly "rosy" picture of how such a game could be integrated not just with the formal planning effort, but actually with the entire decision-making process within the organization. In this company, there is no separate group performing the planning function or running the simulation (except maybe for a maintenance and clerical coordination group). All departments participate in the game (and in the planning process as a consequence) in the same role they play in the real airline.

Figure 24 shows a diagram of how the decision-making levels would interact using the game as a decision-evaluation tool. Starting from the bottom, we have a number of people dedicated to the gathering, analysis and evaluation of environment and internal data. The results of this activity is a "best estimate" of current data (market parameters, cost

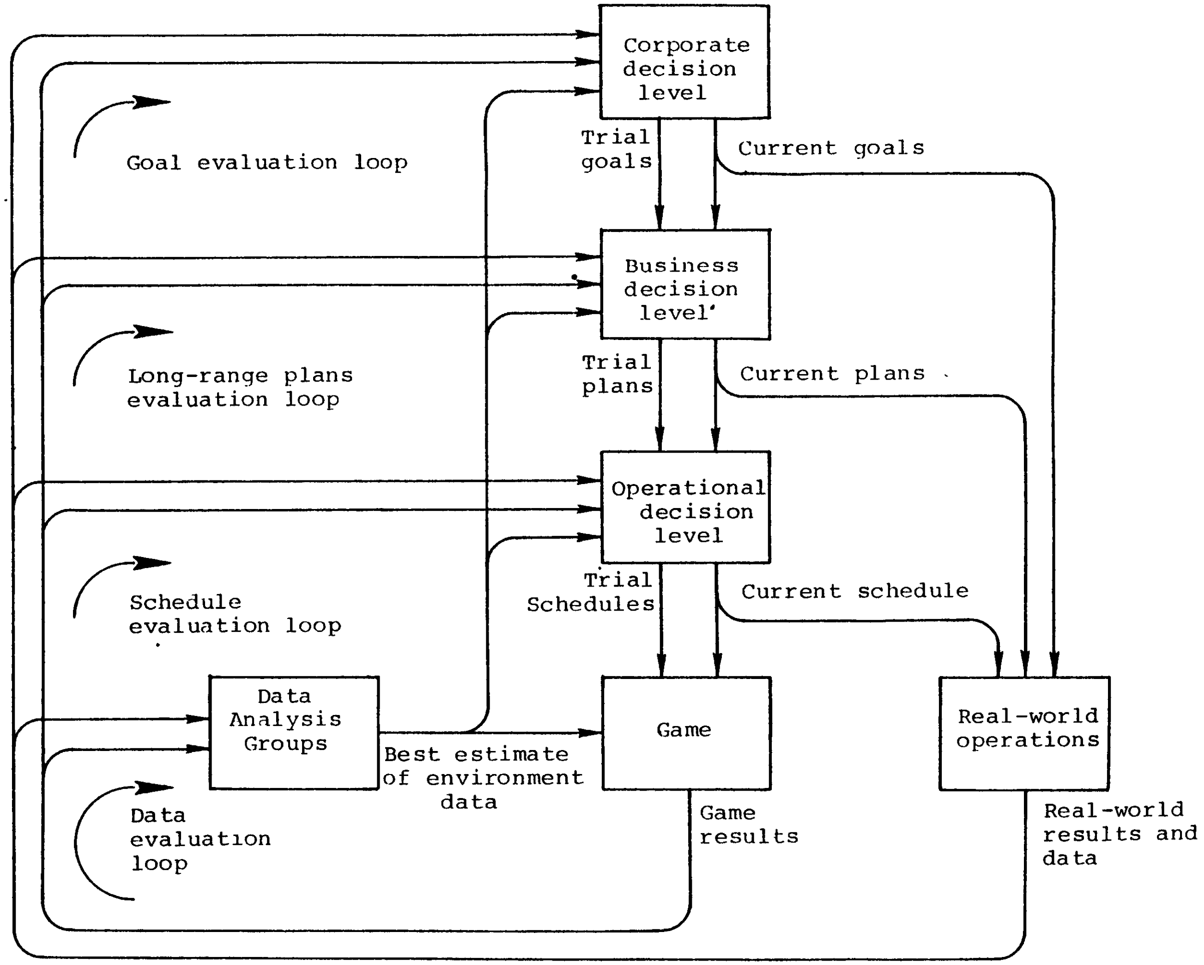


Figure 24.- Integration of gaming activity with airline planning activities.

structure, etc) and the range of variation expected in the future ("forecasting"). This data, normally used in the day-to-day decision-making process, is also used in the games run, including games where the current operational decisions are used as inputs. Comparison of the results of such games with the real-world observed results are then used to refine the "best estimates", in an iterative fashion, labelled in Figure 24 as the "data evaluation" loop.

In a competitive regulatory environment, the competitor's strategies and policies become part of the environment data. This data may be estimated by having "enemy teams" play the competitors' part in the games. It is in this area that feedback from the game may prove indispensable in order to arrive, in an iterative fashion, at an understanding of "what makes the competition tick".

The top (corporate) decision-making level is responsible for defining and setting goals and objectives for the company. In our idealized situation, along with the current goals and objectives, a (small) number of alternative policies are also postulated. These alternatives are then "fed" to the next decision level along with the current official objectives. This decision level, which we have labelled "business" level, is responsible for transforming the corporate goals into actual long-range resource (aircraft, money, etc.) acquisition plans. Its primary responsibility is to produce plans that will reflect the current company goals, but it would also spend some time producing plans corresponding to the "trial goals" that the corporate level wishes to evaluate. Thus, the output from this level of decision-making would be made up of:

a) The current ("best?") long-range fleet and other resources acquisition plan, according to the company's current goals.

b) A number of "trial" plans to be evaluated; some are alternatives to the current long-range plan in response to the current corporate goals, that the business level wishes to evaluate, while the rest are responses to the trial goals and objectives that corporate management wishes to evaluate.

Similarly, the operational decision level, responsible for the actual scheduling, receives, along with the current fleet level and predictions based on the current long-range plan, a number of hypothetical fleets, marketing directives, cash flows, etc corresponding to all the "trial" plans. Again, the main responsibility of this organizational level is to the "current" plan and the "current" schedule, but it would also produce schedules in response to the trial decisions of the previous management level. From the description of the process so far, it would seem that the multiplicity of different strategies, plans, schedules, etc. to be evaluated is such, that more activity would be spent on managing the game than on managing the real airline. This need not be so.

First, the level of detail and verification required by the current schedule (or long-range plan, or objective) is not necessary for the "trial" decisions. For example, the legal department does not have to approve the wording of the lease contracts of the simulated games. Second, the range of trial decisions produced in response to the previous level's trial decisions need not be as comprehensive as those produced in response to the _current_ decisions; for example, five alternative schedules may be evaluated in response to the current marketing plan, but only one may be produced in order to evaluate alternative market decisions.

Eventually, multiple games are run, corresponding to each alternate schedule, plan, and objective to be evaluated, and the results fed back to the appropiate decision-making level, resulting in the three planning loops identified in Figure 24. Both the generation of options and the selection of alternatives to form the "current" plan would use, among other inputs, the results of the games generated and run with this framework.

Admittedly, this process is expensive, and even with the simplifications mentioned above, a considerable amount of effort is spent in generating decisions that will never be implemented*. But this approach has a number of benefits: The process is capable of spotting "methodological", as well as substantive, problems. For example, a certain long-range plan (such as the one postulated in the following Section) may impose such scheduling constraints that the scheduling process currently used by the airline is incapable of producing an acceptable schedule. Therefore, the development of an alternative scheduling process must be added to the costs (or benefits!) of that long-term plan. Thus, the game usage framework proposed would yield valuable information even without running the game.

---

*A significant reduction in clerical overhead could be achieved by integrating the game's data bases with the company's Management Information System. For example, if a game trial schedule is selected as the next schedule, it can be automatically converted to the format required.

Also, the game acts as a "backbone" for the entire planning process. Although the results of the games are the main reason for running them, the mere fact that so many departments within the airline are simultaneously considering both the actual and hypothetical decisions is a way of carrying a formal planning activity without the tedious forms to fill and boring planning meetings to attend that have characterized other formalized planning systems. And, since each decision-making level receives a tangible result from its gaming efforts (the results of their own decision alternatives), nobody feels that he is wasting his time just to please his bosses' whim.

Finally, the integration process mentioned by Vancil and Lorange is automatically carried out, since the games cannot be run until all the operational components are present. And since the generality of the game is such that a significant range of out-of-the-ordinary situations (both environmental and managerial) can be simulated, the adaptation process is strengthened by allowing exploration of alternatives that often are dismissed because "its effects are impossible to analyze".

5.4.2 A Specific Planning Application: Dual Objectives

The operations of bulk shipping companies (e.g. oil tanker lines) have traditionally been influenced by the large swings in the market prices of equipment (shipping tonnage) caused by periodic surges and depressions in the world shipping requirements. Income (or loss) derived from speculating with the equipment market prices is some times comparable to the income and costs of operating that equipment, and this fact is reflected in the way bulk shipping companies are managed (Reference 20).

It has been suggested that airlines may benefit from a form of this dual corporate strategy: to combine revenue-producing operations with the potential oportunity for revenue from speculating with aircraft prices. This would involve the use of sub-optimal fleets (too large when aircraft are bought at low prices, too small when they are sold at a profit), and the flying operations and schedules would have to be tailored to the available fleet. Simultaneously, the amount of aircraft that can be purchased and sold for profit would be limited by the need to fly an acceptably profitable schedule.

Arguments exist to the effect that the airline industry's and the shipping industry's operating conditions are so dissimilar that it is impossible for airlines to carry out this dual business goal (particularly since air carrier operational revenues have historically been marginal even with optimized fleets). On the other hand, current trends in deregulation (which may change the operating environment, such as free entry and exit from markets), and the even more current surge in aircraft prices indicate that such a proposal may not be dismissed lightly.

In order to evaluate this concept, it is necessary to analyze the effects of both activities (speculation and flight operations) simultaneously. The level of detail of the game developed in this work is sufficient to carry out a feasibility analysis on this proposal. Such analysis is beyond the scope of this work, but we will outline the methodology with which it could be carried out.

First, a "grid" of scenario assumptions must be postulated. This grid consists of combination of aircraft market price variation assumptions with market demand assumptions*.

---

* Obviously, the two are not independent: low aircraft market prices are usually caused by a reduction in demand for air travel.

Next, a set of operating tactics are developed to maximize the existing fleet's profitablilty in spite of its suboptimal size and/or composition. Some of the tradeoffs to be explored include whether to "mothball" surplus aircraft vs. utilizing them by "packing" the schedules around the prime day-time hours, or whether, faced with a reduction in fleet size, to pull out completely from some markets vs. a reduction of level of service across all markets.

The evaluation of the game's results should incorporate the determination of the "optimum" balance between the speculative aspect and the operating aspect. The two extremes would be the current airlines' operating mode (little or no emphasis on planned speculation) at one end, and a simple aircraft "trading post" (no flying operations altogether) at the other.

It is interesting to note that whereas the previous example (use of the game as an integrated decision-evaluation tool) required that the game operating models achieve a substantial degree of quantitative accuracy in their results, this dual-goal evaluation application relies more on comparative results than on absolute results (e.g. if a suboptimal fleet schedule proves to be ruinous no matter what the market parameters are, this is an indication that this policy is likely to be ruinous with the <u>real</u> market data, i.e. real-world operations).

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The goal of this work was to design a high-fidelity game for passenger airlines that could be used to carry out experiments that could not be performed on a real airline. It is first concluded that the minimum level of detail required for this pupose is the schedule level, since this is the lowest level of detail at which exact aircraft requirements (and thus financial requirements) can be determined.

The next conclusion is that existing demand and cost models seem to be usable for the degree of fidelity sought, while existing demand allocation models are not. In particular, the models reviewed were subject to "funny" results (obviously incorrect results to particular combinations of input data). The effect of these "funny results" is that, upon discovering them, participants are tempted to increase their scores by selecting those particular inputs, even though they would not make any sense in the real-world case.

The demand allocation model developed to satisfy the requirements of the game seems to be free of extraneous results over the game's entire range of operating conditions, including those that could not be handled by the existing models. However, scarceness of empirical data on the operation of airlines under these extreme conditions (e.g. 90% average load factors) makes testing of this model (other than by "common sense" observations) a difficult task indeed.

The combination of this demand allocation model with a state-of-art total demand model and simple cost and revenue models produces a simulation of airline operations of broader scope and higher level of detail than has been achieved in previous efforts.

The game has been shown to be a useful training device; students in the 1978 MIT summer session special seminar on Air Transportation that participated in a brief, limited game, responded positively to the use of the game as a teaching tool. Only one out of 32 participants was of the opinion that use of the game was not relevant to the course. Indeed, a majority indicated that they wished that the game had been started earlier, and that more time be devoted to the game * . They also expressed a preference for individual, rather than group, participation in the game. A total of nine game itera-

---

* In spite of having to work on the game decisions on their free time.

tions were carried out, and the only "funny" results observed was a tendency by the part of the participants to "pack" their schedules around the fixed, common minimum gate time.

The post-game analysis performed by the author on the results of the game showed that the data produced by the game is of a level of detail and realism sufficient to perform than same type of analysis that would be carried out on data from real airline operations. Thus, subject to validation of the quantitative accuracy of the models used, the game seems to meet the objectives for which it has been designed.

There is a considerable amount of work that can be done in this area. The most urgent is to verify the accuracy of the demand allocation scheme used by comparison with real-world data. The best way of performing this checking is by implementing the "Origin-Destination" data structure mentioned in Section 5.1, and comparing the segment data thus obtained with C.A.B. segment-load data. The large amount of data involved in such checking will require careful selection of the test cases (e.g. simple multi-stop terminal routes where the Origin-Destination passenger load on each segment can be rationalized).

The traditionally fixed price structure under which the industry has been operating made the determination of price elasticities difficult to determine by traditional time-series and cross-sectional statistical analysis. Use of the game to estimate, by a trial-and-error process, some of these parameters (e.g by simulating the recent "super-discount" fare experiments that some airlines have been conducting recently) should be explored: in this approach, the real-world situation is replicated in the game, and the game's price and level of service elasticities modified until the results match the real-world observations. In particular, the time-price substitution effect can be quantified by comparing the performance of night coach discounted flights with regular daytime fares.

In the academic field, it is recommended that effort be devoted to the development of a unified curriculum in air transportation using the game as the skeleton for demonstration, exercises, and practice. Finally, some of the extensions mentioned in the previous Chapter should be implemented, in particular gate time modeling, in order to eliminate the tendency of participants to "squeeze" the minimum gate time.

REFERENCES

1.- Hausrath, A.W.: Venture simulation in War, Business, and Industry. New York: McGraw-Hill, 1971.

2.- Roberts, Arthur L. "What's Wrong with Business Games", Journal of Industrial Engineering, November-December 1962.

3.- Graham, Robert G. and Gray, Clifford F.: Business Games Handbook. New York: Americal Management Association, 1969.

4.- Cotter, Richard V.: The Business Policy Game - Players Manual. University of Nevada, 1973.

5.- Brooks, LeRoy D. III," The Financial Management Decisions Game. Richard D. Irwin, 1973.

6.- Walton, B., Million, E.Z. and Viavant, W.: University of Oklahoma Petroleum Game. University of Oklahoma, 1961.

7.- Shubick, Martin.: Games for Society, Business and War. Amsterdam: Elsevier, 1975.

8.- Tyber, H.B.: "An Airline Management Game" Douglas Paper 6671, McDonnell-Douglas Corporation. Presented at the Joint National Meeting of the Operations Research Society of America/The Institute of Management Science, Atlanta Ga. November 1977.

9.- Walker, L.E.: "Airline Schedule Planning and Evaluation Model" Douglas Report C1-8061SD COR-1340, Douglas Aircraft Company, November 1968.

10.- Mathaisel, Dennis F.X.: "Airline Schedule Planning and Evaluation Model" Douglas Paper 6)96, McDonnell-Douglas Corporation. Presented to the Airline Group of the International Federation of Operations Research Societies, San Francisco, Cal. December 1972.

11.- "SSFX Users Guide", Boeing Commercial Aircraft Company, Renton, Wash., October 1973.

12.- Eriksen, Steven E.: "Policy-oriented multi-equation models of U.S. domestic air passenger markets" Ph.D. thesis, Sloan School of Management, M.I.T. 1977

13.- Eriksen, S.E., and Taneja, N.K.: "The evaluation of Scheduled Air Passenger Service in Domestic Markets". AIAA Conference on Air Transportation, Loa Angeles, Calif., August 1978, AIAA Paper No. 78-1556.

14.- Eriksen, S.E., Scalea, J.C., and Taneja, N.K.: "A Methodology for Determining the Relationship Between Air Transportation Demand and the Level of Service", M.I.T. Flight Transportation Laboratory Report 76-3, January 1976.

15.- Speyer, Jean-Jacques W.: Planning processes in U.S. Airlines. M.S. Thesis, Massachusetts Institute of Technology, September 1978.

16.- Lorange, Peter: "A Framework for Strategic Planning in Multinational Corporations", Journal of Long Range Planning, June 1976.

17.- Vancil, Richard F., and Lorange, Peter: "Strategic Planning in Diversified Companies", Harvard Business Review, January-February 1975.

18.- Lorange, Peter, and Rockart, John F.: "A Framework for the Use of Computer-based Models in the Planning Process", in Strategic Planning Systems, Lorange and Vancil, Editors. Englewood Cliffs: Prentice-Hall, 1977.

19.- Swan, William: "FA-4.5 User's Memo". M.I.T. Flight Transportation Laboratory Memo FTL-M-73-3, January 1973.

20.- Lorange, P., and Norman, V.: "Portfolio Planning in Bulk Shipping Companies", in Shipping Management, Lorange and Norman, ed. Bergen: Institute for Shipping Research, 1973.

APPENDIX A

OVERVIEW OF AIR TRANSPORTATION ECONOMICS

This appendix contains an overview of basic economic concepts as they apply to air transportation. It is included here as an introductory reference for readers not familiar with the peculiarities of air transportation, particularly as they affect the design of the game. First, the general concept of an economic market is introduced. Next, the principal characteristics of the air transportation market are discussed.

In the most general terms, an economic market is composed of two elements: the demand (for goods or services) and the supply (of goods or services). For simplicity, both goods and services are called by the single name "product" (air transportation happens to be a service). These products are "sold", i.e., the supplier transfers them to the "customer" in exchange for a consideration. The monetary value of this consideration (usually, but not always, cash) is called the "price" of the product sold. The total amount of a product that buyers are able and willing to purchase is called the "demand" for that product. The total amount of that product that producers are able and willing to sell is called the "supply" of that product.

The amount of the product actually sold is equal to the lowest of the two quantities, supply or demand, including the case ("microeconomic equilibrium") where both are equal. If there is more than one producer of a single product, the market is "competitive". In addition to determining how many units of the product are sold, we want also to know how many were purchased from each producer. This is called "market share" (of that producer), and the process that leads to the determination of market share is the "demand allocation".

In order to simulate a market, the demand must be determined as a function of all the variables deemed significant, including, but not limited to, price. The supply must also be determined based on some variables, including, but not limited, to, price and costs of production. Supply and demand may very well be interdependent. Finally, the demand and supply must be matched in some fashion to determine the quantity of product actually sold.

In the case of the passenger air transportation industry, the product (actually, service) sold is a seat in an aircraft that departs from an "origin" airport, and arrives to a "destination" airport. If the seat is indeed a seat in a single aircraft, the service is called a "direct flight" (in spite of possible intermediate landings!), whereas, if the passenger is required to change aircraft, the service is called a "connecting flight".

From this definition, it can be seen that the air transportation industry produces an enormous number of different products: a Boston-San Francisco seat is not considered the same product as a Boston-Los Angeles seat. There are other characteristics of this service that may or may not be considered as differentiating one product from another: type of aircraft, time of day of deparure, number of intermediate stops or number of plane changes, etc. Whether a first-class seat is a different product than a coach seat, or just a "deluxe version" of the same product is debatable. The difference between being different products or grades of the same product is crucial in determining the mechanics of the competition between these products, or whether they cater to the same group of buyers or to separate groups of buyers.

The structure of the demand for air transportation differs from the structure of the supply. An individual desires air transportation (and is willing to pay the price and the time that it costs him) because, being in a certain place, he desires to be in a different place at a certain time. Thus, the demand is basically region-to-region (or city-to-city). The area around an airport in which air travel using that airport originates (or terminates) is the airport's "catch basin".

The passenger will use surface transportation to the most convenient airport, and will fly to another airport in his destination area. In the process, he may transit through different intermediate airports which are related to the structure of the supply of air transportation (i.e. connections, intermediate stops), rather than to his transportation needs ("natural" demand). Sometimes, the flow of passengrs through these intermediate airports is viewed as an "induced" demand between them. An example would be the traffic between a small municipal airport and a large hub airport via a commuter or "feeder" carrier: most of the traffic is not between the small city and the large city, but rather connects out at the large airport to other cities, and thus belongs to other city-pair markets. This demand (between the small airport and the hub airport) does not correspond to an original travel need of the consumers, but is induced by the structure of the supply ("network-induced" demand).

The total supply, i.e. the network of flights offered, is of course airport-to-airport. If air transportation consisted exclusively of non-stop direct flights, and all connections were prohibited, then there would be a one-to-one correspondence between the supply of flights between two airports, and the demand for seats between the two airport's catch basins. The ratio of seats offered to seats purchased would be the load factor for that market, and the maximum daily capacity in that market would be simply the total number of seats offered per day.

Unfortunately for the analyst, but fortunately for the air traveller, the real world consists also of multi-stop flights and connecting flights. Thus, the passengers filling up a leg (or segment) of a flight between two airports include not only passengers from the catch basins of those two airports, but also passengers from the other airports in the flight, and even from airports of other flights (connections). Thus, the one-to-one relation between the segment's two airports, and the source of the passengers flying that segment is lost.

To further complicate matters, an airport's catch basin depends on the structure of the air transportation under consideration. Long markets (i.e. transportation between cities that are at a considerable distance - also called "long-haul") will have a larger catch basin for a given airport than small ("short-haul") local markets, due to the competition of other modes of transportation. The size of the catch basin depends also on the level of detail of the analysis being performed: if both trunk and feeder carriers are considered simultanously, then the "small" catch basins must be used. If only the long-haul lines are considered, then the effective catch basin for the hub airports must be enlarged to include the "catch" brought in by the feeder carriers.

This same problem appears in another context when analyzing partial (e.g. regional) markets. If, for example, the New England region is being considered, the demand for Hyannis-Boston transportation must also include the demand for Hyannis-Los Angeles, Hyannis-Chicago, Hyannis-Denver seats. Since Los Angeles, Chicago, and Denver are outside the region being considered, the natural demand for travel from Hyannis to those points must be added to the natural demand for travel between Hyannis and the "gateway" airport, Boston (assuming all those passengers connect out of the region at Boston).

This is the "boundary" effect, and is similar to the network-induced demand mentioned above.

On the supply side, another problem occurs due to the fact that the product, (seats from one airport to another), is supplied in fixed-sized "batches" called "aircraft departures". A departure is the movement of an aircraft from an airport to another carrying revenue-paying passengers. This aircraft carries a certain number of seats, whether occupied or not. This leads to the concept of "load factor", the ratio of occupied seats to total seats. Since, as mentioned before, those seats may be occupied by passengers flying different origin-destination combinations, the net capacity offered in a single city-pair is not uniquely determined by the size of the aircraft and frequency of flights, but may depends on the traffic in other, interacting, markets that share the same flights.

The cost of producing the product depends on the load factor that is actually achieved. If the flight costs a thousand dollars, and there is only one passenger flying, the cost to the producer of that product is a thousand dollars per passenger. If, however, ten passengers are occupying seats, the cost of production is $100 per passenger. In practice, (and we will follow this practice in this work), production costs are calculated per aircraft departure, not per seat sold.

A final source of confusion occurs when demand, and supply, are aggregated over a period of time. If there is a daily (or weekly, or monthly) variation of demand, while the maximum capacity is fixed, the various mean values obtained by averaging the demand may be lower than if the mean demand is used. This is particularly important when high load factors are present: the mean load of a 150 passenger day and a 75 passenger day is 100 passengers per day only if the aircraft's capacity is 150 seats or more. If the aircraft's capacity is, say, 105 seats, the mean load is 90 passengers, not 100.

APPENDIX B

DERIVATION OF TIME-OF-DAY VARIATION OF DEMAND

From a purely theoretical standpoint, the variation of demand for air travel in a given market, as a function of the time of day is determined by the convenience (or utility) of the consumer. This convenience depends on the type of consumer considered:

a) A non-business (e.g. pleasure) traveler generally prefers to travel during the natural active part of the day (i.e. not by night). Thus, in theory, his relative demand function is uniform from, say, 7:00 AM to, say 8:00 P.M.

b) A business traveler generally gears his travel to the beginning and end of the business day, i.e. 8:00 A.M. and 6:00 P.M. Thus, his relative demand function is bimodal, with peaks around the beginning and the end of the business day.

The question arises, of course, of whether the departure or the arrival time is the determining factor, or a combination thereoff. We will take here the approach suggested by Eriksen (Reference 12) that the desirability of travel at time t is the product of the desirability of departing at time t, by the desirability of arriving at t+dt, where dt is the difference between the (local) departure time and the (local) arrival time. Therefore:

$$D(t;dt) = d(t)\ d(t+dt) \qquad (B.1)$$

where the function d is the same, evaluated at the departure time or at the arrival time. The difference dt depends thus on both the flight time and the difference between the departure and arrival time zones.

Eriksen then uses data for the Eastern Airlines Boston to New York Shuttle service (published by the Port of New York and New Jersey Authority), to derive d(t). This data (Figure B1) is really D(t;1), since the flight time is very approximately one hour (with no time zone differential). The principal approximation made in Reference 12 is:

$$d(t) = D(t;1) \qquad (B.2)$$

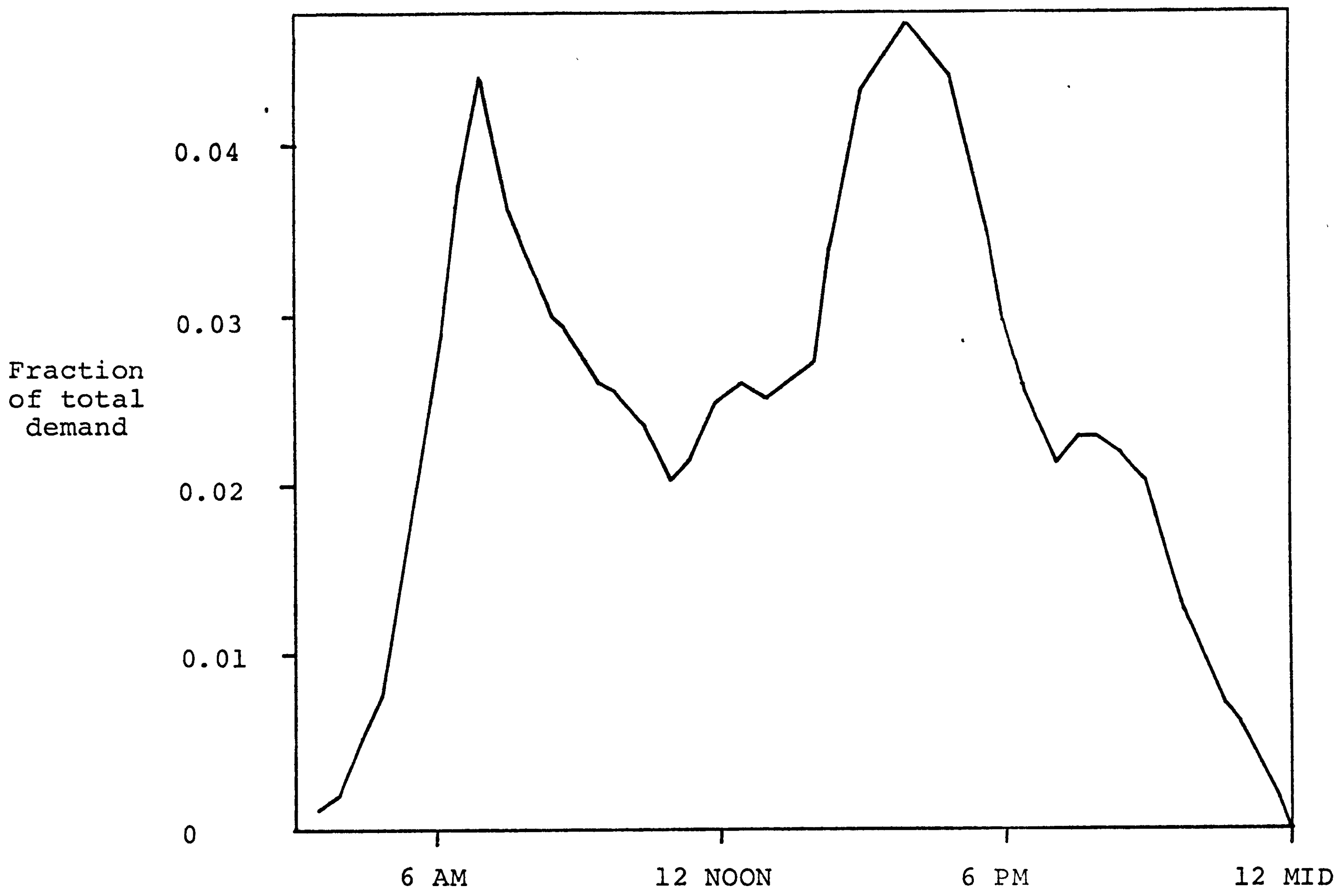


Figure B1.- Observed time-of-day variation of demand for Eastern Airlines' Boston-New York shuttle service

From this, Eriksen derives D(t;dt) for various dt's. There is no further justification of this approximation than the fact that it produces very reasonable results. To verify this assumption, we have undertaken to derive the d(t) from the same data and equation B.1. This process is similar to the mathematical deconvolution process, which is in itself analogous to differentiation. A problem often found when differentiating empirical data is that the noise has usually a higher frequency than the desired data. Since differentiation enhances the high frequencies, this process degrades the data's signal to noise ratio. This is particularly true of sampled data such as this. The pseudo-deconvolution process (inverse of B.1) can be expressed as:

$$\begin{array}{lllllll} D(1;1)= & d(1) & d(2) & & & & \\ D(2;1)= & & d(2) & d(3) & & & \\ \cdot\;\cdot\;\cdot\;\cdot\;\cdot & \cdot\;\cdot\;\cdot & \cdot\;\cdot\;\cdot & \cdot\;\cdot\;\cdot & \cdot\;\cdot\;\cdot & \cdot\;\cdot\;\cdot & \qquad (B.3) \\ D(23;1)= & & & & d(23) & d(24) & \\ D(24;1)= & d(1) & & & & d(24) & \end{array}$$

This system can be linearized by taking logarithms:

$$LD(t;1)= M\ Ld(t) \qquad (B.4)$$

where M is the matrix:

$$\begin{bmatrix} 1 & 1 & 0 & . & . & . & 0 & 0 \\ 0 & 1 & 1 & . & . & . & 0 & 0 \\ . & . & . & . & . & . & . & . \\ 0 & 0 & 0 & . & . & . & 1 & 1 \\ 1 & 0 & 0 & . & . & . & 0 & 1 \end{bmatrix} \tag{B.5}$$

thus, we can solve for d(t) by inverting M:

$$Ld(t) = M^{-1} \; LD(t;1) \tag{B.6}$$

Actually, the data is given in half-hour intervals, so that the matrix M is

$$\begin{bmatrix} 1 & 0 & 1 & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & \cdot & \cdot & \cdot & \cdot & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & \cdot & \cdot & \cdot & \cdot & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 0 & 1 \end{bmatrix} \tag{B.7}$$

Unfortunately, this matrix is, in the 48x48 case, singular. However, only minor erors are introduced by interchanging two points, for example d(2:00 A.M.) and d(2:30 A.M.), since both desirabilities, and their neighbors are presumably, extremely small. With this trick, the matrix can be inverted (and is well-behaved), to yield d(t).

As predicted, the resulting d(t) is extremely noisy, the frequency of the noise being, not surprisingly, one-half hour (the sample period). Figure B2 shows the deconvoluted data, while figure B3 shows a 64-point Fourier Transform (FFT) of the data, with the peak harmonic (No. 15) being at the half-hour frequency.

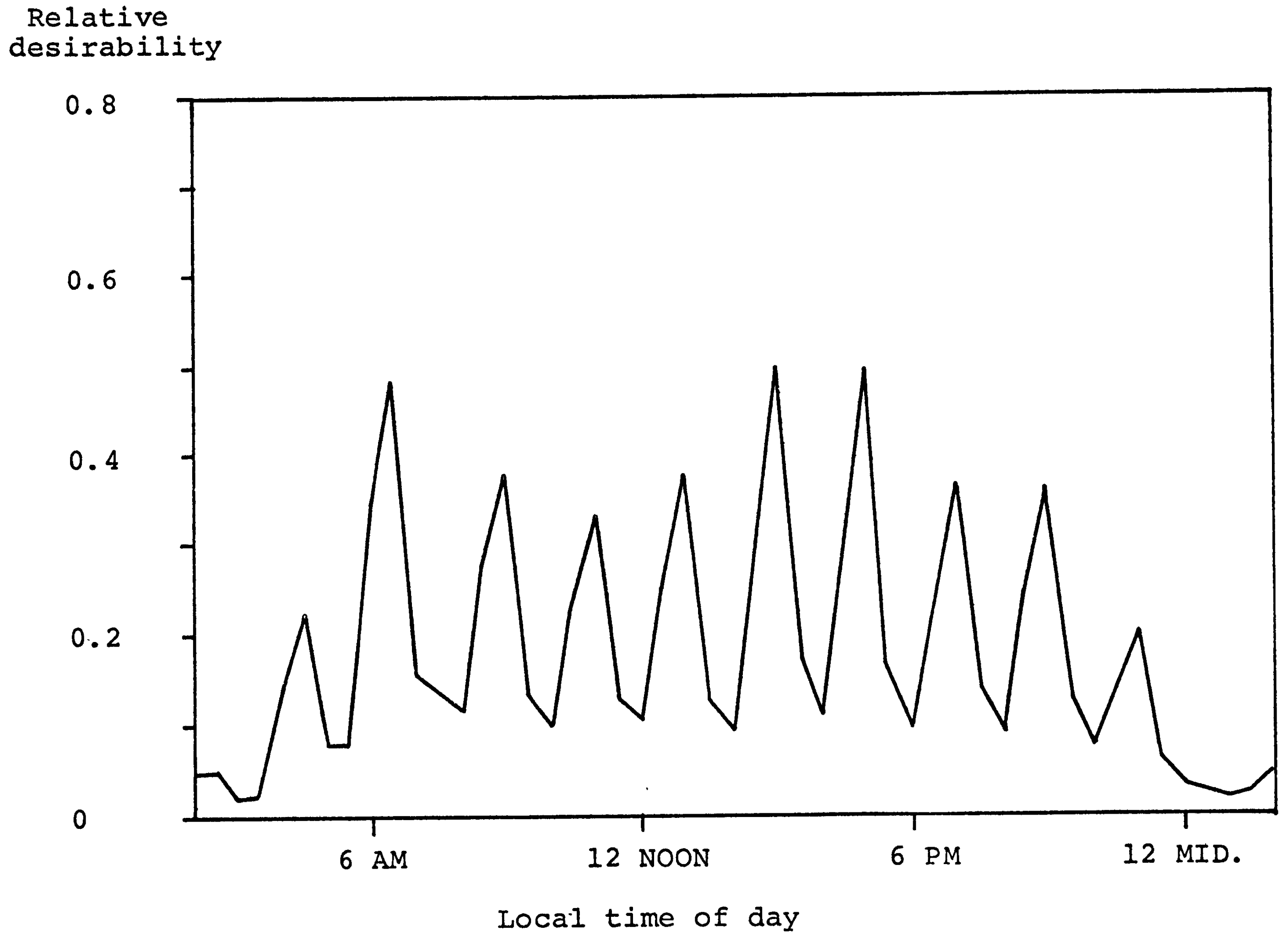


Figure B2.- Departure/arrival desirability function derived from observed data.

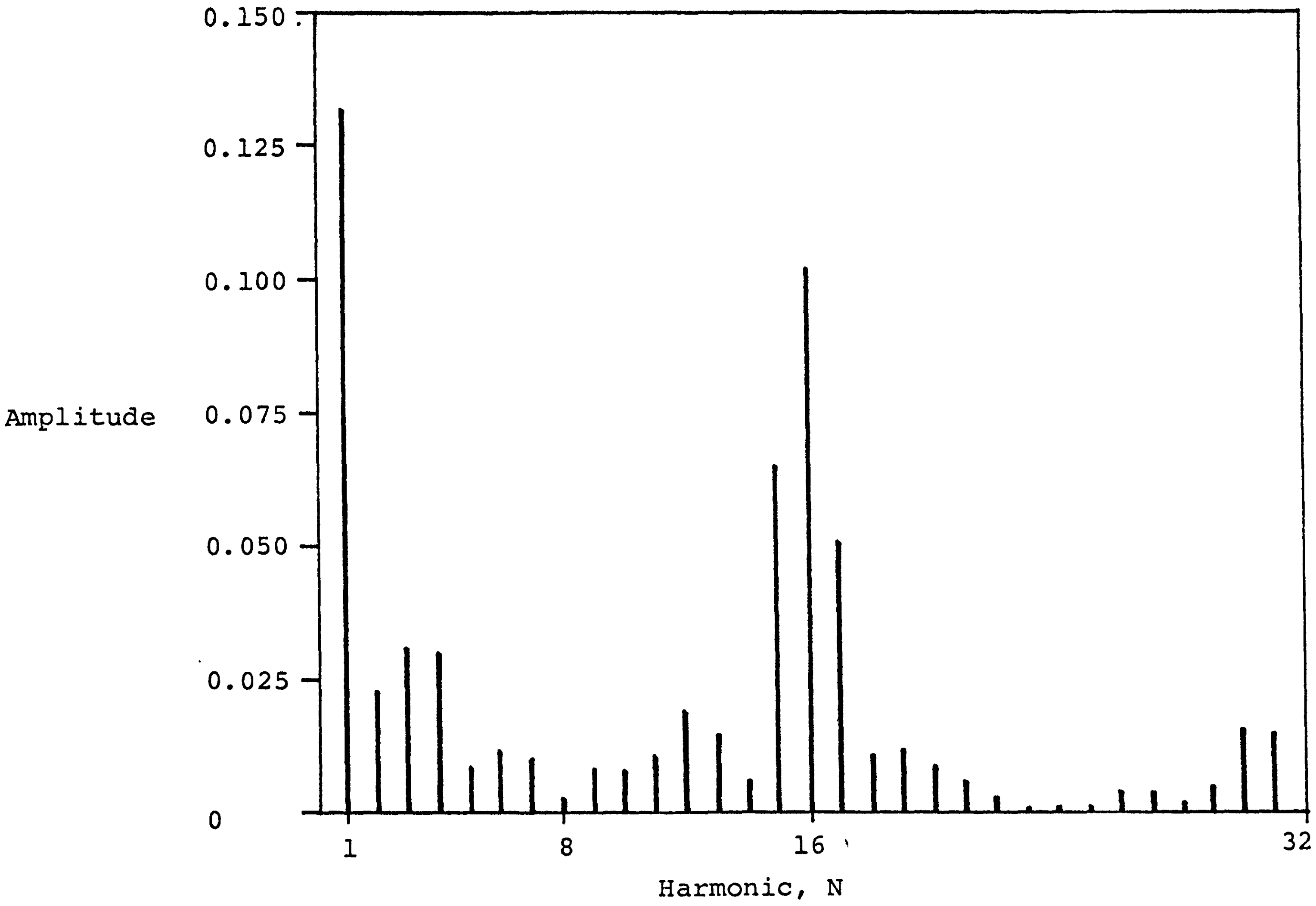


Figure B3.- 64-point Fourier Transform of raw desirability function.

Several means of filtering d(t) can be found. A zero-phase filter is desirable, or else the filtered data would be shifted in time. The simplest scheme is to truncate the real-coefficient Fourier series at the 14-th harmonic and re-transform the data back to the time domain. This was done, and the results are shown in Figure B4. As it can be seen, further reduction in the number of harmonics used to reconstruct the data smooths both the d(t) and the D(t;1) obtained from it. Indeed, D(t;1) seems to converge towards the sum of a 6 AM-to-8 PM uniform plus two peaks distribution theoretized at the beginning of this Appendix.

The ten-harmonic version was selected for initial use in the simulation. Figure B5 shows how the filtered data compares with Eriksen's approximation for various values of dt. As it can be seen, the agreement is excellent, confirming the soundness of Eriksen's approximation.

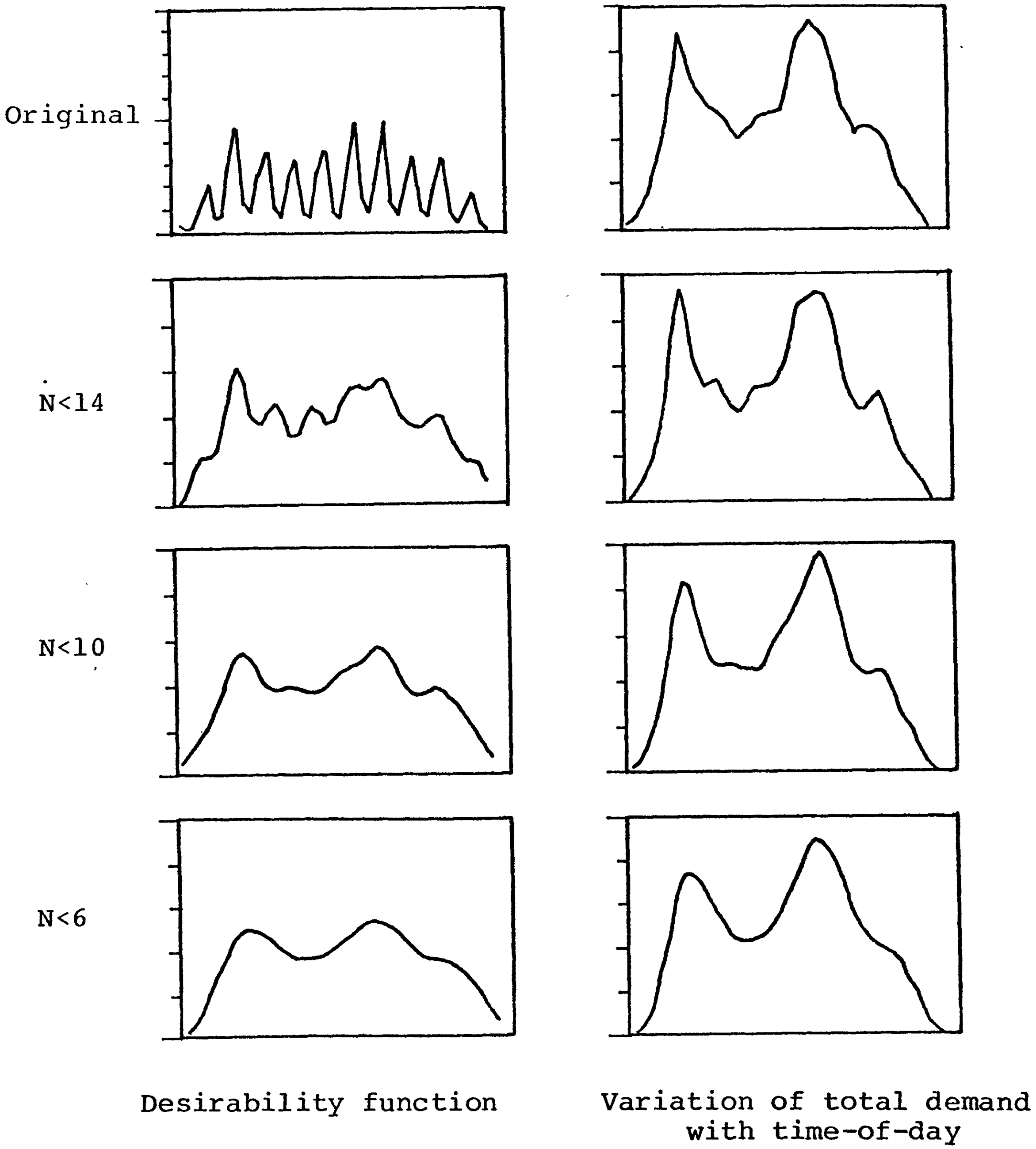


Figure B4.- Evolution of time-of-day demand variation and desirability function with harmonic filtering.

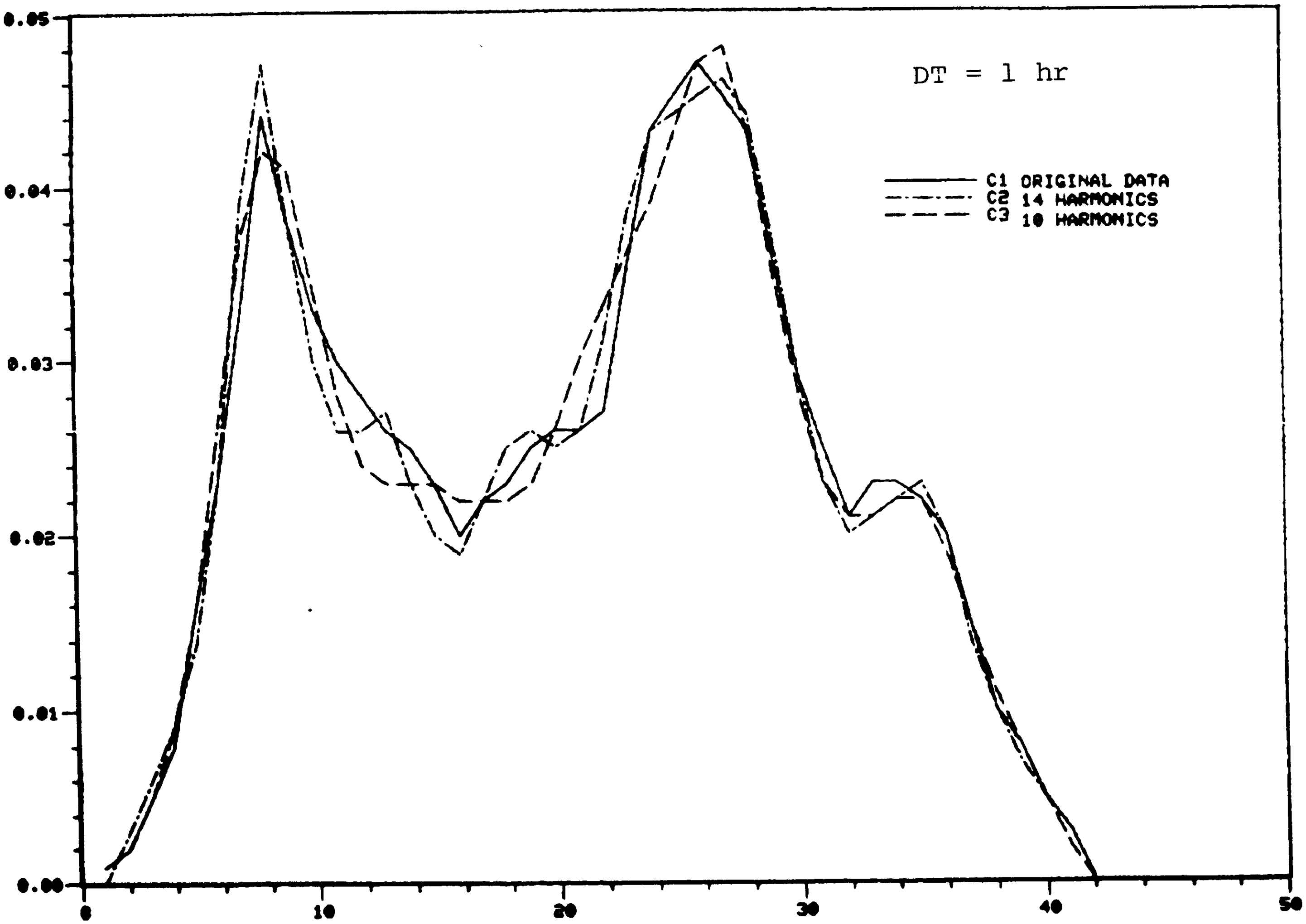


Figure B5.- Resulting time-of-day demand curves for various departure-arrival time differences.

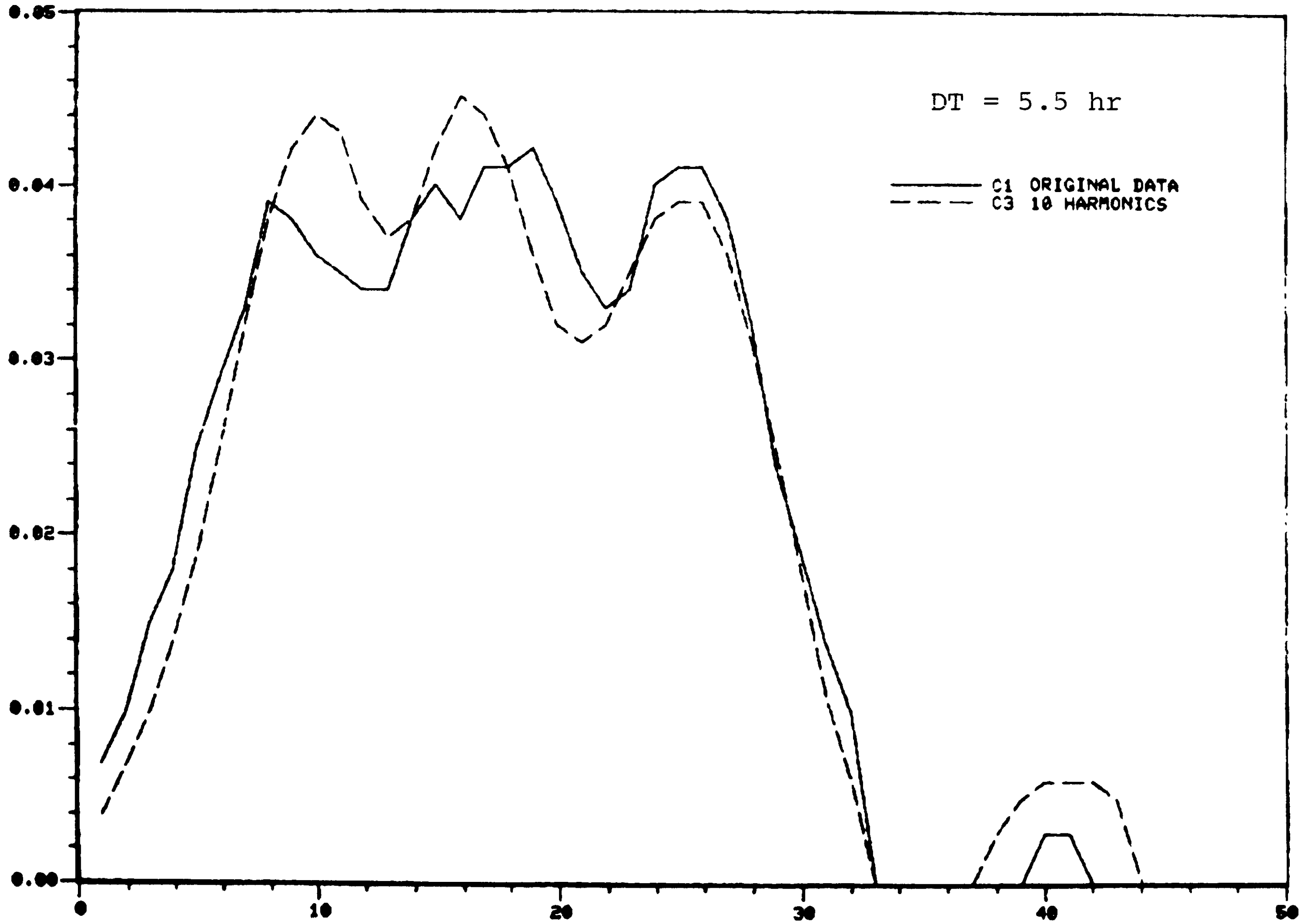


Figure B5.- (continued)

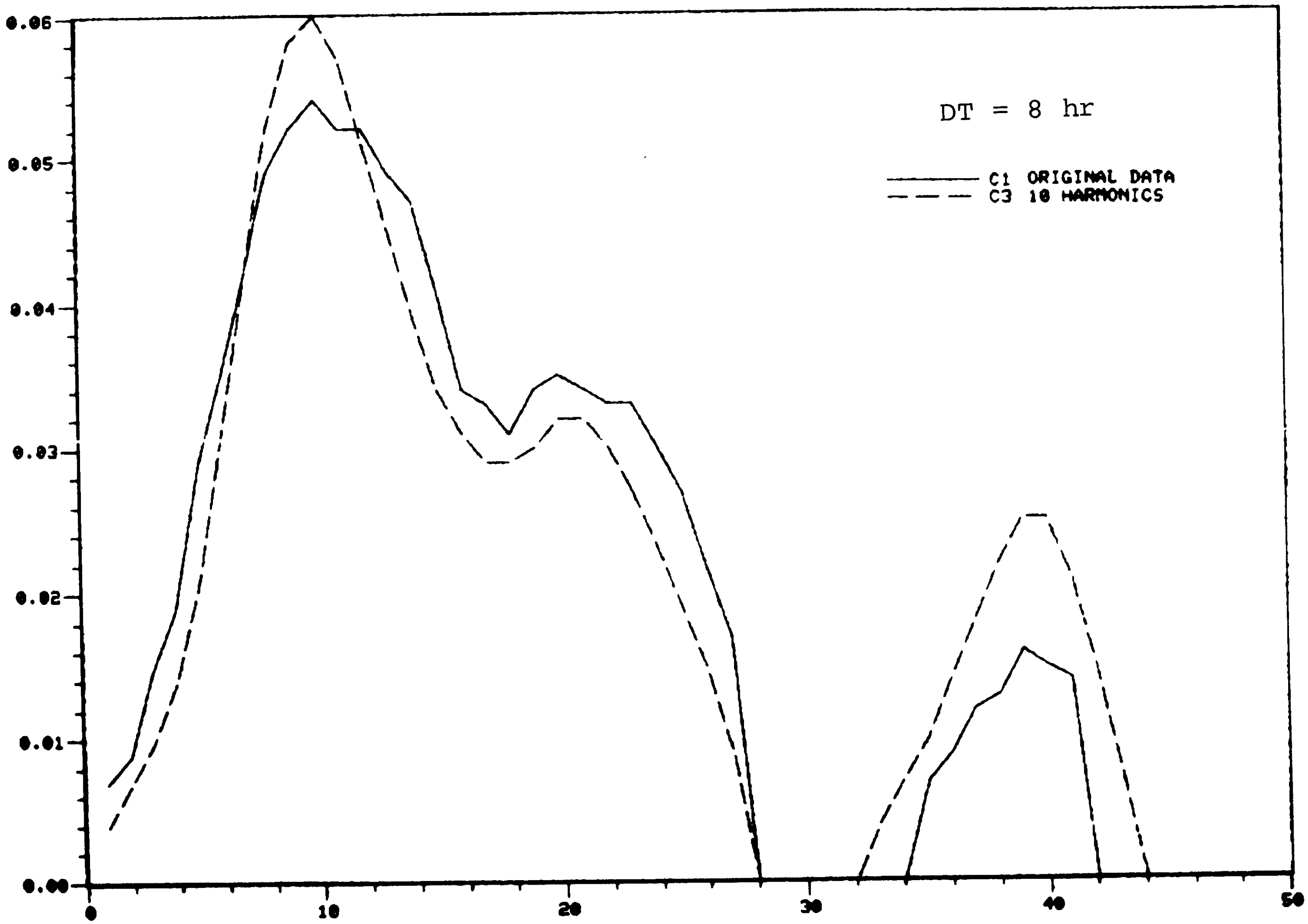


Figure B5.- (continued)

APPENDIX C

LOAD FACTOR TAIL-OFF

We will model the daily variaton of demand by means of a modified Gaussian distribution. This modified, or μ-truncated Gaussian, is the result of truncating a Normal distribution a distance μ from the center, so that only positive values of the variable are considered. This truncation requires a renormalization of the usual expression (to insure that the area under the curve is still unity, see Figure C1). If $f(x)$, $F(x)$ are the Normal distribution's density and probability functions respectively, then the expression for the probability density of the μ-truncated Gaussian is $f(x-\mu)/F(\mu)$.

Note (Figure C1) that the centroid ("expected value") of the new distribution is not at μ any more, but at a slightly larger value m.

The "ideal" or theoretical average load factor, for an aircraft capacity c is m/c. The actual average load factor is the expectation of the traffic actually carried (the lowest of x or c) divided by c:

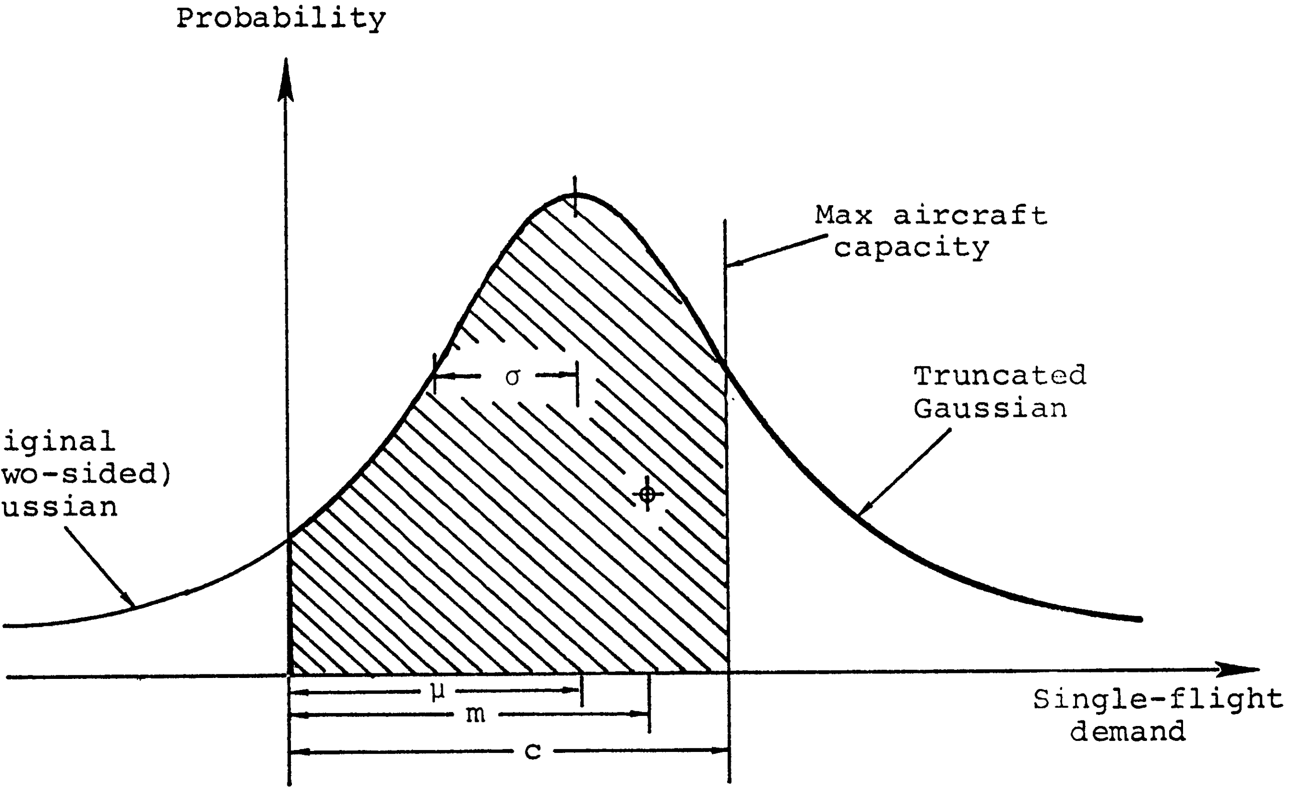


Figure C1.- Statistical distribution of demand for a single flight

$$\bar{a} = E\left(\frac{L}{c}\right) = \frac{1}{c}\left(\int_0^{\infty} \min(x, c-\mu)\,\frac{1}{F(\mu)}\,f(x)\,dx\right) \qquad \text{(C.1)}$$

For computational convenience, this can be expressed as:

$$\bar{a} = \frac{1}{c\,F(\mu)}\left(\int_0^{c-\mu} x\,f(x)\,dx + \int_{c-\mu}^{\infty} (c-\mu)\,f(x)\,dx\right)$$

$$= \frac{1}{F(\mu)}\left[\int_0^{c} \frac{x\,f(x)\,dx}{c} + (1 - F(c-\mu))\right] \qquad \text{(C.2)}$$

where the values of μ and c have been normalized (by dividing them by the standard deviation, σ). In this case, we have assume that $\mu = 2\sigma$.

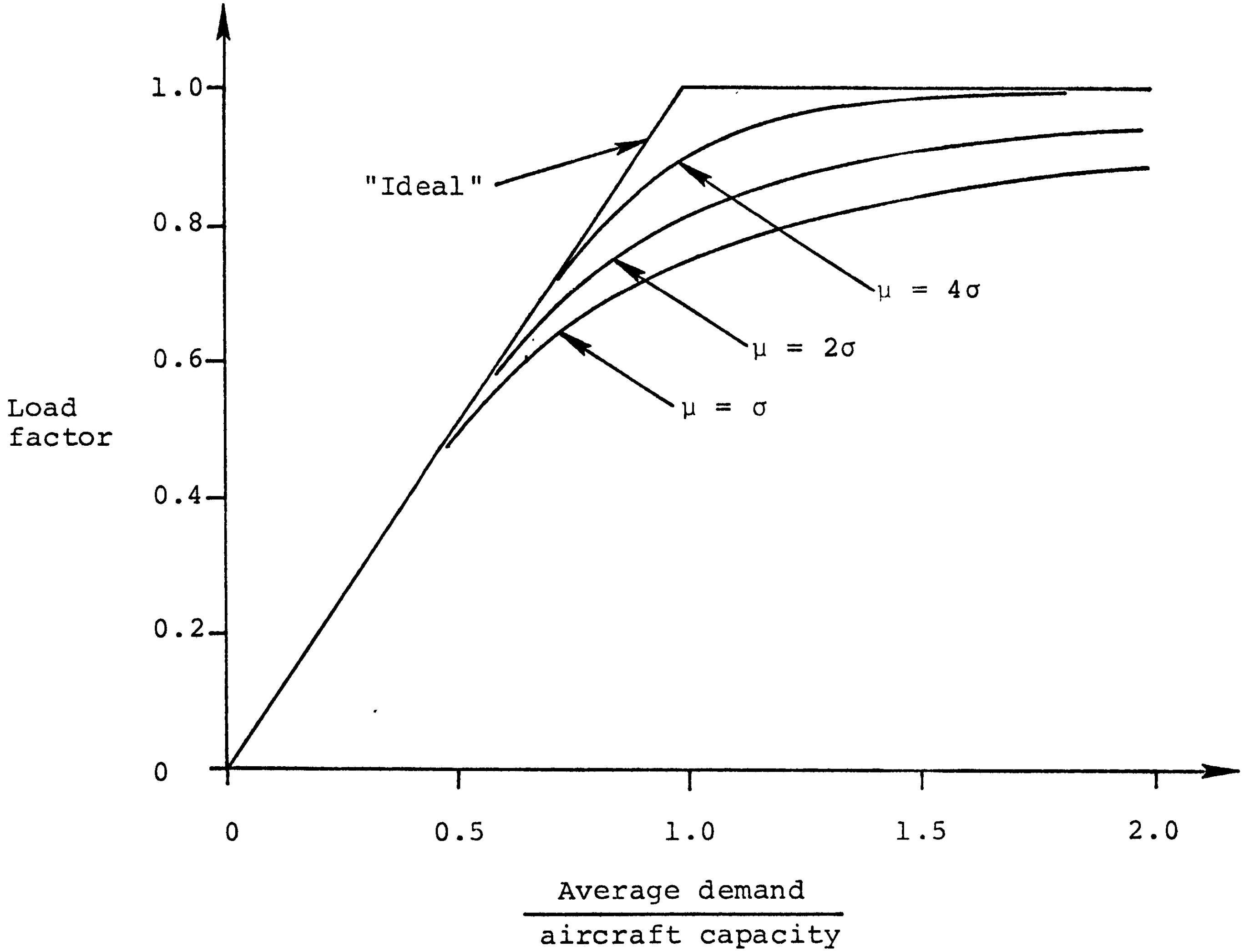


Figure C2.- Ideal and real average load factors vs. demand

APPENDIX D

DATA BASE ELEMENTS AND FORMATS

Included for reference are the record formats of the different data bases used in the simulation. These formats, along with the model descriptions included in the main text, constitute a complete specification of the simulation from which computer code may be generated.

There are three kinds of files: a Universe file, a Participant file (one for each participant), and a Simulation file. The Universe file contains data that is reasonably constant during the entire simulation. The Participant file contains both the participants' decisions for the next simulation period, and the results from the previous period (pertaining to that participant) that are required for the next simulation period. The Simulation file contains data unique to a single simulation period. The Universe and Simulation files are under control of the simulation manager, while each participant carrier is responsible for maintaining and updating his respective Participant file. Access to all these files is by means of three conversational data base management programs, one for each kind of file. Each file consists of a variable number of different kind of records. The sequence order of these records is essential, and must be preserved. Each record contains a number of data items. The Participant's file (Figure D1) consists of the following types of records:

-A heading record, containing:

The user i.d. (two characters).
The file i.d. (8 characters).
The date and time it was last saved.
The file's processing status (8 bits).
The name, and save date/time, of the Universe file used to process the file.
The name of the last period of simulation.
The date/time of the last simulation using it.
The participant's current cash on hand, accumulated Investment Tax Credit, deferred taxes, and fare formula coefficients.

-A flight record for each flight offered by the participant, consisting of:

The flight number.
The type of aircraft used.
The aircraft capacity (seats).
The revenue produced by the flight during the last simulation period.
The origin airport of the first flight segment.

-A segment record, immediately following the flight record, for each segment in a flight (minimum of 1). These records contain:

The destination airport's i.d.
The segment departure time.

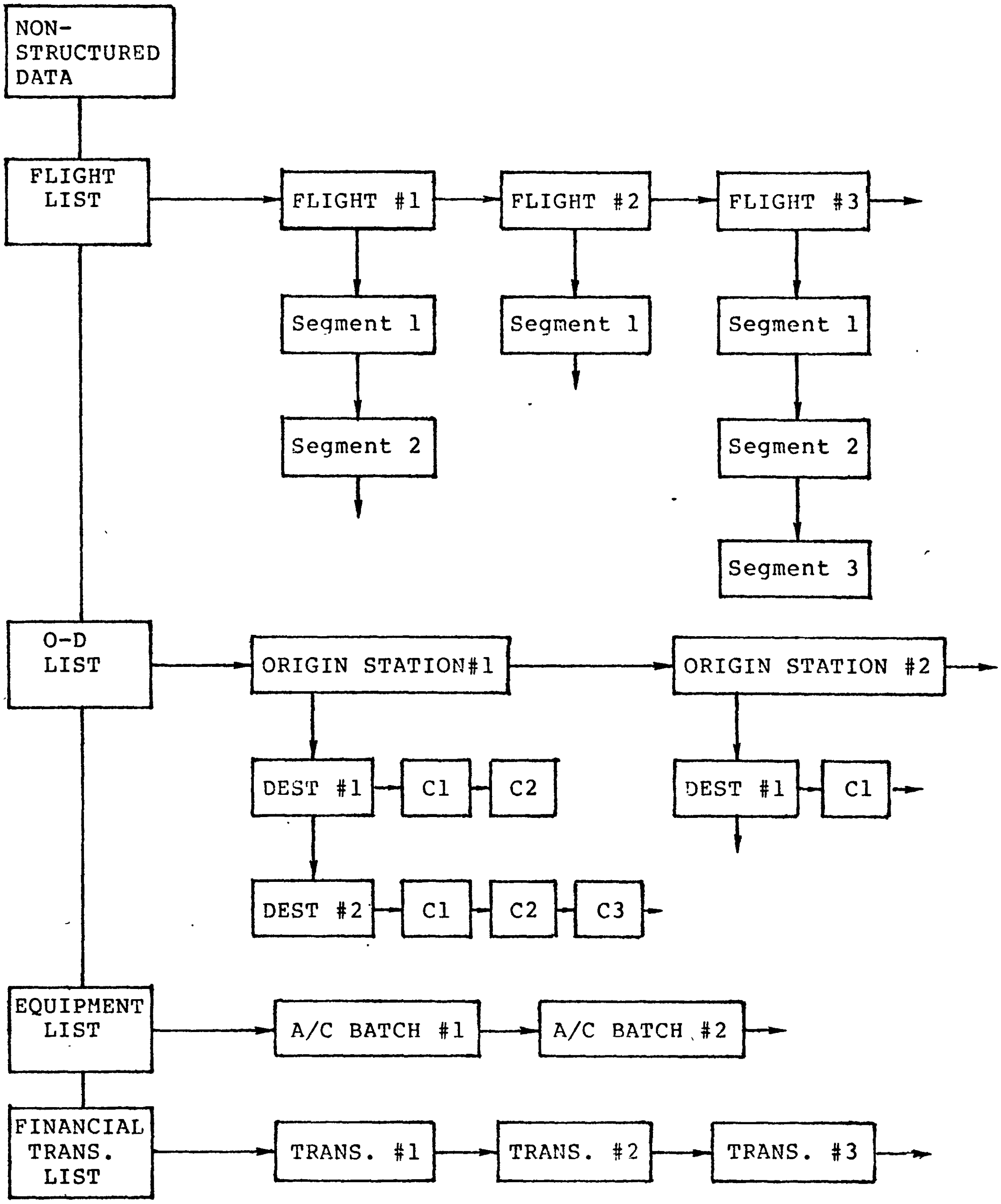


Figure D.1 - Participant file data structure.

The segment's block time, flight length, and direct costs.
The segment load (av. no. of passengers carried daily) during the last simulation period.

-An "Origin record", consisting simply of the name of an airport (origin airport). Following this record, there are a number of "destination" records containing data relative to the city-pair formed by the origin airport, and the destination airport. Each destination record contains:

The name of the destination airport.
The discrete fare charged by the participant in that city pair.

-Following each destination record, there may be one or more "online connection records", one for each online connection that the participant wishes to advertise. Each online connection record contains:

The i.d. of the connecting airport.
The numbers of the two flights making up the connection.
The connection's effective departure and arrival times.
The proportion of the total revenue that is to be allocated to the first flight.

-Similarly, there may be one or more "interline connection records". These records are different from the on-line ones because no preprocessing of connection data (e.g. to check the validity of the connection) can be done by the participant file processor. Each interline connection record consists of:

The i.d.'s of the two carriers offering the two flights that make up the connection.
The two flight numbers.
The i.d. of the connecting airport.

-Fleet records, one for each "batch" of aircraft owned or leased by the participant, made up of:

The type of aircraft making up the batch.
Their time in service (or time remaining in the lease).
The number of aircraft making up the batch.
The original cost per aircraft, (or lease payments, for a lease).
The book value, life, and residual values for the linear and accelerated depreciation.

-Financial transaction records, one for each financial transaction active for the participant, including:

A 50-character verbal description of the type of transaction.
The remaining active time of the transaction.
The periodic cash flow (e.g. interest).
The final cash flow at the end of the life of the transaction (e.g. debt repayment).

The Universe file (Figure D2), similarly, consists of the following records:

-A heading record, containing:

The file's i.d.
The date and time it was last modified.

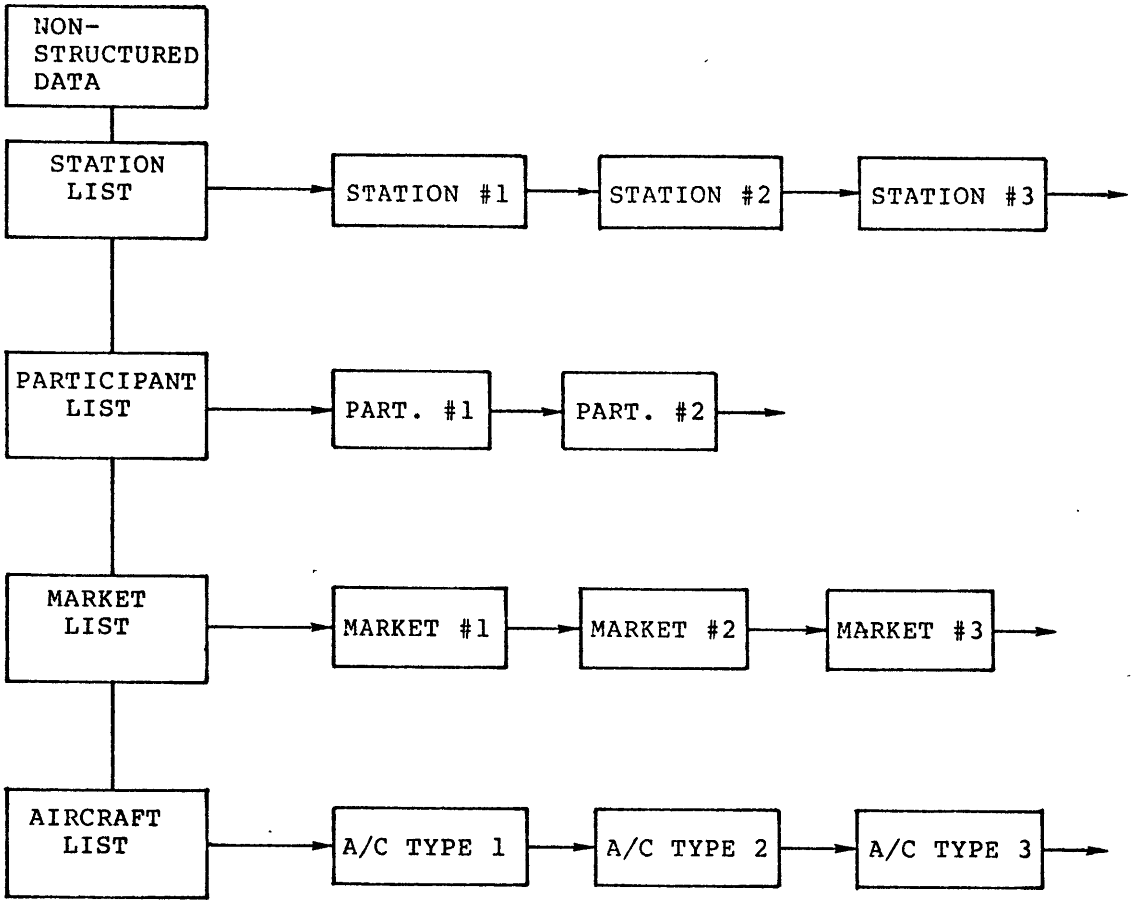


Figure D2.- Universe file data structure.

-A "station record" for each airport used in the simulation, consisting of:

The station's standard three-letter i.d.
The full name of the city served.
The i.d. of the region served by that airport.
The latitude, longitude and time zone.
The minimum connecting time at that airport.
The average air and ground maneuvering time for an operation at that airport.
The fees/cost per operation (a basic amount plus an amount per seat).
The aircraft/runway size restriction code.

-A "participant record" for each participant authorized to use the simulation, consisting of:

The participant's two-letter i.d.
The participant's full name.
The minimum ground time between flight stops, and the minimum ground time between flights.
The costs per asm, rpm, enplanement, and $ of revenue for the participant.

-A "market record" for each market (region-pair) to be included in the simulation, made up of:

The names of the two regions making up the market.
For each of four seasons, the nominal demand, the nominal fare and level of service corresponding to that demand, and the fare and level of service elasticities of demand.

-An "aircraft record" for each aircraft type,including:

The aircraft type standard three-letter i.d.
The aircraft's capacity (seats), range and average cruising airpseed.

The aircraft's direct operation cost per hour, cost per takeoff/landing, and cost per day of availability.

Finally, for the simulation file (Figure D3), we have the following:

-A header record, containing:

The file's name and date/time of last update.
The Implicit Price Deflator.
The short term bank deposit interest rate.
The global demand multiplier.
The allocation process elasticities, multiplier and deadband.
The season to be simulated.
The name to be given to the period.
The time penalty to be added to connecting flights above their own trip time.

-A "participant record" for specific data to be used for each participant in this period, consisting of:

The participant's i.d.
The subsidy payments for that participant for this period of simulation.

-A "transaction record" for each new financial transaction that is to be added to a participant's active transaction list during the next simulation period, made up of:

The i.d. of the participant.
The verbal description of the transaction.
The active life (number of periods).

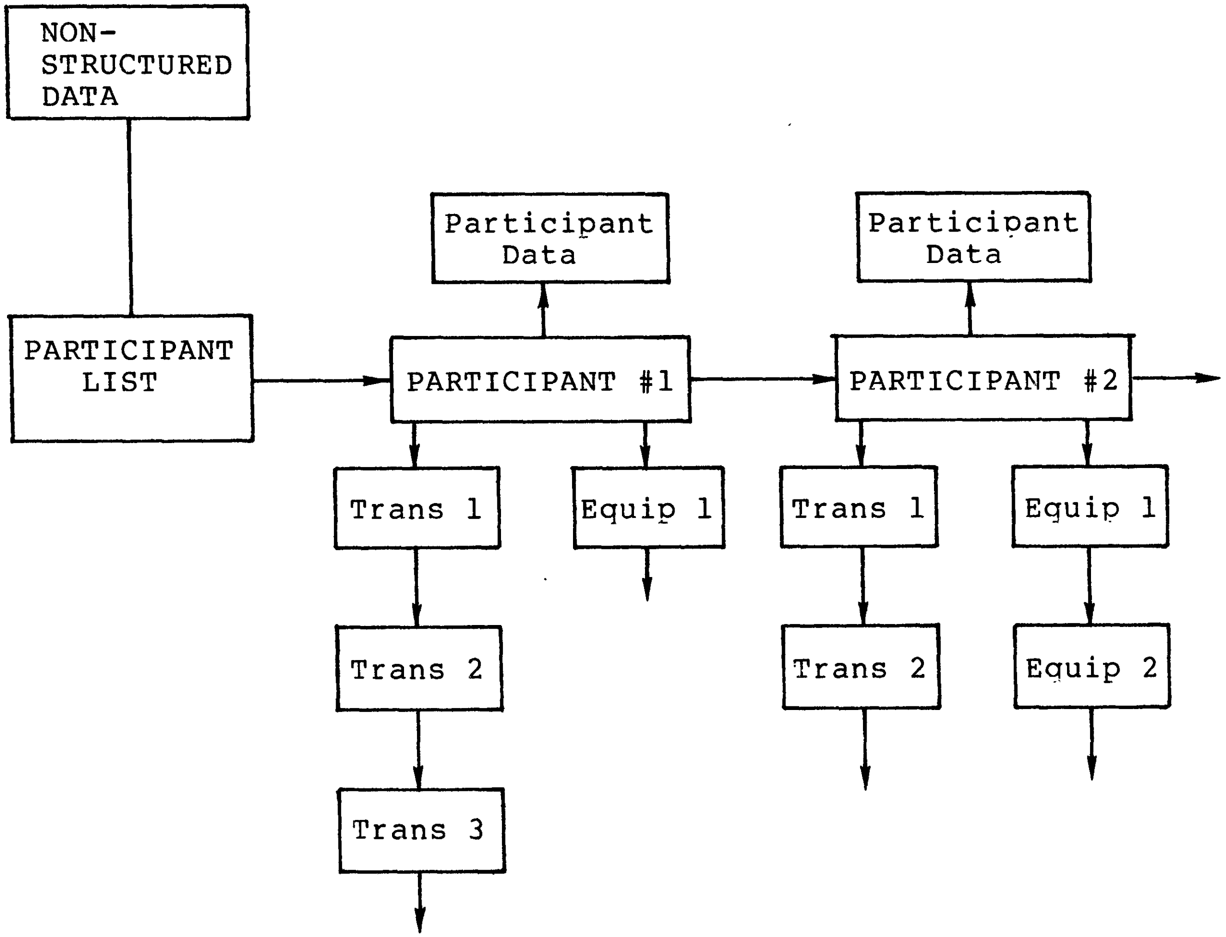


Figure D.3 - Simulation file data structure.

The initial, periodic, and final cash flows implied by the transaction.

-An "equipment record" for each equipment transaction (purchase, sale or lease) that is to take place at the end of the next simulation period. Each record is made up of:

The i.d. of the participant involved.

The type of aircraft.

The time in service of the aircraft being sold, the length of the lease, or zero (purchase).

The purchase/sale price, or lease payments.

The life and residual values to be applied for the straight line and Double Declining Balance depreciations.

APPENDIX E

CONVERSATIONAL COMMANDS AVAILABLE

As a reference, and to illustrate the level of complexity involved in the data base management procedure required to run this simulation, the conversational commands available under each of the three file management programs are listed, along with a brief description of their function.

Universe file processing program (UFP) commands and subcommands:

ADDA	Add aircraft. Adds a new type of aircraft, and its characteristics.
ADDM	Add market. Adds a new market (region pair) and its demand parameters.
ADDP	Add participant.
ADDS	Add station. Adds a new airport and its data.
DELETEA	Delete aircraft.
DELETEM	Delete market.
DELETEP	Delete participant.
DELETES	Delete station (airport).
END	End. Terminates the conversational session.
HELP	Prints out at the terminal information useful to the user about each command/subcommand available.

LISTA Lists either all the aircraft types available, or the parameters of a given aircraft type.

LISTM Lists either all the markets known or the parameters of a given market.

LISTP Lists either all the participants, or the parameters of a given participant.

LISTS Lists either all the airports known, or the parameters of a given airport.

MODIFYA Modifies the parameters of a given aircraft. This command has the following subcommands:

C/DAY	Modify the cost per day of availability.
DOC/H	Modify the direct cost per hour.
DOC/O	Modify the direct cost per operation.
RANGE	Modify the aircraft range.
REST	Modify the aircraft's restriction code.
SEATS	Modify the aircraft's capacity.
SPEED	Modify the aircraft's cruising airspeed.

MODIFYM Modifies the parameters of a given market. This command has the following subcommands:

FELAST	Modify the fare elasticity of demand.
LELAST	Modify the level-of-service elasticity.
NDEMAND	Modify the nominal total demand.
NFARE	Modify the nominal fare.
NLOS	Modify the nominal level-of-service.

MODIFYP Modifies the parameters of a given participant. This command has the following subcommands:

CASM	Modify the cost per asm.
CENP	Modify the cost per enplanement.
CRPM	Modify the cost per rpm.
C/REV	Modify the cost per $ of revenue.
INTERT	Modify the minimum interflight time.
NAME	Change the participant's full name.
STOPT	Modify the minimum ground time.

MODIFYS Modifies the parameters of a given airport (station). This command has the following subcommands:

BASICC	Modify the basic operation cost.
BASICT	Modify the ground/air maneuvering time.
CITYN	Change the full name of the city served.
CONNT	Modify the minimum connecting time.

COST/S	Modify the landing fee per seat.
LAT,LON	Modify the latitude, longitude.
MARKETA	Change the i.d. of the market area served.
RESTC	Change the aircraft/airport restriction code.
TIMEZ	Change the time zone.

NOVERB	Request short form of terminal messages.
READ	Read data from existing file into the processor.
SAVE	Write current data into a file.
VERB	Request long form of terminal messages.

Participant file processing program (PFP) commands and subcommands:

ACCD	Add connection (online or interline).
ADDF	Add flight. Adds a new flight to schedule.
CHECKS	Check station. Checks the aircraft flow in and out of each airport used; if flow balances, the no. of aircraft required by type is displayed.
COPYF	Copy flight. Copies one flight into a new one, at a different departure time.
DELETEC	Delete connection.
DELETEF	Delete flight.
INTERFT	List the minimum interflight time parameter.
LISTA	List the participant's active financial transactions.
LISTB	List the cash balance and other data.
LISTC	List connections.
LISTE	List the aircraft available to the participant.
LISTF	List either all the flight numbers, or the data for a given flight.

LISTS	List the aircraft flow through a station.
LISTT	List the tariffs available between two cities (airports).
MODIFYF	Modify the parameters of a given flight. This command has the following subcommands:

EQUIP	Change the type of aircraft used.
ITIN	Modify the flight itinerary.
SCHED	Modify the flight schedule.
SHIFTD	Shift the entire schedule in time.

NAME	Change the file name.
NOVERB	Request short terminal messages.
READ	Read data from existing file into processor.
REDOF	Re-compute a flight's parameters.
SAVE	Store the current data into a file.
STOPT	List the minimum ground time parameter.
TARIFFC	List/change the fare formula coefficients.
USER	Change the user to whom the file belongs.
VERB	Request long terminal messages.

The data validity checks that the participant file processor makes on the input data are:

a) Spelling of abbreviations (airport names, aircraft types).

b) Airport - aircraft compatibility (runway length).

c) Stage length - aircraft range compatibility.

d) Minimum ground time between arrival and departure of the same flight.

e) Validity of interline connections, with regards to both itinerary and schedule (including minimum connecting time at the connecting airport).

The processor performs the following operations on the input data, either in preparation for the simulation step, as an aid to the user, or both:

a) Computation of the block times for each flight segment.

b) Computation of the direct costs (see Section 3.2.1) for each segment.

c) Computation and display of the earliest time at which an aircraft is available after a flight.

d) Preparation of a list of flight initiations and terminations for each airport at which flights initiate and terminate.

e) Check of the aircraft flow at these airports.

f) Computation of the number of aircraft required to fly a (balanced) network, by aircraft type.

g) Computation and display of the Standard, carrier formula (see Section 3.1) and carrier discretionary fares for each market.

h) Display (only) of the carrier's financial and equipment data.

Simulation file processing program (SFP) commands and subcommands:

ADDE	Add an equipment transaction.
ADDF	Add a financial transaction.
ALLOCM	Modify the allocation multiplier.
CONCO	Modify the connection correction parameter.
DELETEA	Delete an equipment transaction.
DELETEE	Delete a financial transacton.
DELTAA	List/modify the allocation deadband param.

DEMM	Modify the global demand multiplier.
IPD	Modify the Implicit Price Deflator.
LISTB	List a participant's balance and other data.
LISTE	List the equipment transactions entered.
LISTF	List the financial transactions entered.
LISTS	List a summary of simulation parameters.
NAME	Change the name of the period simulated.
READ	Read data from existing file into processor.
SAVE	Save current data into a file.
SEASON	Change the season for next simulation.
SHORTR	Modify the short-term deposit interest rate.
SUBSIDY	List/modify the subsidy paid to each participant.