APPLICATION OF OPERATIONS RESEARCH IN THE AIRLINE INDUSTRY

by

ARTHUR ALEXANDER
B.Sc., University of Alberta, 1954

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF BUSINESS ADMINISTRATION

in the Faculty
of
COMMERCE AND BUSINESS ADMINISTRATION

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1971

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

ARTHUR ALEXANDER

Department of Commerce and Business Administration

The University of British Columbia
Vancouver 8, Canada

Date 23 April 1971

ABSTRACT

The problem was to review and evaluate operations research techniques and models that had been applied in the airline industry and to discover problem areas where further research is needed.

The method was to review management and operations research literature pertaining to airlines, and to formulate the thesis outline on the basis of literature consulted. More specialized literature was then sought under each of the main chapter headings: Marketing, Production, Airports, Finance.

In Marketing, little was found that originated from airline companies, except in the area of forecasting. Advertising and pricing models studied were chiefly from manufacturing industries.

Airline Production, the revenue-earning part of airline operation, has been extensively studied by operations researchers in the airline industry. Reservations systems, manpower planning, scheduling of aircraft and crews and passenger check-in and baggage handling were main topics of study.

Airport models dealing with traffic congestion, Air Traffic Control, aircraft maintenance, and inventory control

have been successfully implemented.

Financial models have been developed largely by airframe manufacturers as selling tools for new aircraft, and for market research by the plane builders. Cash flow models and models that aid financial control have been applied.

General conclusions are that operations research has been investigated as a means to better airline management in most departments of airline operation. Much remains to be done to develop practical operations research competence in the following areas:

1. Advertising and Pricing.
2. Routing and Scheduling of aircraft and crews.
3. Financial Investment.

The volume of the literature on operations research is growing rapidly. This thesis includes only a small sampling of the work done prior to 1971. For more intensive study, bibliographies of current and past work should be consulted. An excellent source of bibliographical data is the International Abstracts in Operations Research, by the International Federation of Operational Research Societies, (IFORS).

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENT

For giving me an opportunity to write this thesis, I owe warmest thanks to Howard Stewart and Dorothy Stewart.

For innumerable cups of coffee and for her persistent encouragement, I thank my wife, Marilyn Jean Alexander.

For assistance in preparation of the material and for many helpful suggestions, I am indebted to Dr. Bernard Schwab, to Dr. Karl Ruppenthal, and to Dr. William Ziemba.

For typing the final draft, much praise is deserved by Maryse Ellis.

CHAPTER I

DEFINITIONS OF OPERATIONS RESEARCH

In 1970, airlines began to economize. About 10,000 employees were laid off and many in-flight amenities were withdrawn. Economy class passengers paid to see movies, and in most morning flights, the trend was to sandwiches instead of hot meals, first class meals without soup, higher charges for cocktails, and cream or sugar for coffee only if requested. Washroom towels were changed from cloth to paper. United Air Lines was said to save about $300,000 annually by the use of less expensive paper and fewer colours for tickets, timetables and entertainment programs.

On a larger scale, United Air Lines cancelled eight orders and fifteen options for DC-10 airbuses, and postponed delivery of four Boeing 747's. Over 1971 and 1972 this was expected to save the company $130 million.[1]

Most large airlines and the three large U. S. aircraft manufacturers use operations research, (O/R). Was the use of O/R a factor in the 1970-71 downturn in airline fortunes? If O/R is unable to prevent serious misjudgements

---

[1] TIME Magazine, February 8, 1971, p. 53.

in corporate policy, what use is it? Practical men in high positions may well ask questions like these.

The proper use of O/R improves corporate performance in many ways, some of which are discussed in the chapters that follow. The great decisions that deal with market prediction and major policy are far from academic formality. If O/R was a factor in choosing poor policy, then the O/R was misapplied, perhaps from faulty assumptions, from careless analysis of the problem, or from literal acceptance of model results.

> A stringent set of assumptions is needed to go from the real world to a manageable model. Naturally these assumptions do not describe the real world; if they did, there would be little purpose in making them at all. A model should be examined to see if it is consistent with the assumptions made. The usefulness of the model, then, depends on whether the results given by the model will hold when the assumptions underlying the model are modified to fit the many facts existing in the real world. 2

The O/R model is a tool and not a substitute for judgement. Models provide logical means for utilizing available information to narrow the range over which decisions are made.[3] Users of O/R should be aware that output is a function of input provided. Managers may not follow details of the mathematics but they *can* understand the factors used

---

[2] F.M. Bass, et al. (eds.), Mathematical Models and Methods in Marketing, Homewood, Irwin, 1961, p. 173.

[3] Ibid., "The Uses and Limitations of Mathematical Models for Market Planning," by R.S. Weinberg, p. 34.

and the assumptions made. Airline size, traffic density, degree of competition, or mean stage length all affect profitability, but the big factor is often management.[4]

Study Routine usually follows a pattern approximately as follows:

1. Formulate the Problem. (What are we trying to do?)
2. Model the system mathematically. (How do we go about it?)
3. Derive model solutions.
4. Test model and solutions. (What did we find out?)
5. Establish controls for solutions. (What do we conclude?
6. Implement the solution.[5] (What do we recommend?)[6]

Steps 2 and 3 above usually involve one or more of the standard operations research techniques. However, when new problems are encountered, unsolved difficulties often lead to the development of new theory. If a model is a poor representation of the world, it may have been the result of trying to force a real world situation into a stereotype mould.

---

[4] G. Burck, "A New Flight Plan for the Airlines," Fortune, April 1969, p. 206.

[5] F.S. Hillier, and G.J. Lieberman, Introduction To Operations Research, San Francisco, Holden Day, 1967, p. 12.

[6] R.E. Jacks, "Passenger Check-in and Information System," AGIFORS Proceedings, 1969.

> A new engineer has a rather naive belief in the traditional advisory concept of staff. He believes he will be called upon because of his superior training and knowledge. Most industrial engineering supervisors, however, envision the department not as a consultant or service group, but as a catalyst, a questioner of existing procedures and a force in instituting new methods. 7

Briefly, O/R techniques are as follows:

1. Mathematical Programming.

Linear programming and special cases, including the transportation problem, the transhipment problem, and the assignment problem.

Non-linear programming, including integer, stochastic, and quadratic programming.

2. Combinatorial Analysis

    the Critical Path Method. (CPM)

    PERT

3. Dynamic Programming

4. Game Theory.

5. Queueing Theory. In the discussions that follow, the Kendall classification for queueing systems is used: A/B/S:(d/e), where A = arrival pattern, B = service pattern, S = number of servers, d = maximum number waiting or being served, e = queue discipline.

---

[7] R.A. Webber, "Innovation and Conflict in Industrial Engineering," Journal of Ind. Engineering, Vol. XVIII, No. 5, May 1967, pp. 306-313.

6. Models of Stochastic Processes.

7. Simulation.

Operations Research at Aer Lingus[8]

O/R is the application of quantitative analysis and scientific concepts to the construction of decision models as an aid in solving management problems. Aer Lingus in 1968 had a mixed fleet comprised of Boeing 707 and 720, BAC-111 and Viscounts. B737 and B747 aircraft were planned for the future.

The use of O/R at Aer Lingus began in 1961. By 1968 there were nine management science specialists. A partial organization chart, shown in Figure 1, illustrates the company O/R configuration of 1968. Three management scientists in the economic planning group focused on corporate planning such as investment oriented models of company operations. The six under the systems manager worked on tactical problems.

Some of the main applications of O/R at Aer Lingus were the following:

---

[8] M.A. Foley, "O/R at Aer Lingus," The Aeronautical Journal, Vol. 72, No. 691, July, 1968, pp. 596-602.

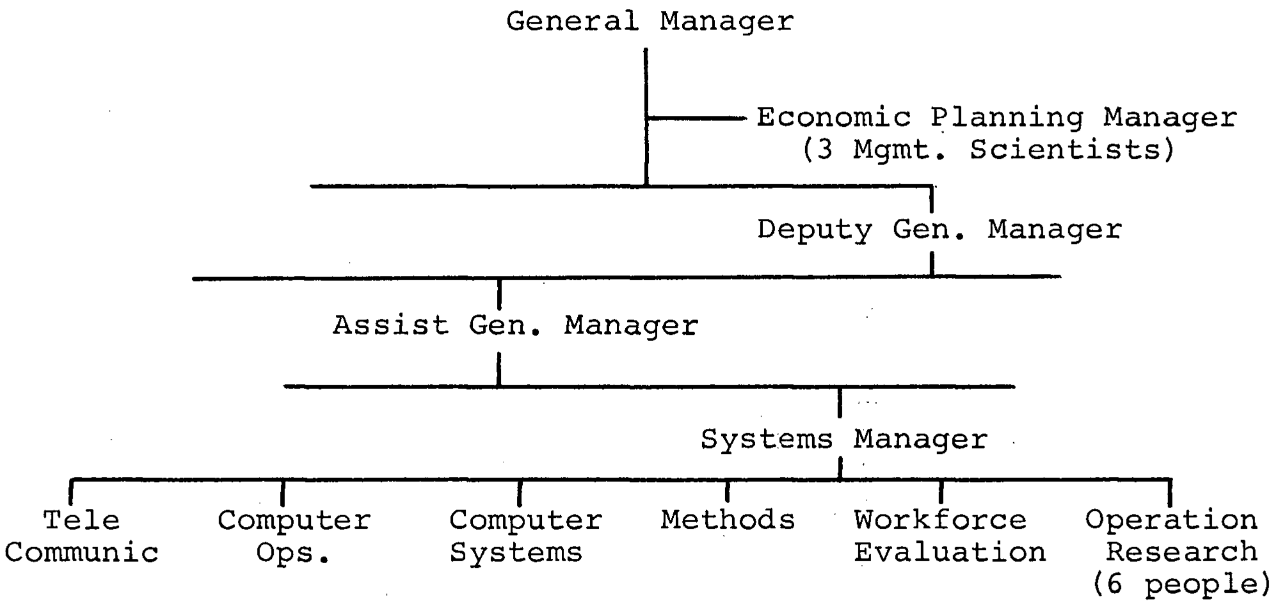


Figure 1 Operations Research at Aer Lingus. (from The Aeronautical Journal, July 1968, p. 597.)

Inventory Control difficulties arose from the number of items, (125,000 part numbers), infrequent and irregular demand, short consumption history, very high shortage costs, long and variable lead times, and the need to purchase large initial stocks before operating experience was obtained. Problems of implementation were in weaving decision models into practical computer systems that served many other needs.

Fleet Planning, subject to peaked demand characteristics. Aircraft mix depended on types of aircraft available, traffic loads, and route characteristics. Selection of the

B737 for short haul work was based on this model. A second model evaluated Supersonic Transport and Jumbo jet effects on the trans-Atlantic routes. A third model gave as output the number of aircraft required to fly a given schedule for given route structures.

Fleet Simulations required detailed schedules of flights nine to eighteen months ahead. Weather, Unscheduled maintenance, airport congestion, random fluctuations in turn around time . . . dictated a requirement for slack. Monte Carlo simulations were used to evaluate alternatives. Tradeoffs were made between punctuality and aircraft productivity.

Computer Systems, real time passenger name records and reservations should be handled on the most suitable equipment. O/R was used to solve specific problems, for example the capabilities of alternative facilities, or passenger service standards as a function of the number of agent sets.

Manpower Planning in sales offices to give a specified level of service, included queueing problems based on expected call-arrivals, hourly over the year.

Manpower for passenger and aircraft handling at the airport. A queueing model by week, to accommodate demand fluctuations, and to provide acceptable service levels at reasonable manpower costs, the model was used to assess some of the costs of adding extra flights.

Aircrew Rostering, an allocation problem using mathematical programming to minimize the *number* of crews assigned to flights.

Traffic Forecasting by exponential smoothing was used for short term, and multiple regression analyses for medium ranges of up to two years. Until 1968, few useful models rewarded all the effort.[9]

Pilot Training. Deterministic simulations provided valuable insights into the costs of training pilots.

Air Hostess Recruitment by dynamic programming methods attempted to accommodate fluctuations in need and in attrition, within the limits of available training facilities. Hiring and training is cheapest if spread out over time, but this may produce surplus hostesses at off-peak times.

Survey of Operations Research in Ten Airlines.[10]

In response to a 1967 survey by Japan Air Lines, ten airlines were asked to give data with respect to their O/R activities. Names of O/R groups varied from company to

---

[9] Ibid.

[10] Japan Air Lines, "Operations Research Organization, Functions and Activities," AGIFORS Proceedings, 1967, p. 123.

company. The main *functions* described in response to the survey are listed below.

Plan, develop, assist other departments by providing mathematical techniques.

Research and develop O/R techniques.

Advise management of O/R approach.

Carry out studies, analyses, and projections.

Improve profitability by the use of scientific techniques.

Advise or assist management using O/R and similar techniques.

Scientific programming.

Provide consulting service.

O/R *Activities*, past, present, or future in the ten airlines included variations of the following:

1. Survey of O/R applications.
2. Market demand analysis and forecasting.
3. Aircraft routing, scheduling, and fleet simulation.
4. Inventory control and spares location.
5. Maintenance recording, scheduling.
6. Manpower requirements, rostering.
7. Crew recruitment, training, scheduling.
8. Airport facilities simulation.
9. Passenger servicing at airports, booking policy.
10. Corporate planning--long range staff planning.
    (a) model of the firm
    (b) accounting methods, sampling

11. Computer capacity evaluation--system evaluation.

    (a) reservations system

Figure 2 shows the composition of ten airline O/R groups as surveyed in 1967. The following abbreviations are used in the Figure 2.

AA American Airlines	AC Air Canada
AF Air France	AR Aer Lingus
BA BOAC	LH Lufthansa
SK Scandinavian	SR Swissair
UA United Air Lines	JL Japan Air Lines

Planning and Control--Problem Analysis

The man who insists on seeing with perfect clearness before he decides, never decides.

Henri Frederick Amiel

A descriptive classification of airline problems is illustrated in Figure 3. Airlines, like other forms of enterprise, are faced with the need to make decisions with less information than they would like. N. R. Tobin, inspired by R. W. Linder,[11] suggested that decisions are based on knowledge and understanding. Knowledge is usually partial, and based on historical observation. Understanding is an

---

[11] Linder, R.W., "Models for Planning and Control," AGIFORS Proceedings, 1969.

Airline		AA	AC	AF	AR	BA	LH	SK	SR	UA	JL
Year O/R Began		60	57	56	61	62	67	65	59	55	65
Staff:	O/R Analyst	12	9	4	6	6	4	3	3	6	3
	Mathematician					1	1	1			
	Statistician					1	1	1	1		
	Others	3									
Education:	Engineering	1	3		1	1	2	3	3	3	3
	Maths, Stats.	5	3	4	3	6	2	2			
	O/R	8									
	Economics	1	2		2	1	1		1	3	
	Other		1								
Staff Age:	20 - 30	11	5	4	4	5		3	4	2	
	30 - 40	2	4		2	2	6	1		2	2
	40 - 50	2						1		2	1
	50 - 60					1					
Years of Company Experience	0 - 2	11	2	2	4	5	6	3	4	2	
	3 - 5	3	5	1	2			1			
	6 - 9	1	2	1		2				3	
	10 - up					1		1		1	3
Total O/R Staff		15	9	4	6	8	6	5	4	6	3
Special Education		✓	✓	No	✓	✓	✓	✓	✓	✓	✓
- By invited lectures							✓				
- By educat. institution		✓	✓		✓	✓	✓	✓	✓		✓
- Other			✓			✓	✓			✓	
Staff Rotation	No	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Yes							✓			
Computer Program	By O/R staff	✓	✓		✓	✓	✓	✓	✓		✓
	By Programmer	✓	✓	✓	✓	✓	✓	✓		✓	

Figure 1.2 O/R Staffs in Ten Airlines
(From AGIFORS Proceedings, 1967 p. 390.)

outgrowth of partial knowledge. Understanding is therefore incomplete, particularly when applied to future events. Yet decisions must be made, and are being made very largely on bases of judgement and experience. Figure 3 illustrates the importance of judgement in model application.

While many long-run decisions are somewhat flexible, investment decisions made today are reasonably binding and in many cases will not affect operations for two or three years.

A novel view of airline management problems is taken in Belgray's comparison between Israel's Air Force and airline operation.[12] In an interesting breakdown of air force characteristics and functions, the Israeli Air Force is set as an example in management effectiveness. The lesson is that *any* well run operation can provide useful ideas.

O/R as an Airline Product

BOAC, a latecomer to computerization, became a leader in the field of real-time systems, and in 1971 sold hardware and software as a sideline. Eastern Air Lines and Continental in the United States also sold software. Although BOAC developed more than fifty programs for airline operation,

---

[12] Belgray, D.C., "The Israeli Air Force, The Six Day War, and Their Relevance to Airline Management," AGIFORS Proceedings, 1968, pp. 464-482.

KNOWLEDGE

	Control	Short Range	Long Range
Internal	What alternative actions can we consider?	What options are open to us next season?	What options are available in the long run?
Competitive	What are the competitors doing?	What will the competitors do next year?	What will the competitors do in long run?
Public	What is the state of the public?	What are the socio-economic variables?	What will be the socio-economic variables?

UNDERSTANDING

	Control	Short Range	Long Range.
Internal	How will current actions affect costs?	How do costs relate to decision variables?	What capital, operating costs @ given mkt share?
Competitive	How will current actions affect demand?	How do revenue & service relate? For competitors?	How do market shares relate to company variables
Public.	What demand for football game next week?	How will market relate to socio-economic variables?	How is market affected by socio-econ. variables?

DECISION.

	Control	Short Range	Long Range.
Internal	Which engine do we o'haul? Which path do we fly?	How do we roster pilots next year?	What major long-run investments?
Competitive	Should we put on an extra flight?	What schedule? What market share next year?	What is our long-run market aim?
Public.	Should we accept this booking, delay this flight?	What schedule? Will it match demand?	What passenger target in long run? Where?

Figure 1.3 Judgement Elements in Model Application.
(From AGIFORS Proceedings, 1969.)

many real-time systems such as reservations and departure control were largely routine activities. On the tougher problems such as forecasting, scheduling and routing, BOAC was in the same situation as others who have struggled to develop satisfactory models--still looking for better answers.

By 1970, BOAC's computer system, BOADICEA, was credited with improving load factors by two per cent, equivalent to $9 million in extra annual revenues. The roles of middle and top management were not eliminated, nor was this expected.[13]

---

[13] Airline Management and Marketing, Vol. 2, No. 12, December 1970, p. 23.

CHAPTER II

OPERATIONS RESEARCH IN AIRLINE MARKETING

The product of an airline, the movement of passengers or cargo, is not usually wanted for its own sake. Time saved, or arrival at destination are the real products--products that are essentially undifferentiated among airlines.[1]

Several factors promote the growth of air traffic. Over long distances air transport is faster than alternative modes for travel or for cargo shipment. Airline fares and cargo rates, while usually more expensive than surface transport rates, are nevertheless competitive when costs of time in transit are significant. Increasing concentrations of urban populations put more people within convenient reach of airports at both ends of their journey. Growing population and increased national productivity gradually increase personal discretionary income. The result is increased personal spending on airline tourism.

While total airline costs are rising,[2] unit costs are falling in some areas. For example, direct costs for

---

[1] J.L. Grumbridge, Marketing Management in Air Transport, London: George Allen and Unwin Ltd., 1966, p. 24.

[2] Aviation Week and Space Technology, January 11, 1971, p. 23.

flying freight have fallen from about twenty cents per ton mile with DC-3 aircraft to about three cents per ton mile with the Boeing 747.[3] Marketing concern for costs is implicit in the logical search for prospective demand. This can originate two ways. Either a demand is recognized, and the problem is to find feasible solutions that meet cost constraints, or the means for low cost transportation are available, and the problem is to seek out the demand. The Lockheed company was faced with the latter problem in seeking potential civilian uses for the C5 transport aircraft.[4]

Airport development has tended to lag behind needs for longer and stronger runways for larger aircraft, for passenger facilities and freight handling capacity.[5] Resulting congestion and delay are negative factors that tend to discourage prospective airline customers.

Airlines generally are bound by regulation in their own national territories, and on international routes by

---

[3]C.W. Foreman, "The Hidden Benefits of Air Freight," Business Horizons, Vol. 11, No. 6, December 1968, pp. 27-34.

[4]Aviation Week and Space Technology, January 12, 1970, p. 30.

[5]Stanley H. Brewer, The Environment of International Air Carriers in the Development of Freight Markets, Seattle: University of Washington, Graduate School of Business Administration, 1967, p. 54.

International Air Transport Association (IATA), and International Civil Aviation Organization (ICAO) standards, as well as by bilateral agreements. In 1970 the United States Civil Aeronautics Board (C.A.B.), became aware of excess competition on some national routes, but the C.A.B. was reluctant to allow joint capacity reductions because this would be collusion (that violated anti-trust laws and United States aviation policy). Predetermined capacity at home implies acceptance of predetermined capacity on international routes, contrary to United States policy of the past two decades.[6]

> The cardinal sins of the regulators have been in legislating, in effect, wasteful ruinous over-competition along air routes and then intervening unwisely to forestall the natural adjustments for over-competition--merger, statesmanlike agreement, or business failure. 7

This was demonstrated in 1969 when five carriers were permitted by the C.A.B. to join three already-certificated carriers in flying the Hawaii route.[8]

Marketing provides the foundation that supports the business structure. Market surveys usually precede business

---

[6]Aviation Week and Space Technology, February 2, 1970, p. 36.

[7]Tom Alexander, "Is There *Any* Way to Run an Airline?" Fortune Vol. LXXXII, No. 3, September 1970, p. 117.

[8]*Ibid.*, p. 204.

activities, and success depends upon flexibility and innovation in adapting to market changes. Eastern Air Lines' "Air Bus" service is an example of innovation in the American market for air travel. There are no reservations, no food, no refund within twenty-four hours, and passengers carry their own baggage to the gate.[9] Marketing is demand-oriented and is concerned with actual or potential revenues from fares, excess baggage, mail, freight, charter and other services to the public or to other airlines. Airline marketing organizations are subject to change, as in United Air Lines' transfer of sales promotion to advertising, or Trans World Airlines' elimination of its advertising department (but not of advertising).[10] Experimental services, for example, suburban check-in for the New York metropolitan area, with waiting rooms, parking space, baggage and ticket checking, have been tried in an attempt to generate traffic and to relieve airport congestion.[11] to meet competition from charter operations, scheduled transatlantic European carriers began pooling marketing data that were formerly confidential.[12] Feedback from the travelling public is of

---

[9] M.A. McIntyre, "Managerial Initiative and Government Regulation," Perspectives in Transportation, edited by Karl M. Ruppenthal, Stanford California, Stanford University Graduate School of Business, 1963, pp. 1-8.

[10] Aviation Week and Space Technology, September 7, 1970, p. 30.

[11] Ibid.

[12] Ibid., 26 April 1970, p. 35.

great interest to the airlines. Immediately following Pan American Airways' introduction of B747 service, passenger surveys were conducted to test reaction to the new aircraft.[13] The 1969 increases in passenger complaints regarding service irregularities and oversales could not be ignored.[14] Ground handling problems with "belly" freight, (freight carried below the passenger deck), came with the jet age. Better service and higher profits depend on better knowledge of air freight users, their reasons for using air freight, types of cargo and origin-destination patterns.[15]

Operations research in marketing will be considered under three headings: (1) Forecasting, (2) Promotion, and (3) Pricing.

I. OPERATIONS RESEARCH IN AIRLINE FORECASTING

Trunkline load factors (domestic United States and international routes), averaged forty-six per cent in November 1969. The United States domestic average load

---

[13] *Ibid.*, August 3, 1970, p. 21.

[14] *Ibid.*, January 12, 1970, p. 33.

[15] D. H. Reeher, "Air Freight Has Problems on the Ground," *Business Horizons*, Vol. 11, No. 1, February, 1968, pp. 33-38.

factor was only forty-three per cent, ranging between thirty-seven and fifty-three per cent. These low averages reflected a dip in traffic growth from eighteen per cent per annum in 1968 to ten per cent per annum in 1969, and the addition of significant new capacity.[16] During 1969 available seat miles increased by about sixteen per cent. Scandinavian Airline System requested postponement of the delivery of five DC-9 aircraft from McDonnell Douglas because actual traffic growth was below the expected twenty per cent for 1969.[17]

Forswood C. Wiser Jr., president of Trans World Airlines, was quoted as saying that introduction of the Boeing 747 was premature, and that the tri-jets, the Lockheed L-1011 and the McDonnell Douglas DC-10 should have come first.[18] By the end of 1970 the airlines faced serious overcapacity. However, decisions to buy the 747 and tri-jet aircraft were made during a period of optimism. In 1967 passenger traffic forecasts for 1975 predicted three or four times the 1965 volume. Freight traffic was expected to multiply by a factor of seven or eight.[19]

---

[16] Aviation Week and Space Technology, January 12, 1970, p. 29.

[17] Ibid., January 19, 1970, p. 31.

[18] Ibid., February 2, 1970, p. 37.

[19] Knut Hammarskjold, "Economic Implications of High Capacity Jets and Supersonic Aircraft," Financial Analysts Journal, March - April, 1967, p. 67.

In 1971, worries at airlines head offices resulted from over-capacity. Evidently traffic growth forecasts were high. Does this mean that the forecasting models were incorrect? Will there be revisions in forecasting techniques to prevent a recurrence of such errors? Perhaps the answers to these questions are best given by examination of some forecasting methods.

Demographic Studies and Regression Analysis attempt to relate airline activity to market conditions. Characteristics of the market such as geographic divisions, economic activity and growth, transportation economics within the market area, per capita wealth, and so on, are assumed to affect airline traffic. Regression analysis indicates how airline traffic is affected by selected market characteristics. Regression analyses can usually specify degrees of confidence that may be placed in the results obtained.

Proper forecasting depends upon inclusion of all significant factors, (to which the model is sensitive), but omission of significant factors may be acceptable in the model provided that the omitted factors remain constant during the forecast period. Government monetary policies and the consequent economic slow-down were significant between 1967 and 1971. This affected business generally, including airline traffic. Actual events in 1970 should have been in closer accord with 1967 forecasts were it not for changes that occurred in variables omitted from forecast consideration.

New markets may lack adequate histories from which to develop regression analyses. Two studies by Stanley H. Brewer illustrate methods of estimating market needs from data available.[20,21] In 1956, the Boeing company commissioned a study of the Europe-Asia market for air freight. As a potential trading zone, Europe-Asia had long distances and prospects of rapid economic growth, particularly in high-value commodities. Unfortunately, organized air transportation information was considered inadequate.[22] Model formulation was therefore achieved partly by analogy.

The hypothesis was that there should be a close and positive correlation between economic growth and growth of air transport. If this proved valid for any trading zone, it might be assumed valid for the Europe-Asia trading zone. Published data on trade and economic growth in post war Europe provided a record of commodity movements in Europe and commodity movements between Europe and the United States.

---

[20] Stanley H. Brewer, J. Rosenzweig, and J. Warren, _British Columbia's Need for a Unified Regional Air Transportation_, Seattle: University of Washington, Graduate School of Business, 1965.

[21] Stanley H. Brewer, E.K. Fremont, and J.E. Rosenzweig, _The Europe-Asia Market for Air Freight_, Seattle: University of Washington, College of Business Administration, 1963.

[22] _Ibid._, p. 1.

The hypothesis was confirmed for post-war Europe, chiefly by regression analysis of data available.[23] A model was developed, expressing air transport as a function of economic activity. As air cargo constituted less than one per cent of total cargo shipments, it was necessary to relate the use of air transport to the value and type of commodity, rather than merely to extrapolate air traffic as a function of total trade growth. Using this model a forecast of Europe-Asia air traffic was derived, giving projected air cargo potentials for 1965, 1970, and 1975. In 1963 the annual rate of growth for air cargo traffic between Europe and Asia was predicted at nearly thirty per cent. These results were related to cost-price developments in air transport by forecast statements in the form of graphs for potential freight in each direction over a range of conceivable charges per ton-mile.

Europe-Asian development was projected in terms of population and gross national product, based on United Nations estimates. Two questions are suggested by the growth assumptions. What are the effects of population growth on gross national product in countries that are already heavily populated? What effects on trade patterns could be expected from potential political realignments? These questions may

---

[23] Ibid., p. 21.

have been outside the study terms of reference.

In evaluating trends, several methods are available. The simplest method is to plot absolute demand data against time and to draw a visual approximation of a best fit straight line. Greater precision of fit can be obtained using the method of least squares.[24] Curvilinear trends can be fitted in similar fashion by plotting logarithms of the functions, or by means of Gompertz functions of three variables, selected by hypothesis or by trial and error methods.[25] Multiple linear regression expresses a dependent variable such as demand, in terms of up to fifteen independent variables (such as exports, imports and population), but forecasting the independent variables may be as difficult as forecasting demand itself.[26]

Mr. R.W. Linder has described Air Canada's econometric model for long term forecasting:[27]

$$T = cx_1^{a1} \cdot x_2^{a2} \cdot x_3^{a3} \cdots\cdots Y_1^{b1} \cdot Y_2^{b2} \cdots\cdots ,$$

where T = Air Canada total traffic volume

x_i = policy variable i

Y_j = socio-economic or competitive variable j

c = a constant

a_i, b_j = elasticities of T with respect to the independent variables

---

[24]Taro Yamane, Statistics: An Introductory Analysis, New York: Harper & Row, 2nd edition, 1967, p. 339.

[25]Winfried Grassman, "The Intricacies of Forecasting," AGIFORS Proceedings, 1967, p. 244.

This multiplicative model is updated annually by regression analysis of Air Canada and other data. Selection of variables is fundamental to validity of the model, both for inclusion of significant variables and for exclusion of redundant variables. The presence in the model of correlated variables is called multicolinearity, a condition that may bias model output.

A regression analysis well known to airlines is the McDonnell Douglas Econometric Passenger Demand Forecasting Model, a complex structure comprised of six main parts that are briefly described below.[28]

Part One is an additive linear multiple regression that forecasts city pair revenue passengers by relating city pair air traffic growth to the total domestic airlines industry growth. City pair trends are assumed to hold relatively fixed relationships with total market trends. These relationships can change over time, and are tested and

---

[26] Ibid.

[27] Roger W. Linder, "Models for Planning and Control," AGIFORS Proceedings, 1969.

[28] Ronald J. Schmidt, "Econometric Passenger Demand Forecasting Model," Long Beach, California, Douglas Paper 5057, May 1968.

redefined if necessary. The quality of forecast data obtained at this stage, is reflected in a coefficient of variation for each city pair:

$$V_i = S_i / \bar{X}_i$$

where V_i = coefficient of variation for city pair i

S_i = standard deviation of the estimate for city pair i

$\bar{X}_i$ = mean of the estimates for city pair i.

Part Two predicts city pair traffic by extrapolation of historical city pair traffic data, using a geometric progression technique. This procedure is independent of the approach taken in Part One.

Part Three is a microanalytic approach that forecasts city pair traffic by measurement of pertinent historical variables such as per capita disposable income.[29] The resultant equation resembles Air Canada's econometric model.

Part Four is an alternative forecasting routine used instead of parts one, two, and three when market growth is negative. It is a microanalytic approach based on disposable income distribution, population household distribution, and quality factors such as service frequency, and type of

---

[29] Ibid.

aircraft. The procedure is called cross-section analysis.

Part Five is an averaging process by which the results of Parts One, Two, and Three are weighted inversely in proportion to the coefficients of variation. This procedure is not required in the circumstance of a cross-section analysis, when only the Part Four forecast is available.

Part Six allocates market share among competitors. In 1968, Douglas could offer no viable objective function for determination of market share. The difficulties of formulating such a function are many. Market share is affected by entries and exits of carriers in city pair markets, changes in numbers and types of aircraft used, market growth and density changes, through service or stop-service authorizations, and historical market share rationalization. Consequently, the three approaches most often used are as follows:

1. Subject weighting of historical market shares.
2. Historical revenue passenger miles weighted market shares.
3. Intuitive extrapolation of last year's share.

Although the Douglas model contains much sophisticated statistical analysis, output is highly dependent upon intuition and judgement both in the assessment of competitors' actions and in proper interpretation of general economic conditions.

Exponential Smoothing. Without a demand history, forecasting can be done by intuitive weighting of known demographic factors. After a period of scheduled operation, actual demand may exhibit seasonal and trend patterns. The simplest form of exponential smoothing, however, assumes no knowledge of trend or seasonal factors and is given by the following:

$$\tilde{S}_{t+1} = AS_t + (1-A)\tilde{S}_t ,$$

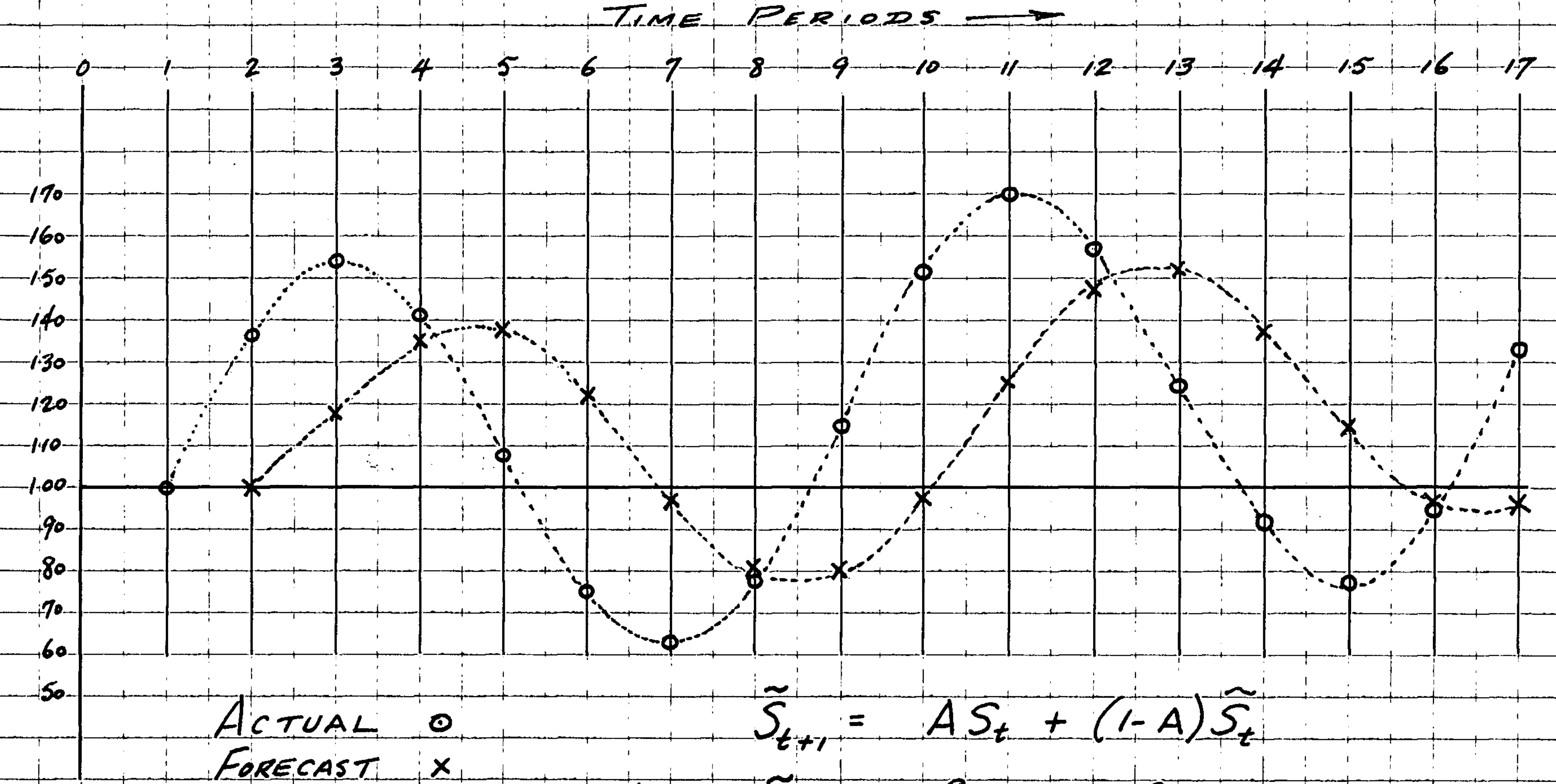
where S_t = actual demand in period t

$\tilde{S}_t$ = forecast demand for period t, (made in period t-1)

$0 \leq A \leq 1$. Small values for A make the model less sensitive to current demand.

Forecasts based on the simple exponential smoothing model are easily compiled. Figure 1 compares actual and forecast demand for a sinusoidal demand pattern with constant upward trend. The forecast pattern resembles the pattern of actual demand, but the forecast departs from reality in two respects. The *amplitude* of the forecast is less than actual and the forecast *lags* the actual demand curve, in this case by approximately one quarter cycle.

Both ot these faults in the forecast can be reduced by increasing the forecast frequency, but some deviation and some lag will always be present. More satisfactory corrections can be built into the exponential smoothing



$$\tilde{S}_{t+1} = AS_t + (1-A)\tilde{S}_t$$

where $\tilde{S}_t$ = forecast for period t.

S_t = actual demand, period t.

$A = 0.5$

FIGURE 2.1 FORECASTING by EXPONENTIAL SMOOTHING.

model if seasonal and trend data are given.[30] Forecasts obtained by these methods assume that no factor of demand changes rapidly. The model is sensitive to gradual change, and in effect, smooths out random fluctuations. If major changes are recognized in demand factors, forecasts should be adjusted accordingly.

Exponential smoothing models are relatively easy to construct. In operation they require very little computer storage capacity.

Exponential smoothing was used to project traffic volumes for individual sectors of the Air Canada route network. Forecasts for short range up to two years were based on three exponentially smoothed components: (1) current average traffic, (2) current trend in traffic volume, and (3) current monthly seasonal factor. This model was described as crude, descriptive and deterministic, but was considered practical for short range projections.[31]

Simulation in market forecasting was illustrated by two Lockheed programs; Airline Simulation for Analysis of Commercial Airplane Markets,[32] and Airline System Simulation.[33]

---

[30] P.R. Winters, "Forecasting Sales by Exponentially Weighted Moving Averages," Mathematical Models and Methods in Marketing, Bass, F.M., et al., (eds.), Homewood, Irwin, 1961, pp. 482-513.

[31] R.W. Linder, op. cit.

[32] Lee R. Howard and O. Duane Eberhardt, Airline Simulation for Analysis of Commercial Airplane Markets, Transportation Science, Vol. 1, No. 3, 1967, pp. 131-157.

Both models were based on similar assumptions with respect to market forecasting.

Route interaction occurs when two or more scheduled routes connect a given city pair. In the diagram below, two-directional paths connect the points LAX, CHI, and PIT. A passenger travelling from LAX to PIT may go directly or by way of a one-stop route through CHI. Similarly, a passenger going from LAX to CHI may use the one-stop route through PIT. Thus on the LAX-PIT route there are three components

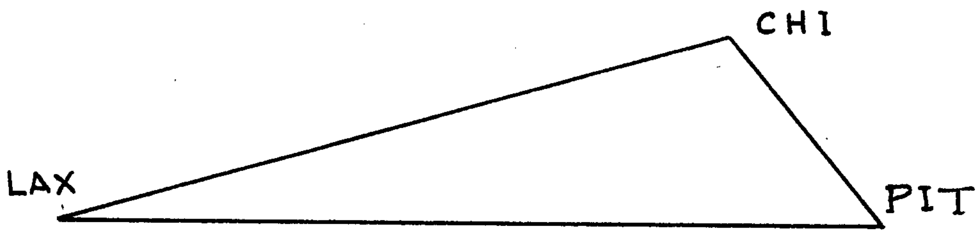


Figure 2 Simple Route Network

of demand. For realism in traffic forecasting these should be considered. Unfortunately, neither Lockheed paper explains how route interactions are evaluated and incorporated into the models.

Flight frequency affects demand except sometimes where no alternative form of transportation is available. The

[33] William A. Gunn, "Airline System Simulation," Operations Research, 12, 1964, pp. 206-229.

assumptions of the model were that (1) demand is uniformly distributed, (2) flights are uniformly spaced throughout the schedule period, (3) persistence of passenger demand for a particular flight is normally distributed about the passenger's desired departure time, and (4) the standard deviation of the persistence of demand time-distribution will be one-half of the corresponding time to travel by road.

Demand is *not* uniformly distributed from the point of view of a single carrier. Connecting flights can impose sharp demand break points and time of day demand fluctuations are real. Flights are not uniformly spaced in practice. There tend to be periods of greater activity between 8 and 10 AM and between 5 and 10 PM.[34] The persistence of demand assumptions appear reasonable if competitive airline traffic is included in the model.

Fares affect demand in two ways. A low fare *generates* demand by attracting traffic that otherwise would not have flown, and by *diverting* traffic from more expensive alternate flights and from other modes of transportation. The two effects were not evaluated precisely, mainly for lack of sufficient data, but Lockheed estimated external elasticities of demand for travel as follows:

---

[34]Melvin A. Brenner, "Public Demand and Airline Scheduling," Air Transportation Association paper, 1968, p. 24.

Business: 10 per cent. Non-business: 140 per cent.

Speed is a demand factor in terms of both absolute and relative trip times. Jet aircraft have short absolute trip times compared with propeller-driven aircraft. However, slow aircraft may have a relative trip time advantage if there is a significant waiting time before the next scheduled jet flight. Absolute and relative trip time demands are incorporated into model allocations of traffic.

Passenger preference is "surely a factor of ignorance, prejudice and emotion as well as other more quantitative factors such as size, number of engines,"[35] and although it is real, passenger preference has been omitted form models for lack of quantifiable and objective data.

The Lockheed Airline System Simulation has been in use since 1961. During this time the model was improved, but despite the complex simulation based on demand factors described above, the resultant model may have been an oversimplification. Perhaps this would be true of any forecast that offered comprehensive assessment of all route traffic characteristics.

The main assumptions of the model appear to be those that pertain to flight frequency. Demand was assumed to be uniformly distributed. Flights were assumed to be uniformly

---

[35] William A. Gunn, "Airline System Simulation," Lockheed-California Company Paper, April 1962, p. 18.

spaced in time. This does not reflect the world of peak demands and aircraft rotations and connections that prevent uniform time spacings between flights. However, certain aberrations of input may be tolerable. Professor Shaw's simulation of schedule effects on passenger volume indicates that demand is sensitive to frequency but much less sensitive to time of departure.[36]

Conclusions: Market Forecasting

Three basic techniques have been described: (1) regression analysis, (2) exponential smoothing, and (3) simulation. All three approaches attempt to steer by "watching the rear view mirror," and all require major contributions of human judgement. These observations prompt the question of why models are used at all. Some justifications are as follows:

1. Computer or manual models allow management to concentrate on the judgement aspects exclusively. Operational details can be delegated to a computer or to junior staff.
2. Models serve to pinpoint specific judgemental inputs and provide explicit evaluation of alternate input assumptions.

[36] G.C. Shaw, "The Schedule--its Effect on Passenger Volume," AGIFORS Proceedings, 1968, p. 160.

3. Models remove some of the mystique of forecasting by the use of standard procedures, and at the same time treat judgemental inputs in a consistent manner.
4. Models can be adjusted or updated explicitly whereas human experience is largely personal and non-transferrable, particularly in the short term.
5. Computer models should be fast and accurate. They can interpret a number of inputs and ramify the output to include thousands of details contingent upon the input decisions.

II. OPERATIONS RESEARCH IN ADVERTISING

Airline markets can be considered under two main headings:

1. Business, and
2. Non-business.

The business market buys transport presumably for economic reasons. Business demand is presumed to be relatively inelastic. The "product" is time saved. Private individuals travelling for urgent personal reasons could be included as part of the business market. The non-business market buys passenger transport for reasons that are partly non-economic.

The product is arrival at a chosen destination, reunion with friends or family, or other pleasure activity. Demand is relatively elastic.[37]

Business market susceptibility to advertising appeal is considered somewhat stolid. Business advertising then should be informative, factual, and helpful in showing what services are available (door to door), and how to calculate economic shipping quantities to take advantage of price breaks. The aims of business advertising would appear to be: (1) realization of full economically justified air traffic potential, and (2) attainment of high share of market for reasons of performance and service.

The non-business market is generally more susceptible to emotional appeal than the business market, and market potential is not limited entirely by economic factors. Advertising should aim at increasing market demand, and at capturing the best possible share. Glamorizing a particular resort may attract more customers, but if the airline is one of many serving the same route, the benefits of advertising may go in large part to competitors.

In concept, advertising decision requirements are straightforward. Simple and persuasive messages are to be

---

[37]Lee R. Howard, and Duane O. Eberhardt, op. cit., p. 137.

delivered to everyone who may be interested, subject to the constraint that expenditures on advertising should yield new profits that reward the advertiser at his required rate of return on investment. Advertising decisions may be represented diagramatically as follows:

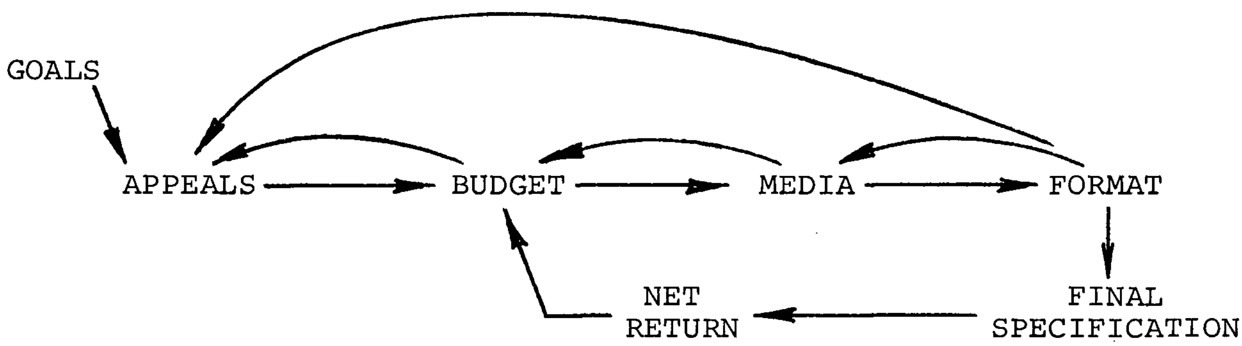


Figure 3 Advertising Decion Factors

Potential advertising reach includes all who may be exposed to a given medium. Word of mouth includes everybody, but is slow. Radio and television messages are received at the instant of delivery or not at all. Advertising in journals and magazines may not be seen, or if seen, may not be read. Actual reach is less than potential reach, but actual reach can be measured by sampling methods.

On the other hand, advertising *response* is difficult to measure except in special circumstances such as want-ads that publicize a single event, or advertise a single article.

Response to airlines advertisements may persist for many months after delivery of the message. Using aggregate data it is easy to confuse cause and effect in constructing marketing models.[38]

Advertising Reach

Advertising reach for radio or television can be estimated by means of telephone surveys. Magazine and journal circulation figures are known. However, if advertisements are inserted in several magazines, reach is not the cumulative circulation but something less because of duplication. Magazine advertising reach was found to be well approximated by M.M. Agostini's model:[39]

$$R = \frac{A(1)}{(K \cdot A(2)/A(1) + 1)}$$

where $A(1) = \sum_{i=1}^{I} A_i$ = total target group members in audience of media 1, 2, ..., I

$A(2) = \sum_{i=1}^{I} \sum_{j=i+1}^{I} A_{ij}$ = total of all pairwise duplication of the I media

$K = 1.125$

---

[38] A. Mercer, "Operational Research in Marketing," Operational Research Quarterly, Vol. 17, No. 3, p. 244.

[39] David B. Montgomery, and Glen L. Urban, Management Science in Marketing, Englewood Cliffs, Prentice Hall, 1969, p. 100.

Simulation has been used to model the press and television reaching a target.[40] A detailed simulation incorporates many more variables than say, Agostini's model. Simulation should offer more realism than simple models but despite thousands of interviews, assumptions are crude. Readership is a function of demography, and characteristics of the target with respect to the product and the advertisement.

Advertising Response

Analysis of response has been attempted by several investigators. Four approaches to the problem are discussed briefly in the paragraphs following. Some impressive results have been obtained for specific industries, but response to advertising remains a difficult task for analysis.

Benjamin, Jolly and Maitland postulated that response to advertising is a logarithmic function of the type:[41,42]

$$\text{Response} = a \cdot \log(\text{advertising spend}) + b,$$

where a, b, are constants.

---

[40] E.M.L. Beale, P.A.B. Hughes, and S.R. Broadbent, "A Computer Assessment of Media Schedules," Operational Research Quarterly, Vol. 17, 1966, pp. 381-411.

[41] B. Benjamin, J.W.P. Jolly Maitland, "Operational Research and Advertising: Theories of Response," Operational Research Quarterly, XI, 1960, pp. 205-218.

[42] B. Benjamin, J. Maitland, "Operational Research and Advertising: Some Experiments in the Use of Analogies," Operational Research Quarterly, IX, September 1958, pp. 207-217.

Marginal effectiveness of advertising declines as the advertising budget increases. The value for "a" depends on total industry sales. Variable "b" is a negative quantity that represents minimum expenditure for threshold response.

J. Simon's assumption was that revenues from advertising decline at a constant rate.[43] This is a time relationship that can be used to compare present values of advertising budget strategies. Evaluation of response itself must be obtained by separate means.

K. Palda studied a fifty-two year history of advertising and sales for Lydia Pinkham's Vegetable Compound.[44] A model for sales as a function of advertising was obtained by regression analysis. In this case the regression analysis accounts for ninety-two per cent of annual sales variation, but to be relevant in the airline industry, the model might require extensive modification.

Assuming that the advertising-sales relationship can be specified, either by analysis or hypothesis, Gupta and Krishnan offered a differential equation approach to

---

[43] J. Simon, "A Simple Model for Determining Advertising Appropriations," Journal of Marketing Research, August 1965, pp. 285-292.

[44] K. Palda, The Measurement of Cumulative Advertising Effects, Englewood Cliffs: Prentice Hall, 1964, pp. 19-28.

optimization of sales:[45]

$$\text{Total Sales} = (\text{market potential})(1-e^{-\gamma A})$$

where γ is a constant

A = advertising expenditure.

This model yields the result that $\frac{dS}{dA} = \gamma(a-S)$, where "a" is market potential. The effectiveness of advertising is a variable that declines as total sales approach the market potential. The model ignores time effects in response, and does not provide for present-value analysis of alternative strategies.

Perhaps the most impressive response analysis model is A.E. Amstutz's Microanalytic Simulation. Thirteen consumer characteristics were related to price, personal selling effort, advertising and advertisement characteristics, and word of mouth communication.[46] In one example, ten competing brands were ranked according to percentage market share. In a comparison between actual results and model results, the sum of the ten absolute forecast errors was 5.1 per cent. This was an impressive demonstration of simulation capability combined with skillful assumptions in the model structure.

---

[45] S.K. Gupta, and K.S. Krishnan, "A Differential Equation Approach to Marketing," Ops. Res., Vol. 15, No. 6, 1967, p. 1030.

[46] Arnold E. Amstutz, Computer Simulation of Competitive Market Response, Cambridge, Mass., M.I.T. Press, 1967.

In contrast with microanalytic simulation, decision theory offers simple model constructions for advertising budgets, but simplicity in the model is offset by the complexity of the assumptions involved. If the decision maker in company A is willing to assign subjective probabilities that competitors, say company B, will spend at various prescribed levels, then a payoff table might be constructed for each combination of company A and company B expenditures for advertising. Although company B's future actions are unknown, the subjective probability estimates, transform the problem of uncertainty to one of risk. The following table shows three strategies for company B, with associated subjective probabilities. Three strategies are also shown for company A. The table itself consists of estimated payoffs for company A under the various combined strategies.

Budget B: (Probability) Budget A	$100 (1/4)	$200 (1/2)	$300 (1/4)	Expected Payoff
$100	400	200	160	$240
200	390	225	200	260
300	350	300	250	300

Based on this table, the highest (net) payoff expected is realized if A spends $300 on advertising. Apart from the difficulty of assigning subjective probabilities to the actions of competitors, payoff values themselves must be assumed.

Market share might be assumed proportional to company expenditure as a fraction of total industry expenditure (on advertising).[47] This assumes that advertising effectiveness is uniform throughout the industry, and that competitors are defined. In the non-business airline market, competition is for discretionary spending that buys many things other than air travel. At best, competition is ill-defined.

A constant sum game has a constant prize. The prize is shared according to the success of the participants. An example is gasoline sales. Total sales are hardly affected by promotional activity because consumers buy only what they need; they buy no more when prices are low. Airline sales to business passengers might be a parallel example. H.D. Mills developed three models that can apply to industries with constant sum market characteristics. In general, Mill's models are of the form:[48]

$$\text{Profits of brand } i = V \cdot \frac{E_i}{\Sigma E_i} \cdot M - C_p - C_f$$

where V = present total market

E_i = effective promotional outlay, firm i

M = unit contribution to margin

C_p = promotional outlay in dollars

C_f = fixed costs of production and selling

---

[47] Montgomery and Urban, op. cit., p. 121.

[48] H.D. Mills, "A Study in Promotional Competition," Mathematical Models and Methods in Marketing, Bass, F.M., et al., (eds.), Homewood, Irwin, 1961, pp. 271-301.

Model validity depends heavily on the assessment of E_i, a factor that intuitively can not be constant. Perhaps the value in models of this type is that formulation requires an assessment of competitors' advertising expenditures, and some subjective evaluation of marginal benefit from company investment in advertising.

Several other game approaches have been developed. L. Friedman has put forward at least five models.[49] One model that overcomes the difficulty with Mills' model, (the evaluation of E_i), was of the form:

1. $$\begin{pmatrix}\text{advertising budget} \\ \text{Company A}\end{pmatrix} = \sqrt{\begin{matrix}\text{Price less} \\ \text{variable} \\ \text{costs/unit}\end{matrix} \cdot S \cdot B} - B$$

2. Allocate budget to market "i" in proportion to market "i" as a fraction of total sales potential

where S = total market sales potential

B = advertising budget, company B

If competitors all follow this rule, the major determinant of company advertising budgets is: price minus variable costs. This implies that the company with least costs (relative to price) will advertise most and capture a

---

[49] L. Friedman, "Game Theory Models in the Allocation of Advertising Expenditure," Bass, et al., (eds.), Mathematical Models and Methods in Marketing, Homewood, Irwin, 1961, pp. 220-244.

market share corresponding to its share of total industry advertising expenditure. The model yields a stable solution after several cycles (and adjustments) in both companies.

Media Selection

Intuitively, an advertising budget should be spent on the best media first, and on successively less effective media until the budget is spent. On the other hand, the most expensive advertising in any of the media could exhaust a large budget and leave little or nothing to spend in other media. Several linear programming models have been put forward for media selection. One of the simplest of these models was proposed by Bass and Lonsdale:[50]

$$\text{maximize total exposure} = \sum_{i=1}^{I} R_i X_i$$

$$\text{subject to} \quad \sum_{i=1}^{I} C_i X_i \leq B$$

$$0 \leq X_i \leq L_i \quad \text{for} \quad i = 1,2, \cdots, I$$

where R_i = rated exposure value of an insertion in medium "i"

---

[50] F.M. Bass, and R.T. Lonsdale, "An Exploration of L/P in Media Selection," *Journal of Marketing Research* III, May 1966, pp. 179-187.

X_i = number of insertions in medium "i"

C_i = cost per insertion in medium "i"

B = total advertising budget available

L_i = physical limit of insertions in medium "i"

This formulation is simple, but it has shortcomings suggested above:

> . . . the result is optimal but it represents concentration of the budget in one or a few media. Since this is intuitively implausible, users of the model were let to specify lower limits for the numbers of insertions in each medium. These artificial constraints were added on the basis of judgement. 51

Part of the trouble with this linear programming approach is that the R_i are constants. A piecewise linear formulation of the Linear Program could be achieved by assigning two or more discrete values to each of the R_i, high values for exposure values of the first insertions, and lower values for succeeding (and less effective)insertions. This would be, of course, further exercise for subjective judgement.

Other approaches to media selection include non-linear optimizing algorithms, simulation, heuristic programs and dynamic programming.[52]

---

[51] Montgomery & Urban, op. cit., p. 144.

[52] Peter Langhoff, Models, Measurement and Marketing, Englewood Cliffs, Prentice Hall, 1965.

Little and Lodish developed a dynamic programming model called MEDIAC, more complex than the Bass and Lonsdale linear program.[53] Included among factors considered were the population of each market segment, per capita sales potential, exposure value of the media during specified time intervals, exposure efficiency and retention from previous advertisements.

Dozens of advertising models are in the literature but, "until knowledge or faith increases, mathematical sophistication and elegance are likely to be of only secondary importance; they may even be a positive disadvantage if they conceal or distract from the crudity of the underlying structure."[54]

Until 1970, airline operations research staffs appeared to be little concerned with advertising models. Perhaps, in sympathy with Friedman's advertising model, they felt that long run success depends on favorable cost-price relationships, or perhaps airline managements had little faith in the advertising models proposed. The reason for the apparent lack of interest in advertising models may have been that current advertising policy and method are

---

[53] J.D.C. Little and L.M. Lodish, "An Exploration of Linear Programming in Media Selection," Journal of Marketing Research, III. May 1966, pp. 179-187.

[54] M.H.J. Webb, "Advertising Response Functions & Media Planning," O/R Quarterly, Vol. 19, No. 1, 1968, pp. 43-59.

proprietary matters not freely discussed outside the company; activity may be greater than indicated by the literature.

III. OPERATIONS RESEARCH IN AIRLINE PRICING

The International Air Transport Association is largely instrumental in setting rates and fares for international airline services. Tariffs are set by unanimous agreement and enforced by a system of inspection which can levy heavy financial penalties. After the IATA agreement, governmental approval of the fares generally is required. Cargo rates are built to the following plan:

(a) a basic rate per pound
(b) special rates for specific commodities
(c) incentive rates for shipments above a given minimum
(d) minimum handling charge
(e) volumetric surcharge for high bulk cargoes
(f) value surcharge for precious cargoes.[55]

Passenger fare pricing can be modified to reduce peaking or to attract more revenue. Price concessions may be permanent or "creative". Creative fares are below basic

---

[55] J.L. Grumbridge, op. cit., p. 61.

fares, designed to promote new traffic without diverting existing traffic. This is achieved by means of restrictions such as:

(a) reduced fares generally are return or round trip fares
(b) excursion fares generally are sold only in country of origin
(c) special fares generally have limited validity, up to forty-five days
(d) stay at destination is usually a specified minimum or maximum period of time.

Special fares are sold to groups, families, or as packaged tours. Standby fares allow the passenger to fly only when space is not filled by regular passengers. In setting special or creative fares, two rules should be kept in mind:[56]

1. Tariff-making logic must not outrage public logic. If a service is from A to C via B, then the low fare passenger bound for C who decides after all to stop at B, will resent having to pay extra for *not* flying to C.

---

[56]J.L. Grumbridge, op. cit., p. 214.

2. Complicated fares should be avoided.

Pricing should begin with a knowledge of costs. For breakeven, total revenues are equal to total costs. Breakeven quantity is generally found by the following:

Breakeven quantity = (Fixed costs)/(Price - C)

where C is variable costs per unit. Seasonal fluctuations may prevent continuous recovery of full costs. In the short run, fixed costs may not be recovered, but under no circumstances is it desirable to operate if revenues are less than variable costs.

The Lockheed company was interested in the possibilities for use of the L-500 in mass cargo applications. The study of this problem was in five steps:[57]

1. Learn the problems faced by large-volume shippers and make in-depth studies of the economics of bulk air shipments of marketable goods.
2. Prove the ability of the L-500 aircraft to handle wide varieties of cargo, and to switch readily from one to another.
3. Generate reliable estimates of overall costs, and not just direct transportation costs.

---

[57] Aviation Week and Space Technology, January 12, 1970, p. 30.

4. Provide data to enable shipping departments to calculate their own best method.
5. Locate back-haul cargo.

The study produced the following table comparing air and sea costs for shipping small cars:

	Air	Sea
Italy to Atlanta	$352	$377
Yokohama to San Francisco	$406	$303

The advantage of sea transport between Yokohama and San Francisco declined for inland destinations, but low seaborne rates from Japan were on ships owned by the car manufacturers. This is not a pricing study as yet. It is only a feasibility study but it gives an idea of the type of analysis that precedes a pricing decision. A tremendous lever in pricing latitude is the availability of back haul cargo.

Airline pricing problems in some ways resemble the style goods problem, particularly on a new service, where demand is uncertain. Style goods are subject to fairly sharp cut off, almost as abrupt as the last call to board an outgoing flight. Reduced prices on outmoded styles are rather similar to standby tickets at half the normal fare.

T.M. Whitin's style goods pricing model is a conceptual device for retail markets.[58] Although applicability of this model to airlines is somewhat strained, the assumptions appear reasonable:

1. Inventory, (scheduled availability of seats), is on hand at the beginning of the period.
2. Inventories on hand at the end of the period are liquidated at a loss. Some standby sales and some unsold seats occur.
3. Shortages yield lost profits and goodwill. Seats should be available to all who will pay full fare.
4. The probability of demand at various levels is known from accurate forecasts.

$$p = \frac{L}{G + P + L}$$

where p = optimal proportion of stockout time

G = unit loss of goodwill due to stockout

P = unit profit on sales at regular price, π

L = unit liquidation loss. In retailing, this is the loss associated with a marked down price. In airlines it would appear to be a probabilistic loss on standby or zero fares

---

[58] T.M. Whitin, "Inventory Control and Price Theory," Management Science, Vol. II, No. 1, October 1955, pp. 61-68.

Assuming that the functional relationships are known or that they can be estimated, a graphic representation would be as follows:

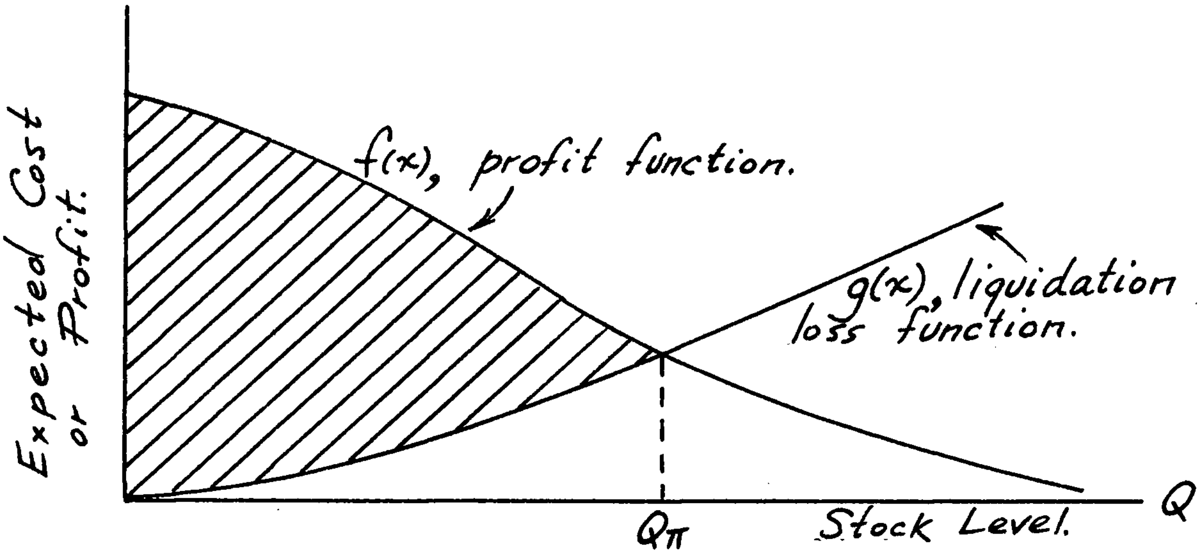


Figure 4 Net Profit Relationship

f(x) - (probability of a sale)·(unit profit)

g(x) = (probability of a loss)·(liquidation loss)

The shaded area in the diagram represents total profit.

The objective is to maximize: $\int_0^{Q_1} (f(x) - g(x))dx$

Given f(x) and g(x), the solution is at Q_π, the optimal stock level. Functions f(x) and g(x), and the resultant Q_π are dependent upon price. These dependencies would be evaluated subjectively in most cases.

A similar style goods model was proposed by Hertz and Schaffir:[59]

$$P = \text{(selling price)} - \text{(variable costs)}$$

$$P' = \text{(reduced price)} - \text{(variable costs)}$$

Profit on item i will be: $p_i(P) + (1 - p_i)\,P'$, where p_i is the probability of selling unit i. No recognition of loss of goodwill is explicit in this latter formulation.

Despite certain similarities between style goods pricing and airline pricing, the situations are obviously different. Style implies monopolistic features not significantly present in airlines. The timing and the amount of the price cut are matters of choice to style goods retailers, but not to airlines that are regulated. However, non-business demand for air travel appears to be price elastic, and perhaps more predictable than the style goods markets, so that in concept at least, style goods models may be of value in airline pricing.

G.L. Urban examined a multiplicative model for packaged goods:[60]

$$q_1 = a_1 P_1^{E1} F_1^{A1} P_2^{C21} F_2^{X21} P_3^{C31} F_3^{X31} (S_1)$$

---

[59] D.B. Hertz, and K.H. Schaffir, "A Forecasting Method for Management of Seasonal Style Goods Inventories," Bass, F.M., et al., Mathematical Models and Methods in Marketing, Homewood, Irwin, 1961, pp. 469-481.

[60] Montgomery and Urban, op. cit., p. 173.

where q_1 = sales of product 1

a_1 = a constant

P_1 = price of product 1

E_1 = industry elasticity for product 1

F_1 = package facings on store shelves

A_1 = industry shelf facing elasticity for product 1

C21 = cross price elasticity between products 2 and 1

X21 = cross shelf-facing elasticity between products 2 and 1

S_1 = observed market share of product 1

This model could be applied to airlines if brands were vacation trips on competing airlines and if shelf facings were posters in travel agents' windows. For the original model, evaluation of elasticities was obtained from observation of q_1/S_1 relative to price and facing observations. The difficulty in the airline situation is in experimenting with price, particularly where adjustments are made by only one competitor.

Conclusions, Operations Research in Airline Marketing

> Can management science be practically and profitably employed in marketing? Many top marketing men are frankly skeptical about the possibilities. They have heard plenty of promises, but except for the area of marketing logistics--inventory control and the like--they have yet to see much in the way of performance. [61]

[61] J.J. Cardwell, "Marketing and Management Science--A Marriage on the Rocks?" California Management Review, Vol. X, No. 4, Summer 1968, pp. 3-12.

In the same article from which the above quotation is taken Cardwell points out that in the more concrete areas of marketing administrative systems (order processing, delivery scheduling, inventory management, commission plans), and information systems, (sales analyses, sales budgets, forecasting), operations research has made a valuable contribution. In subjective areas, Cardwell observes, the success of operations research has been disappointing.

One of the main reasons for disappointment has been in the technique orientation of trying to fit marketing problems into standard solution patterns. A more successful approach has been to concentrate on the *problem,* and to use operations research if and when practical, usually on parts instead of on the whole.

CHAPTER III

PRODUCTION

Airline production is defined here as revenue earning activity, the transport of passengers, mail and freight. From the viewpoint of an airline client, production service begins with the reservation and ends with arrival at final destination. This chapter deals with operations research applications associated with flight bookings or reservations, loading, flying, and unloading of revenue-producing cargo. Ground handling, ground transportation and intermodal transfer of passengers and freight are discussed in Chapter IV as part of airport operation.

The term "airline production" is taken from W. S. Barry but where Barry includes aircraft maintenance as a production activity, maintenance was excluded from production in this chapter because it is not primarily a revenue-earning activity.[1]

Many factors affect airline production activity. Five of the most significant factors are:

---

[1]W. S. Barry, Airline Management, London: Allen & Unwin Limited, 1965, p. 226.

1. public demand for service.
2. airline marketing and service policy.
3. airline physical and financial resources.
4. airport, government, and other regulatory constraints.
5. states of nature, including weather and mechanical failure.

In the long run, through pressure or as a result of management or government policy, all five factors may be altered. Absolute demand for service is perhaps the least flexible of the five factors. Effective demand however, can be influenced by advertising and publicity, by revised service standards, or by government taxation or subsidy. In the scramble to win routs and customers, airlines collectively have under-optimized their pool of resources. This was illustrated by the following comment on revised Civil Aeronautics Board policy under chairman Secor Browne:

> Browne is attempting to reverse policies of some of his predecessors and other government regulatory agencies, not only by encouraging airline mergers but by encouraging airline negotiators to talk to one another about swapping routes, adjusting schedules, or otherwise reducing destructive duplication and overcapacity. 2

---

[2] Tom Alexander, "Is there Any Way to Run an Airline?" Fortune, September 1970, p. 211.

Production deals mainly with short-term decisions, control activities and plans for the near future. Analysis of short term problems points in the direction of long term improvement, and in this sense production affects long term policy formulation. Although not exclusively of a production nature, long range fleet planning models were included in this chapter.

The chapter deals with three main topic headings:

1. *Information Systems*. The development of electronic computers was concurrent with the rapid growth of airline traffic in the decades following World War II. Without computers for passenger booking, airlines could not have grown as rapidly as they did in the years 1945 to 1970.

2. *Scheduling Systems*. Scheduling Systems have a tremendous bearing on airline revenues and costs. Scheduling is perhaps the most significant shortrun airline activity.

3. *Customer Services*. Customer Services, include check-in and baggage handling and most of the personal contact between an airline and its clientelle.

I. INFORMATION SYSTEMS

Management information is important to all business activities, but it is especially vital to Production because:

1. Airline production operations respond to huge inputs of current statistics on passenger and cargo traffic, and on other data such as weather conditions and facilities breakdown.

2. Production information is extremely current and the resultant action decisions must be rapid and accurate.

3. Errors in some production information may endanger human life. For example, take-off weight, weather and flight clearance information directly affect safety. At high altitude airports on hot summer days, allowable take-off weight is less than that permissible at sea level, or with cooler temperatures.

4. Expenditures on production represent the bulk of airline costs.

Trans-World Airlines worked for months with staffs of more than one hundred to develop a Burroughs system for passenger reservations. The airline became discouraged with the Burroughs system and began looking at PARS (programmed airline reservation system), an IBM development.[3] United Air Lines after similar disappointment and problems with their Univac program, signed with IBM for a nationwide passenger reservations system for installation at Denver.[4] IBM services and equipment were to cost approximately fifty million dollars.

In 1969 Eastern Air Lines opened a Systems Operations Center as a trouble-shooting department geared to look for potential problems in operations. The Center was to try to stay four to six hours ahead of real time, anticipating effects of weather, accidents, and foreseeable disruptions to the schedule or to service needs. The main function of the Center, apart from problem recognition, was to translate emergencies into action plans and to deliver plans to the dispatcher. The Center occupied twenty-one thousand square feet of floor space, had its own Univac computer, and was linked with Eastern's vast passenger reservations system.[5]

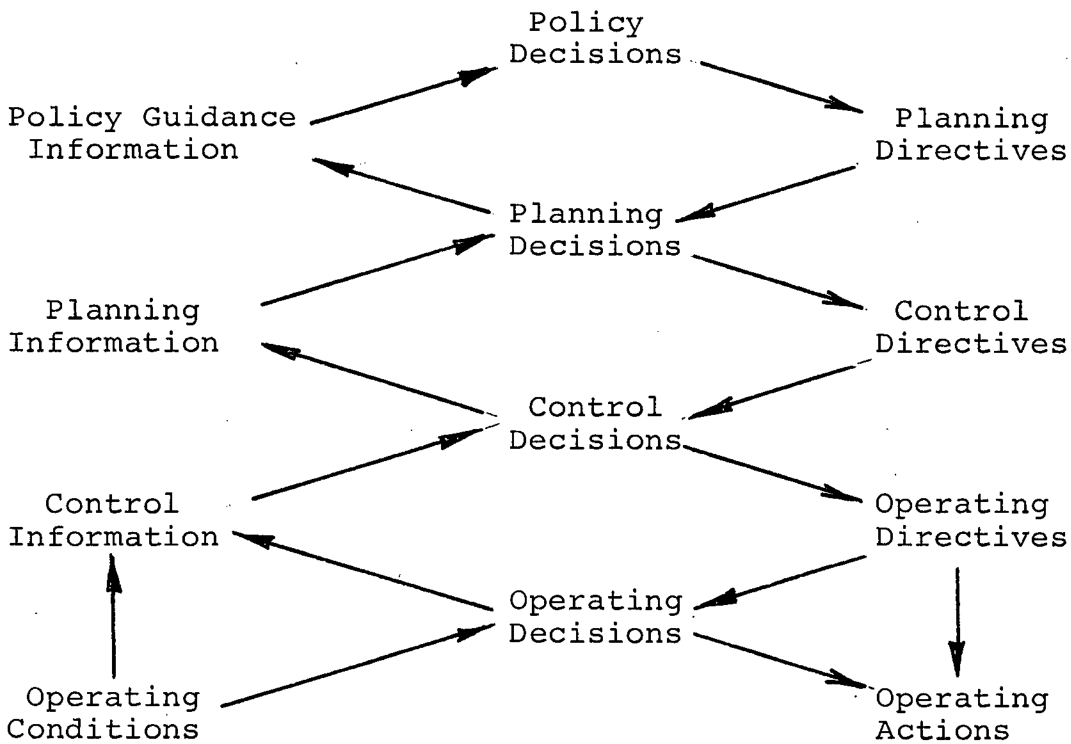
Decisions are made at all levels in an organization such that the higher levels provide goals or constraints for the lower levels. Information travelling upwards is usually selective, aggregated or condensed. Information travelling downwards is usually expanded, detailed and explicit. The process is illustrated by the following diagram.[6]

---

[3] Aviation Week and Space Technology, 7 September, 1970, p. 24.

[4] Ibid., 25 May, 1970, p. 28. [5] Ibid, 1 June, 1970, p. 35.

[6] S.G.N. Presley, "Control Information Distribution," C.P. Air paper, unpublished, 1969.



Information Flow Diagram

One could list many questions concerning proposed information systems. For example:

Who needs information?

What information is needed, and why?

What is the information source?

How much information is there to transmit? What growth rate?

What form? (Verbal, hard copy, tape, et cetera.)

When is the information needed? What delays are permissible?

How important is sequence? Cost? Error?

How accurately can the communications symbols be transmitted?

How well do the symbols transmit desired meaning?

How well does the received meaning affect desired conduct?

Transmission of information is treated elsewhere[7] and is not the prime concern of this paper. The answers to some of the specific questions raised above are of more immediate concern. Payroll accounts, materials control, continuous process control, airline passenger and cargo reservations, all provide examples of data treated mathematically and operating with minimum human intervention. These applications are successful because they deal mostly with internal data. Management, on the other hand, must relate external and internal information in order to plan and control the organization.

"Despite all the advances in data processing, a breakdown in . . . the preparation of managerial planning and control reports is all too frequently observed."[8] The usual reason is that data processing planners and information

---

[7] Harold Chestnut, Systems Engineering Methods, New York, John Wiley & Sons, 1967, pp. 1-69.

[8] J.D. Gallagher, "Management Information Systems and the Computer," New York, American Management Association Inc., 1961, p. 13.

systems people are unaware of management needs for reports on the total course of the business. The result is that data processing groups take refuge in the preparation of data reports--tabulated reports which are only consolidations of raw data, and without reference to the real needs of management.

An Operations Research man should be ideally trained to identify management information needs.[9] Operations research can make a healthy contribution in laying the groundwork for operating decisions in activities that affect more than one functional area of a business:

1. by helping to formalize the elements in recurring decisions.

2. by helping to design the flow of information to concerned functional areas.

3. by helping to test alternative policies for business operation.

Justification for Upgrading the System

Computer systems involve heavy financial outlays. Before making a detailed development of costly system upgrades, potential benefits should be evaluated. If the

---

[9] Ibid., p. 38.

benefits look attractive, further efforts should be directed toward system development. A good example of such a benefit study is found in Dr. MacAirt's analysis of the "no show" problem at Aer Lingus.

Automatic passenger reservation benefits. No shows occur for several reasons: (1) errors in airline procedures, for example, failure to effect a cancellation, (2) late passenger arrival, (3) agents misbooking, and other error outside airline control, (4) multiple booking by the passenger to allow him to select his flight at the last minute. The proposed automatic reservation symtem was considered effective in eliminating only errors of type (1), although errors of type (4) can also be prevented. Type (1) errors were estimated by Aer Lingus to account for forty-nine per cent of all no shows.[10]

$$N = uX - dX - vR$$

where N = adjusted error no shows from type (1) errors

uX = total error no shows from type (1) errors

dX = error no shows occurring too late for resale

vR = total error no records. (Passenger arrives with valid ticket, but airline has no record of ticket sale.)

---

[10] J.G. MacAirt, "Estimation of the Financial Advantages of Eliminating Error No Shows in a Real Time PNR Reservation System, AGIFORS Proceedings, 1967, p. 271.

Assuming that N is uniformly distributed over all flights, then lost revenue is given by:

$$\text{lost revenue} = NpqrF$$

where p = probability that a flight is closed

q = probability of reselling a ticket

r = probability that a passenger refused his first choice of flight will travel other than by Aer Lingus

F = average fare

Much of the analysis of this problem is in the derivation of the parameters p, q, r. A clever analysis of q is given to determine the probability of resale on closed flights. Superficially this may appear a useless exercise because the probability of a resale appears to be more or less unity. However, if resales represent transfers of passengers from other flights, they represent no extra revenue to the airline.

United Air Lines On-Line Check-In. United Air Lines dealt with a similar problem of recognizing no shows, in this case a proposed on-line check-in information system with stations at ticket counters, baggage counters, selected information centres, and at the gate.[11] Manual check-in

[11]R.E. Jacks, "Passenger Check-In and the Information System," AGIFORS Proceedings, 1969.

procedures are slow. No-shows are recognized too late for resale of tickets, say at the next stop. The benefit of an on-line system would be early recognition of no-shows at check-in and elimination of manual counting and calculation by class of service and destination.

Due to difficulties that the proposed check-in procedure would have created in the accounting department, it was rejected in its original form. A description of fifteen systems alternatives evolves around real constraints within the framework of existing operations. This study is largely of an industrial engineering nature, with cost-benefit analysis of all the alternatives. Operations research combines with industrial engineering in evaluation of stochastic variables, (taking into account time of day, day of week and so on), and this paper is a practical demonstration of operations research applied to a real situation.

Indirect benefits from upgraded systems. A booking level model was envisaged by American Airlines after implementation of the SABRE electronic reservations system. The enormous set of statistics provided by SABRE and more recent passenger booking systems are prerequisite to competent assessment of passenger arrival distributions.

Although reservation systems are designed to keep accurate and current inventories of seats sold and seats available for every flight, errors arise due to late passenger arrivals or from travel agents' errors, and other reasons outside the control of the airlines. One booking policy would be to sell no more than the number of seats available. This would ensure that all passengers could be accommodated, and that none would be left at the gate when the flight departed. On the other hand, because the expected numbers of passengers are fewer than the total booked, an airline using this policy would usually fly with empty seats on flights that were closed to further bookings.

Thus a certain amount of overselling should yield higher revenues to the airline, at the risk of increasing likelihood of surplus passengers who can not be accommodated, and at the risk of violating the contract to carry each confirmed passenger. If overselling is the policy chosen, then the amount of oversales can be defined in terms of the expected numbers of passengers left at the gate. For example, set θ_j as follows:[12]

$$\text{specified } \theta_j = \frac{\text{expected oversales}}{\text{expected validated passengers}}$$

Let L = number of passengers arriving for departure out of the total N who were booked when the flight was closed

Let K = number of passengers arriving out of the total number of teletype bookings from other airlines --received after normal bookings are closed

---

[12] M. Rothstein, and A. Stone, "Passenger Booking Levels," <u>AGIFORS Proceedings</u>, 1967, p. 392.

Let H = the sum of no-record passengers arriving at departure with validated tickets

Then J, the number of passengers actually boarding, will be:

$$J = L + K + H$$

Using Taylor's approach,[13] the distribution of J is approximated by means of the Gram-Charlier method, (an infinite series incorporating the moments of random variables as its parameters). The method is described elsewhere,[14] and shall not be discussed further except to say that it was chosen because:

1. nothing better was suggested
2. results obtained seemed reasonable.

A simulation could test the accuracy of the Gram-Charlier approach, but it was felt that the exercise was not worthwhile.

The algorithm:

1. Let N be the number booked r days before departure of flight (Set N = capacity).
2. Calculate the first three moments of the distribution of people from this N who are available for flight at departure.

---

[13] C.J. Taylor, "The Determination of Passenger Booking Levels," AGIFORS Proceedings, 1962.

3. Using the Gram-Charlier series of type A as an approximation of the distribution, calculate the expected oversales ratio θ_c.
4. Compare θ_c with θ_j . . . the specified ratio set by Company policy.
5. If $\theta_c > \theta_j$, set N = N-1, or if $\theta_c < \theta_j$, set N = N+1.
6. Go to 2. and repeat until $\theta_c(N^*) \leq \theta_j \leq \theta_c(N^*+1)$.
7. Compute the probability of one or more oversales, given N*.
8. Go to 1. and repeat for all θ_j.
9. Go to 1. and repeat for all r until r = 0, (day of departure).

For various specified oversales ratios θ_j, the output gives the number of bookings to accept on each of the last twelve days before departure, and the probabilities of one or more oversales occurring at flight time.

American Airlines performed field tests at Chicago, Cleveland, and Dallas. The field tests showed that the model indeed reduced the percentage of empty seats on closed flights although the paper does not indicate numbers of passengers left at the gate, except to say that specified

---

[14]Maurice G. Kendall and Alan Stuart, The Advanced Theory of Statistics, Vol. I, 3rd ed., London: Charles Griffin & Co. Ltd., 1969, pp. 156-163.

passenger service levels were met. The inference is that the model offers a positive revenue potential.

BOAC Sector Control. Booking levels on multi-sector flights normally favour the through passengers. The problem is to decide when to stop booking short flights. The arrival rates of passenger bookings was seen as the key to the problem. The revenue from a short leg flight must be weighed against the probability of a larger revenue on a through flight. However, if short bookings fill up each leg, through bookings may not result in higher revenues, especially if the fare structure fully reflects the higher costs of a short flight.[15]

A nine-sector flight can have forty-five possible journey patterns. The fares for each possible journey and the probabilities of bookings for each possible journey are needed for an LP solution to the sector booking problem. Model formulation in its simplest form is given by:

$$\text{Maximize} \quad \sum_{j=1}^{45} rj \cdot xj \qquad \text{(revenue)}$$

$$\text{subject to} \quad \sum_{k \in Si} x_k \leq c_i$$

$$1 \leq i \leq 9$$

$$x_j \leq f_j$$

where r_j = revenue associated with journey j

c_i = capacity remaining in sector i

f_j = forecast demand for journey j

s_i = set of journeys involving sector i

Although this method produces rough answers, it suffers the limitation of a single estimate of demand for each journey. Probabilities of further bookings can be specified after some bookings have been made, but this leads to a large LP. To reduce computational procedures, the problem can be decomposed. This results in sub-optimization but still yields convenient solution. The method has been used experimentally by BOAC.

Such a model should perform better than human agents working by experience and intuition, or making random decisions. However, the forecast elements within the LP model are judgement items. Over time the model should do better than the human operators because it consistently follows the rules laid down.

Airline Reservations Systems.

Eastern Air Lines' third generation computer system was one of the largest in the world. In March 1969, Eastern received about 125,000 telephone calls each day. Reservation

---

[15] B. Griffiths, and J. Taylor, "Mathematical Formulation of the Sector Control Problem," AGIFORS Proceedings, 1967, p. 436.

calls varied from ninety seconds for an information call to over seven hundred seconds for a round trip booking. The average call lasted 237 seconds.[16] American Airlines' SABRE system kept track of seat availability, passenger name records, meal counts, boarding manifests, and automatic generation of teletype messages required by other airlines.

The dimensions of Eastern's reservations were large: 2,700 daily flight segments between ninety-eight airports, with inventory records up to a year in advance. The system was capable of rapid response to all agent requests regarding fares, schedules and availability. The hardware needed was impressive:

3 IBM 360/65 processors each with 524K core
3 core storage units each taking six million characters
20 disc files, each for two hundred million characters
676 mobile disc packs, each for twenty-five million characters.

In 1969 Eastern planned to use microfilm for off-line storage of relatively static information. The microfilm system was expected to cost $3.3 million, but would streamline the $31.3 million computer system by taking stored material off line. The microfilm system handled 73,500 pages

[16] W.E. Jenkins, "Airlines Reservations Systems," Datamation, March 1969, p. 29.

of information with four second access for whole-page displays on cathode ray tubes. Savings were expected from reduced data communications, reductions in telephone times (about twenty seconds per call), reduced computer programming, storage requirements, and process times.[17]

In contrast with this, CP Air, with about 5.6 per cent of Eastern's volume in 1970 had essentially a manual booking system, using a "big board" to keep track of flights. Physical limitations of board size compound the reservations problem as the scale of operations multiplies. Aer Lingus in April 1965 installed an Altamatic real time reservation system, and subsequently ordered an IBM PARS system. While Aer Lingus and CP Air were approximately the same size (both flew about 1.25 million passengers in 1969)[18] they chose reservations systems that were quite different. It is clear that at *some* point, manual systems must give way to electronic systems.

System Evaluation. In connection with its SABRE system, American Airlines wanted to evaluate effects on response time (time taken to answer queries), caused by

---

[17] R.B. Parsons, "Microfilm Retrieval in an Airline Reservation System," Datamation, Vol. 15, No. 9, September 1969, p. 103.

[18] Airline Management and Marketing, October, 1970, p. 45.

variations in system design. A general model of the SABRE system was developed for use as a guide to system decision making.[19] The model was designed to evaluate the combined effect of a multitude of hardware components, software programs, systems strategies, and communications interfaces.

Response time was accepted as the standard by which to judge real time systems. The path of a message through the SABRE system was as follows:

1. Message "m" is typed at a console.
2. "m" is transmitted on real-time channel to core.
3. A series of tests are performed on "m".
4. An operational program sets up an entry block.
5. The entry is processed.
6. A response is transmitted to the console.

There was no methods problem in evaluating steps 2, 3, 4, and 6. These were dealt with by SABRE personnel. In step 5, however, the interacting demands upon the central processing unit in combination with software features of the system, presented a more difficult problem for analysis.

Entries went on a central processing unit (CPU) list in a first come first served manner. Each entry was processed

---

[19] A. Weingarten, "Response Time in a Total Airlines Computer System," AGIFORS Proceedings, 1969.

to completion unless the CPU was interrupted. When the CPU was interrupted, (for example awaiting access to disc file), the entry left the CPU list. After completion of the interruption, (access to disc et cetera), the entry was returned to the end of the CPU list. If no other entries were in process, work on the original entry continued. If, meanwhile, *new* entries had arrived, a delay "t" ensued before work on the original entry resumed.

The random variable for each waiting time at the CPU was represented as t_i. As the average entry had six accesses, there were six delays t_i in the course of processing the entry, plus an initial delay. Instead of evaluating each t_i individually, this model evaluated $T = t_1 + t_2 + \cdots + t_7$ as a total distribution.

A relationship between T and computer utilization was derived. Thus, American Airlines obtained rapid evaluation of the SABRE system response time. The simplified model was easily modified to suit proposed system changes, and the model provided first-cut systems analyses without the expense or delay of field trials.

Passenger systems of the future. Initially, computer systems kept track of seats sold and seats available. In 1971, systems could handle reservations inventories up to one year in advance, complete with passenger name records for more than a million bookings. Access times were fractions of seconds. Cathode ray tubes sped input, helped error detection in inputting, and sped up retrieval. One airline could obtain booking availability data from most other airlines. (About one third of all passengers use more than one airline to complete their flights).[20] In 1969, United States airlines had $250 million invested in computer reservations systems that made three hundred million bookings for one hundred and fifty million passengers flown.

Air Traffic Conferences of America in April 1968 decided to proceed with ATARS, a common automated reservations system for travel agents. More ambitious were specifications being developed by the Air Transportation Association (ATA), and the International Air Transport Association (IATA), for documents in a computer controlled system that ultimately would display fares for worldwide itineraries, confirm reservations, provide self-service tickets for credit card holders, permit self-service exchange of flights for card holders, provide instant no-show and standby data, provide automatic alternative routings.[21]

Production Information Systems

Manpower planning forecasts provide estimates of future manpower needs. Costs associated with various standards of service may be compared. Air Canada's Airport

---

[20] G.A. Buchanan, "The Outlook for Improved Passenger Systems," Datamation, March 1969, p. 24.

[21] Ibid., p. 26.

Manpower Planning System was for check-in, departure gate and arrival gate, but was to be extended to include other areas of the airport.[22]

Air Canada Manpower Planning. This model was operational in 1969 at Montreal and Toronto for management planning purposes. The model was simple because it was oriented toward relatively non-mathematical users. Implementation of new procedures is usually the most difficult part of an operations research study, because it requires new ways of thinking, and because the results may be difficult to verify. Unless the user has confidence in the results, the procedure will be abandoned. User confidence is greatly increased when the procedures are reasonably well understood. Extra model complexity and precision usually imply extra cost. Such costs should be weighed against the anticipated benefits of precision gained.

Inputs to the Manpower Planning Model included:

1. expected passenger traffic boarding and deplaning by flight.
2. forecast of check-in traffic by time of day.
3. service characteristics at each area studied.

---

[22] V.K. Wozniuk, "Airport Manpower Planning System," AGIFORS Proceedings, 1969.

Outputs of the model:

1. Agents required for each fifteen-minute interval through the day, for service level required. (short interval requirement).
2. Agents required for each eight-hour shift through the day, for service level required. (shift requirement).
3. Slack agents. (shift requirement minus short interval requirement).

The check-in queue model is M/M/2:(∞/FiFo). This was decided partly to facilitate the solution. The actual service distribution was found to be Erlang. Rationalizing the need to be conservative (to allow for irregularities not directly evaluated), the M/M/2 model was chosen. Perhaps an alternative would be to use an imbeded Markov chain model mentioned on page 115.

Service standards were specified as:

$$N_{hour} = \alpha N_{Qmax} + (1 - \alpha)\ N_{Qave}$$

where N_{hour} = hourly agent requirements

N_{Qmax} = maximum quarter hour requirement

N_{Qave} = average quarter hour requirement

If α is set at zero, the requirement is based on the average requirement. If α is set at unity, the requirement is based on the short interval requirement. By changing α between zero and unity, management can evaluate the cost implications for any interpretation of service level.

To incorporate realistic operational constraints, each agent works eight hours consecutively, with lunch breaks, and is subject to sickness, vacation and attrition factors. The heuristic procedure for finding the number of agents is quite simple. The model enabled management to determine manpower needs, and to explore policy alternatives.

Pilot Seniority and Salary Systems. Pilot salaries and training constituted more than five per cent of Aer Lingus' total costs in 1968. Available posts were offered to the most senior pilots first. Salary was a function of rank and type of aircraft flown. Progressive bumping through the seniority sequence led to extra training costs.

A new Boeing 707 required five extra crews. The five most senior Viscount captains could elect to fly the 707. They, in turn would be replaced by the most senior co-pilots--almost certainly jet co-pilots. Thus there would be ten jet or Viscount co-pilot vacancies to be filled in most cases by B707 third pilots. Fifteen Viscount co-pilots would be promoted to B707 third pilot, and fifteen new pilots would be recruited. A progression diagram is shown in Figure 1.[23]

---

[23] J.A. O'Carroll, "Note on a Computer Simulation Used to Evaluate Pilot Seniority and Salary Systems," AGIFORS Proceedings, 1968, p. 552.

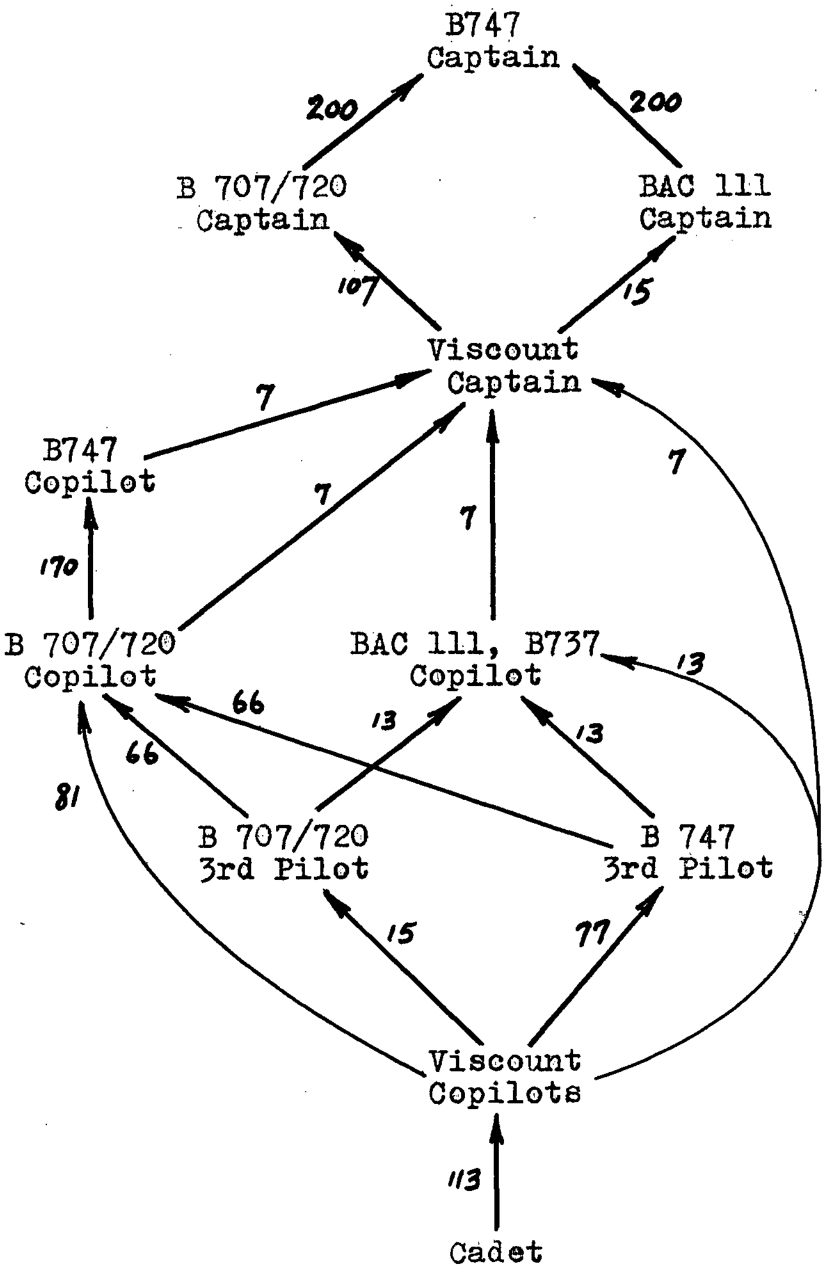


Figure 3.1, Pilot Progression, with Costs.
(From AGIFORS Proceedings, 1968, p. 555).

Benefits from three alternatives were evaluated by simulation. The alternatives:

1. Leave promotion scheme as is. (third pilots on B707/720).
2. Replace third pilots by flight engineers.
3. Create a new grade of senior first officer for flexibility in directing co-pilots to particular aircraft types.

While the second alternative offered some savings, the third alternative was of marginal benefit. Neither alternative was taken. The simulation makes no attempt to evaluate the union problems that might be involved, but was considered a useful planning tool and was kept updated.

Future information systems will give management stronger control than is possible today. There has been some attempt to define future reservations systems. Doubtless computers will feature increasingly in airline information systems. New approaches to system design and development may have profound effects in the long run. Tucker's ratio analysis[24] has been of interest to Quantas[25] as a possible

---

[24] S. Tucker, Successful Managerial Control by Ratio Analysis, New York, McGraw Hill, 1961.

[25] L.G. Klingen, "Control of Materials Costs by Ratio Analysis," AGIFORS Proceedings, 1967, p. 364.

system for materials control. Ratio analysis may play a strong part in model building in the future, at least in the first stages of model formulation.

Plans such as Air France's Tarage[26] that bring together various operations research studies, are used at present to predict equipment needs twelve to twenty-four months in the future. Some day the system may be used for real-time decisions. It is still too early to evaluate fully the MASSOP integrated information system.[27] This plan is an attempt to handle a total airline system by means of a single comprehensive control package. Whatever success the current and projected systems may enjoy, airline operations are recognized as less than perfect. An improvement of only two or three per cent would justify millions of dollars invested in control hardware and software, particularly in the large airlines. One of the major problems currently is the interface between airlines for information transfer. These are reasons enough to expect continued development.

---

[26] J. Agard, "The Air France Tarage Plan," AGIFORS Proceedings, 1968, p. 223.

[27] J. F. Judge, "MASSOP--A New Cost Weapon for Management," Airline Management and Marketing, October 1970, p. 96.

II. SCHEDULING

Airline scheduling is the process by which aircraft and aircrew itineraries are specified. Effective scheduling requires consideration of revenue traffic demand, connecting flights, regulatory and operating constraints and costs. While treated here mainly as a short-term planning function, scheduling is associated with longer range decisions of fleet planning, the acquisition of new aircraft, and the retirement of existing aircraft.

Scheduling begins with aircraft rotation. In the short run, fleet size and maintenance requirements are rigid constraints. Constraints omitted from the models discussed in this chapter include bilateral agreements (on numbers of flights or percentages of total traffic permitted). Flights may be limited to a specific number per week, or to a number related to the activity of another airline. Traffic limits in terms of another airline or in terms of total traffic are bothersome, in Canada and elsewhere. In addition to layover and hours of work conditions, cabin crews must have specific language capabilities. Attrition in cabin crews is high, but owing to seasonal buildups and declines, attrition provides a painless means to reduce crew sizes in off seasons. However, the costs of training are substantial. Reserve crews pose problems of utilization. What percentage of reserves should be used? Should flights ever be cancelled due to reserves shortages--and if so, how often?

Real world solutions are usually compromises. Were it practical, a Boeing 707 flying the United States coast-to-coast with one hundred per cent load factor would earn profits exceeding the cost of the aircraft in one year.[28] The pressure of competition is such that load factors remain close to a breakeven level. Airline profit levels acceptable to the U. S. Civil Aeronautics Board have not been far above a ten per cent rate of return.

A Review of Scheduling Models

Figure 2 attempts to show the relationships between data and scheduling models. Rectangular boxes hold deterministic information. Circles contain predictions subject to uncertainties. Only the schedule models represented in the lower circle will be discussed here. Level of service feedback is applicable mainly in the long run. For most airlines the schedule is static over a period. The chief exception among U.S. carriers is Eastern Airlines' Shuttle service.

Scheduling models can be generalized in the form: Find a combination of values X (the problem variables) that

---

[28]K.M Ruppenthal, Air Line Management, published in draft form by the Graduate School of Business, Stanford University, 1968.

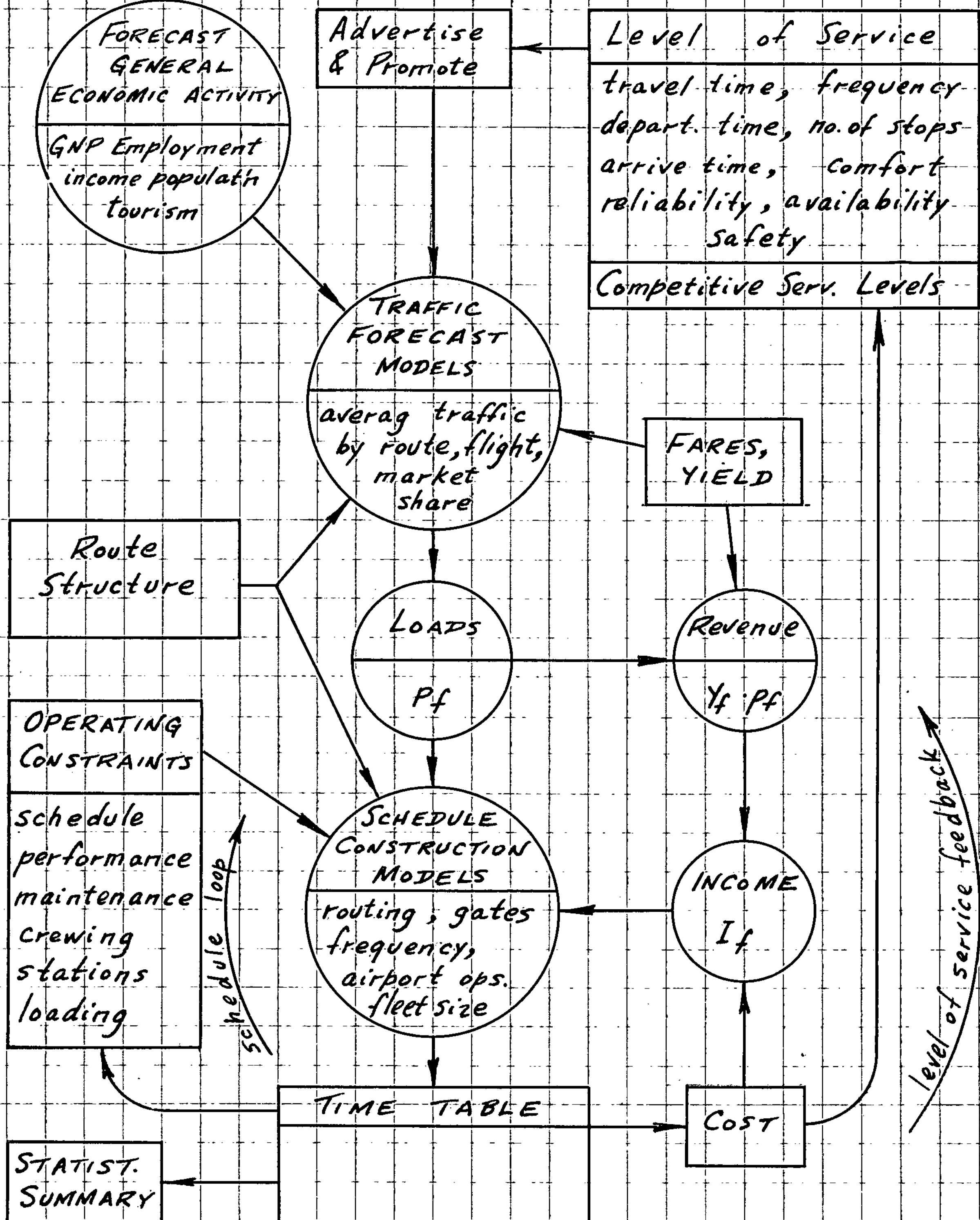


FIGURE 3.2 Schematic Relationships : Models within the Airline System.
(From R.W. Simpson, AGIFORS Proceedings, 1969).

optimizes an objective function R(X) and which satisfies a number of conditions or constraints, $g_i(X) = 0$. Some typical objectives are the following:

Minimize fleet size.

Minimize operating cost.

Maximize (revenue minus cost) for the system.

Maximize (social benefit minus cost) for the system and public.

Some typical constraints to scheduling models are listed as follows:

Number of aircraft in the fleet.

Route constraints in daily service, multi-stop itineraries.

Type of aircraft in the fleet.

Relationship between demand and frequency of service.

Terminal gate restrictions.

Minimum or maximum daily frequencies on routes.

Multiple departure times for any service.

Maximum daily operations at a station.

Station balance constraints.

Fleet acquisition and disposal constraints.

Scheduling model classification. The five main types of model discussed here are as follows:

1. Fleet Assignment Models. Linear Programming, (LP) models assign aircraft types to sets of routes on the route map.
2. Fleet Planning Models. These are extensions of the fleet assignment of aircraft over several planning cycles.
3. Dispatching Models. Usually for a single route, dispatching models determine optimal dispatch time pattern based on demand.
4. Aircraft Routing Models. Given a schedule map, the routing model determines an optimal routine for the individual aircraft.
5. Fleet Routing Models. Using network flow methods, fleet routing models find optimal fleet routings without identifying individual aircraft.

Fleet Assignment Models for short and medium range planning, in LP format have grown from an original model by Dantzig and Ferguson in 1954.[29] Fleet assignment models can be useful as fleet planning tools because they can optimize type and numbers of aircraft for the airline fleet. Assumptions in these models usually include:

1. A solution over a fixed time period T.
2. Average traffic during T is estimated for each route.
3. A load factor assumption is made for each aircraft.

Extensions of this model can include consideration of competition and can fix market share as a function of relative frequency. Size of the LP matrix for two hundred city pairs, five aircraft types twenty cities, and three breakpoints in the market share curves (for linear approximation of demand), gives 1,800 variables and about seven hundred constraints. Fleet assignment models have been used by aircraft manufacturers, and by airlines for medium range planning, and by government regulatory departments. In addition, subject to the constraints of existing fleet size and type composition, the model indicates the optimal disposition of aircraft among the routes available.

Fleet Planning Models . . . are extensions of the assignment LP, and are used for projecting five to ten years in the future. They provide management information for long term planning and financing. Aircraft manufacturers have an interest in fleet planning. To the extent that they are able to anticipate the needs of civil aviation, they can design and build aircraft with the greatest market success.

Individual airlines make long run decisions on the type and number of aircraft needed, and short run decisions on how best to utilize the aircraft available. Airline

---

[29] G. B. Dantzig, Linear Programming and Extensions, Princeton: Princeton University Press, 1963, p. 568.

objectives may be to maximize profit or return on investment, or to give maximum service at a given cost, or to increase national prestige. Aircraft manufacturers evaluate the objectives of individual airlines, summing to obtain a composite picture of future aircraft markets.

Executives of United Air Lines have been disappointed with "cross section analyses" and "gravity models" that try to relate passenger volume to socio-economic factors such as population, gross national product, and disposable personal income.[30] Multiple regression analysis and linear programming have been similarly disappointing as forecasting techniques. The market is the first consideration in scheduling, but there are others:

Route authority and restrictions imposed by law.

Competition.

Aircraft characteristics and service needs.

Airport limitations and congestion.

Passenger aversions, for example, changing planes.

Manufacturers' Models. Three major aircraft manufacturers, Lockheed, Douglas, and Boeing have developed fleet planning models mainly for examining the long range air-

---

[30] W. G. Williamson, "Computer Programs for Fleet and Schedule Planning," AGIFORS Proceeding, 1967, p. 11.

craft market. The Lockheed model is built around the "Airline System Simulation Model," under development since 1959.[31,32] Assumptions of the Lockheed model are principally as follows:

1. Demand is uniformly distributed over time.
2. Flights are uniformly spaced through the schedule period.
3. Time of day effects of demand are ignored.
4. Time effects of aircraft positioning are ignored.

The model generates flight frequencies by route and by equipment type, to serve as input for the "Airline Scheduling Program." The major shortcomings of the Lockheed models have been pointed out as (1) ignoring time of day demand distribution and (2) lack of interplay between frequency and market share.[33] The Lockheed model has been improved and expanded over the years. However, in 1970 the ability to generate a good schedule was still in development stages.

---

[31] Wm. A. Gunn, "Airline System Simulator," Operations Research, Vol. 12, No. 2, 1964, pp. 206-229.

[32] L.R. Howard, and D.O. Eberhardt, "Airline Simulation for Analysis of Commercial Airplane Markets," Transportation Science, Vol. 1, No. 3, 1967, p. 131.

[33] Williamson, op. cit., p. 20.

Douglas constructed an "Airline Operations and Planning Model" that included eight operational models. In 1968 the composite Planning Model was still being improved and expanded. Douglas made no apology for "requiring the user to be both diligent and intelligent. Too often the analysts feel that the program is an end in itself, . . ."[34]

Boeing in 1967 was in the early stages of developing a scheduling model that would reflect time-of-day distribution of demand.

It is apparent that the plane builders' problem is not basically airline scheduling, although all three have worked on scheduling models.

Dispatching Models are used for determining optimal departure times. The frequency pattern for the system is an input. An initial timetable is usually made manually for each route without regard for network considerations. Time of day demand fluctuations should be known.

Dynamic programming may be used. In Figure 3 the stage variable is time and the state variable is the number of passengers waiting.[35] Passengers begin queuing at time

---

[34] J.D. Kingsley, "Airline Operations and Planning Model," Douglas Paper 5058, May 1968.

[35] R. W. Simpson, "A Review of Scheduling and Routing Models for Airline Scheduling," AGIFORS Proceedings, 1969.

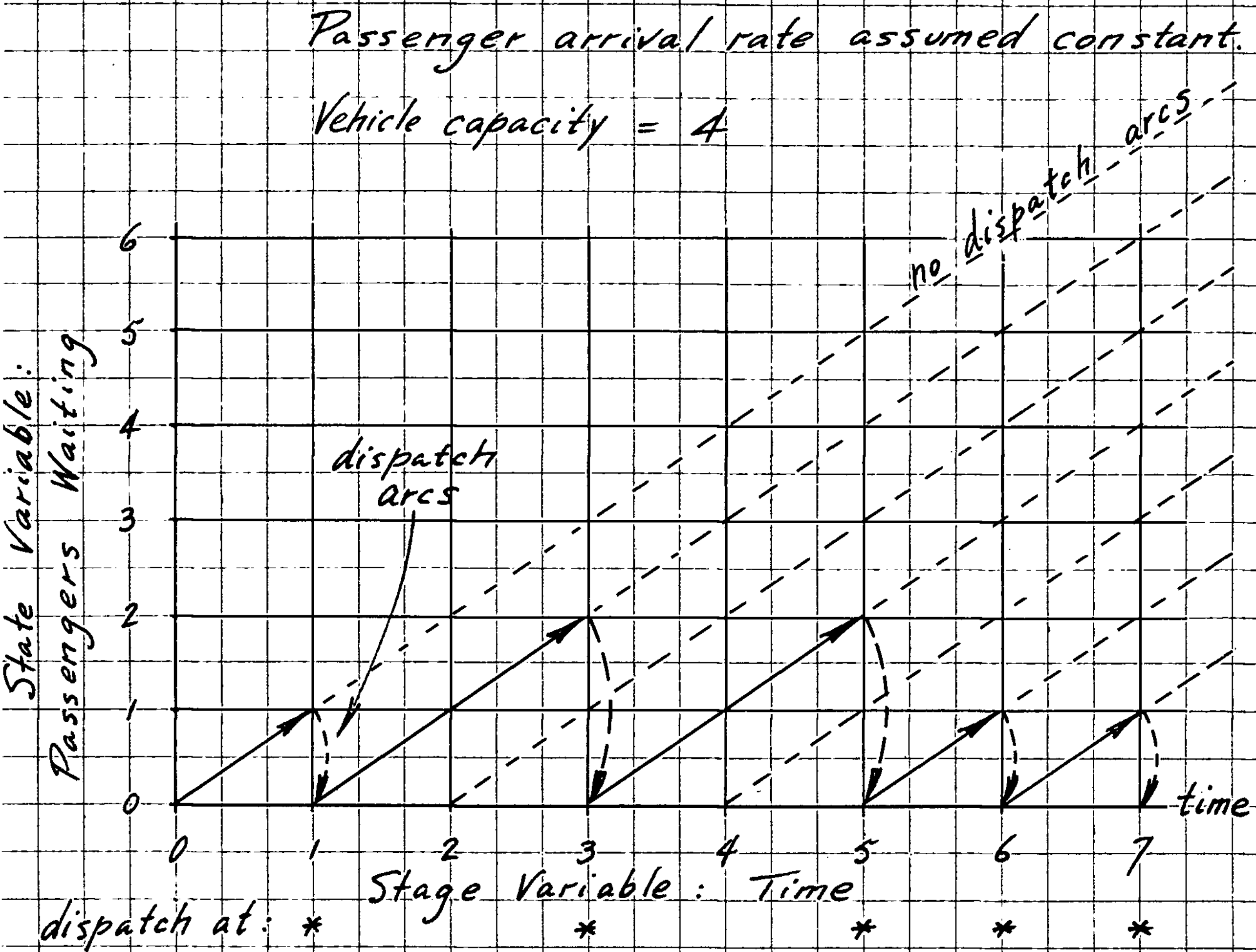


FIGURE 3.3 Dispatching Network

(From R.W. Simpson, AGIFORS Proceedings, 1969.)

zero. This is represented by the "no dispatch arc" (diagonal line) from time zero to time 1. At time 1, (or stage 1), a dispatch arc removes the queue and the process of queueing begins anew.

Such a model has application in Eastern Airlines' Shuttle service, or in more conventional networks for which the frequency pattern is set. In the example of Figure 3, the "no dispatch" arcs are parallel straight lines, but this will not be the case in practice, particularly if arrivals from connecting flights are included.

Aircraft Routing Models. Dynamic programming has been used sequentially in a single-vehicle routing model to give "good" but not optimal routing for a set of vehicles.[36] As the method is inefficient, it will not be described here.

Fleet Routing Models have been constructed using the "Out of Kilter" algorithm of network flow theory. The problem is to find the set of services that will yield maximum income, given a schedule of possible non-stop services, and expected traffic for the level of service planned, (including competitive services). This technique gives an optimal solution for a given fleet size, and evaluates income for varying fleet size.

---

[36] Ibid.

Constrained fleet routing models, using integer LP, determine the minimal fleet size required for a given schedule of services to be flown by a fleet of aircraft of a single type, where discrete departure times are assigned for each service.

Multi-fleet routing models determine the minimal number of aircraft required and the number and routing pattern for each aircraft type such that every service specified is flown. Up to 1970, full scale airline problems had not been tried using this technique.

Simplifying assumptions tend to remove all of these models from reality. Much of the material given in the bibliography[37] was developed at the Massachusets Institute of Technology but does not appear to have been widely known to airline operations departments at the time Mr. Simpson's paper was presented.

Fleet Scheduling at Air Canada

Air Canada developed a three-part program for flowing passengers over route networks. The main variable is the schedule. This is inputted to the model and the output

---

[37] Ibid.

is a list of passenger flows. The model is not an optimizer, but it shows the effects of schedule changes and therefore indicates preferences among the schedules proposed.[38]

Figure 4 illustrates the schematic relationship of the three models used:

1. Attractive Path Generator.
2. Traffic Distribution Estimator.
3. Passenger allocation process.

An attractive path is a flight or set of flights having a flying time during which no alternative path can be traversed between the origin and destination. (Generally the most direct paths with shortest elapsed times are most attractive). The attraction of paths is assumed to be a function of frequency and trip time. Attraction intervals are provided to cover the entire day, without overlap in the period of attraction of any two adjacent paths. Thus the attractive path generator selects from all proposed paths those that will be most attractive. An effective attractive path generator should include existing schedules operated by competitors. A model of this type, could be of interest to regulatory authorities for evaluation of route regulations and awards.

---

[38] G. Gagnon, "A Model for Flowing Passengers over Airline Networks," AGIFORS Proceedings, 1967, p. 29.

FIGURE 3·4 AIR CANADA PASSENGER FLOW MODEL.
(From: AGIFORS Proceedings, 1967, p.32)

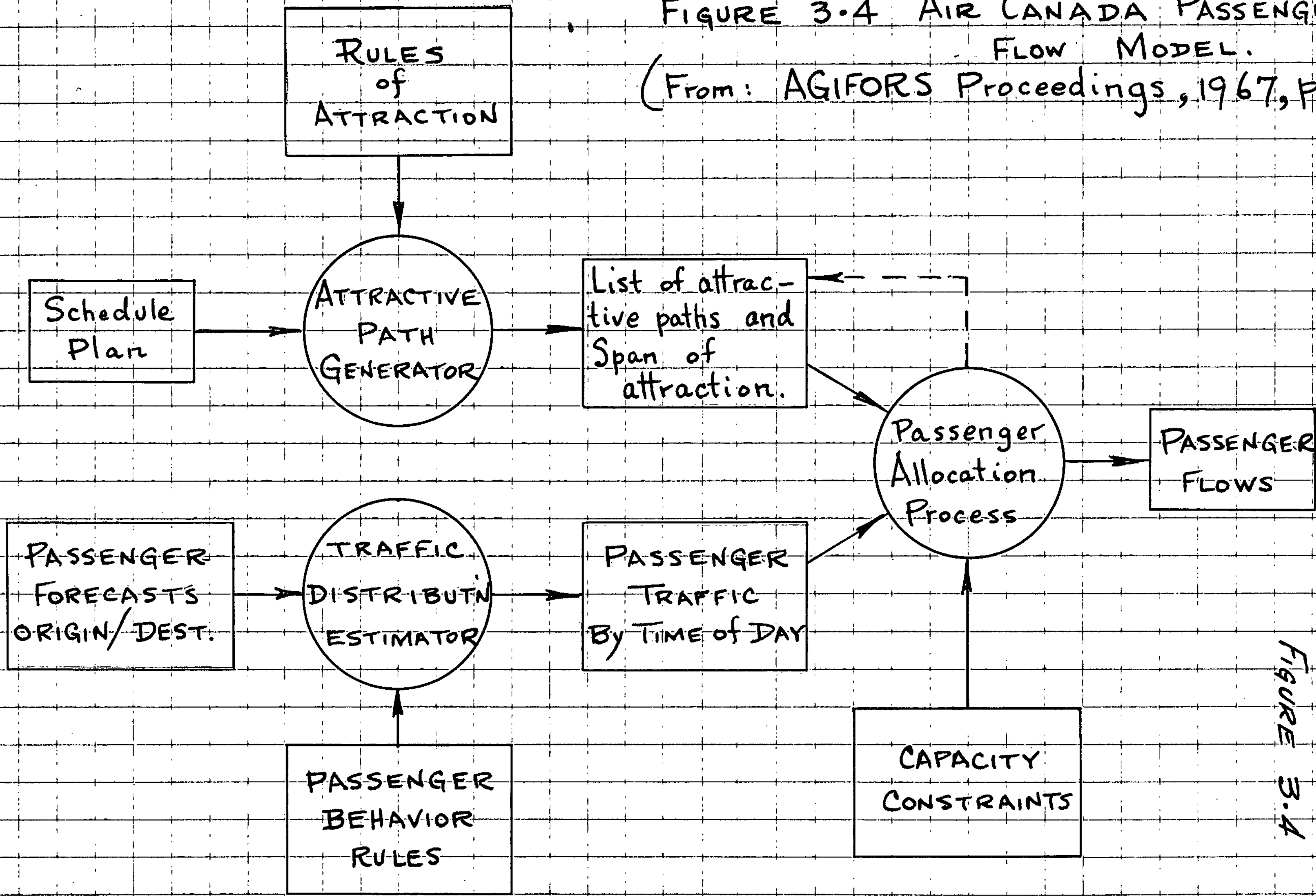


FIGURE 3.4

The Traffic Distribution Estimator defines passenger demand by day of week and time of day based on exponential smoothing of historical data. The resultant distribution (two unimodal curves), was approximated by means of the Beta function,[39] simply by adjusting parameters. However, this is an area where human judgement is still much in force. The model provides a neat quantification method.

The Allocation Process combines the paths from the Attractive Path Generator with the demand of the Traffic Distribution Estimator to predict passenger flows. If a passenger is allocated to a flight that is booked, the path becomes "non-attractive" and the passenger will be reallocated. This means that the attraction pattern is affected by total demand. However, if there are alternative routes (competition, or other modes), these should be considered. The model deals with *leg* travel rather than travel between ultimate origina and destination, and this is perhaps its greatest weakness. A "spurious" demand picture for leg travel is insensitive to major factors such as connecting flights, where the utilities of the departure or arrival times are subject to "all or nothing" variations. Promotional fares might also upset the demand distribution and should be included. Nevertheless, the model is capable of revealing bottlenecks and slacks in a proposed schedule.

---

[39] H.W. Reddick, and F.H. Miller, Advanced Mathematics for Engineers, New York: Wiley, 1948, p. 216.

Aircraft Rotation

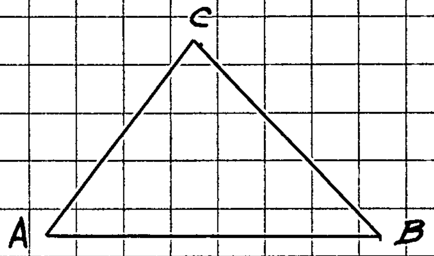
Aircraft rotation is the assignment of specific aircraft to meet a given set of arrivals and departures. Unfortunately, the term "schedule" may be used with reference to aircraft rotation, or with reference to the set of arrivals and departures. Crewing considerations are usually secondary, and can affect the aircraft rotation only indirectly by indicating possible economies that may or may not be achieved by minor adjustments to the aircraft rotation. Within an existing framework of arrivals and departures, rotation might be optimized by finding the minimum number of aircraft required.

An intuitive approach. An experimental approach by Helmut Richter proposed a simple heuristic procedure for minimizing idle times between flight segments.[40] A"coupling matrix" shows the idle times between all possible connecting segments. An illustration of the coupling matrix and the schedule for which it is constructed is shown in Figure 5. This is an assignment problem. By shifting flight segments, idle times in the matrix can be altered. The smallest sum of idle times corresponds with the minimum aircraft requirement.

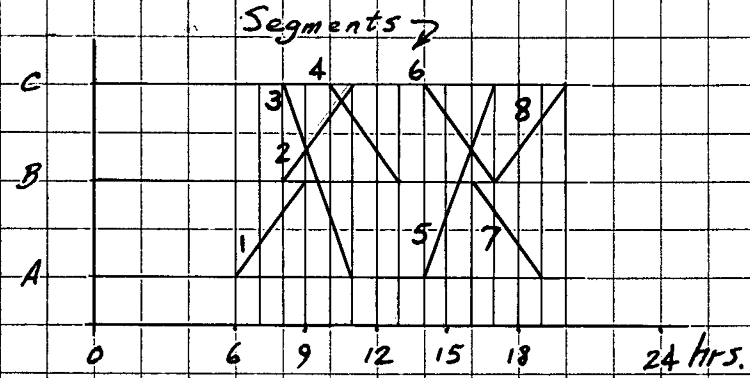
The example given is extremely simple compared with a full-sized airline problem. It is only a one-day rotation

---

[40] H. Richter, "Optimal Aircraft Rotations Based on Optimal Flight Timing," AGIFORS Proceedings, 1968, pp. 36-39.



1. ROUTE NETWORK



2. SCHEDULE DIAGRAM.

1 - 7
7 - (1)
2 - 6
6 - 8
8 - (3)
3 - 5
5 - (4)

i \ j (arriving segment no. \ departing segment no.)	1	2	3	4	5	6	7	8
1		-1					7	8
2			-3	-1		3		
3	-5				3			
4		-5					3	4
5			-9	(-7)		-3		
6		-9					-1	0
7	(-13)							
8			(-12)	-10		-6		

3. COUPLING MATRIX. (3 AIRCRAFT USED)

FIGURE 3.5 AIRCRAFT ROTATION MODEL.
(From: AGIFORS Proceedings 1968 p 38)

whereas a weekly rotation is typical of most airlines. The efficiency of the method might prove disappointing in practice, and any solutions obtained would have to be reviewed with respect to maintenance and crew scheduling.

An extension of this model that overcomes some of these objections is given below in D. teWinkel's model for aircraft scheduling in a radial network.[41]

Aircraft Rotation with severe constraints. A completely different emphasis on rotation was applied by Quantas Airways Limited.[42] Due to the constraints associated with a small airline on long-haul routes, there is less freedom in scheduling, and more complicated crew arrangements than on short haul routes. Because the movements are few, and because restrictions prevent extensive timing alterations, (high revenue ports should be serviced at reasonable hours, and airport curfews and congestion peaks should be avoided), the schedules are prepared manually. The computer is used in this case to make a feasibility check, primarily to ensure that the fleet can handle the schedule, with allowances for maintenance stops and route delays.

---

[41] D. teWinkel, "An Algorithm for Aircraft Scheduling in a Radial Network," AGIFORS Proceedings, 1969.

[42] A.J. Walker-Powell, "Aircraft Scheduling by Computer," AGIFORS Proceedings, 1969.

Route delays are not constant. There are wide variations in arrival times among the routes. "Time pads" for route-to-route linkages are designed to accommodate eighty-five per cent of the delays, based on an assumed log-normal distribution of delays. This rotation model was still in trial operation at the end of 1969, and at that time was known to have some shortcomings, mainly in connection with allowances for minor maintenance.

Rotation of aircraft in a radial network was described in a paper by D. teWinkel, with emphasis on the problems of ground crew and hangar utilization as well as time allocations for the maintenance of each aircraft.[43] Solutions that yield long unbroken intervals of ground time at home base are desirable.

Richter's assignment matrix coupling of Figure 5 is now made n x n for the flight combinations in a week. A configuration matrix $\{a_{kl}\}$ stores the times required to convert from configuration "k" to configuration "l". A branch-and-bound algorithm will solve the assignment problem to minimize the penalty associated with mis-allocation in each row, but the n x n matrix leads to a large number of solutions. Adjusting the algorithm to skip branches in the

---

[43] D. teWinkel, op. cit.

solution tree, the number of solutions generated is greatly reduced. Computing time for a 57 x 57 matrix was about five minutes, yielding 440 useful solutions.

The method is applicable to other combinatorial problems, particularly to crew scheduling.

Spare Aircraft. A special case of aircraft rotation is the use of spare aircraft, kept mainly to reduce schedule perturbations. D. Bindler-Gaspard reviewed the costs and expected benefits, taking into account the assumed binomial probability distribution of perturbations, and their costs, and comparing total expected perturbation costs with spare aircraft costs.[44]

The conclusion reached (for Sabena) was that spare aircraft were not justified. More flexible scheduling of flying aircraft was suggested as a more suitable tactic. This decision would not necessarily hold for every airline. Sabena in 1969 evidently had over-expanded its maintenance facility and was under heavy fire for having spent funds from subsidies in excess facilities.[45]

---

[44]D. Bindler-Gaspard, "Spare Aircraft--A Necessity or a Superfluity?" AGIFORS Proceedings, 1969.

[45]Aviation Week and Space Technology, 7 April, 1969, p. 33.

Scheduling of Personnel and Cargo

Starting with manpower requirements by day and by time of day, and the union contract constraints, an integer LP may be formed to determine the starting times and the numbers of men required per shift. If this leads to a large program, the problem may be rewritten as an optimization over a number of small integer LP's.[46]

The sub-problem is to find the manpower necessary for each shift. Where shift starting times are flexible, there are many possible combinations of shifts. To find the optimal shift schedule, the problem is formulated as a normal LP without integer constraints. The normal LP formulation may be used for non-union employees, where hours of work constraints are less stringent.

Implementation of such a program by TWA in 1969 was expected to save half a million dollars annually in labour costs.[47] However, there was still room for improvement. The solution method apparently did not allow for schedule differences by day through the week, for staff rotations shift to shift, or for days off.[48]

---

[46] K.C. Khanna, and H. Takamori, "Optimal Staff at Airline Terminals," AGIFORS Proceedings, 1969.

[47] Ibid.

[48] D. Thibault, Comments on Khana and Takamori, op. cit.

Crew Scheduling is normally formulated as an integer LP. One of the main difficulties with this approach is the matrix size, with typically hundreds of rows and tens of thousands of columns. Aer Lingus avoided this with an initial matrix that was only 36 x 300, but for large matrices, the methods of reduction are several, and in 1970 were still in the experimental stages.[49]

A common objective is to minimize numbers of crews. Although some feasible solutions were available in 1967, several approaches were under development by different airlines. They fell into two main classes:

1. Integer LP formulations with appropriate algorithms, such as the Glenn T. Martin CEIR Inc. code or the House-Nelson RADO method.

2. Tree structures with combinatorial algorithms for exhaustive or inexhaustive enumerations of the solution space. Several branch and bound and partitioning techniques were being explored in 1967. Some techniques were feasible but deficient in the sense that they took too much computer time or did not optimize.[50]

---

[49] F. Steiger, "Activity Report of the AGIFORS Study Group--Crew Scheduling," AGIFORS Proceedings, 1967, p. 120.

[50] Ibid., p. 124.

Deutsche Lufthansa developed a three-phase model for crew rotation on a seven day cycle.[51] Starting with a given rotation plan for the seven day cycle of flight number, departure stations and times, and crew requirements, (some flights have no cabin crew), an integer LP is formed with zero-one variables a_{ij} for duty on leg "i" and duty "j". This "duty matrix" has the objective of minimizing the number of crews.

Crew assignments are made impersonally in phase (1) subject to maximum duty lengths, minimum rest between duties, and maximum cycle length. Phase (1) of the model was operational and optimized crews for given schedules. Phases (2) and (3) were to assign crews individually and to cover procedures for emergencies such as illness.

In separating aircraft rotation from crew assignments, suboptimization of the whole system is probable. However, the combined problem of a general optimization of aircraft and crews is larger than the aircraft rotation problem or the crew schedule problem, either of which can have thousands of variables and constraints.

Reserve Crew Scheduling is a special type of crewing. Intuitively, the needs for reserve crews are functions of weather, vacations, regular crew workloads, leaves of

---

[51] R. Griesshaber, "A Heuristic Model for the Impersonal Phase of Crew Scheduling," AGIFORS Proceedings, 1968, p. 535.

absence, air traffic control (ATC) delays, training requirements, and the like. Pinpointing the relationship between reserve requirements and any of these factors had yet to be done in 1968.[52]

Airlines generally use a bid system for aircrews. Lists of scheduled and reserve routines are published and all aircrew "bid" on the postings. Assignments are made on the basis of preference starting with the most senior and finishing with the most junior crew members.

At American Airlines it was hypothesized that:

$$\text{Reserve Utilization} = K_1 + A(U_{reg}) + B(R) + C(T) + D(V),$$

where K_1, A, B, C, and D, are constants, and

Ureg = utilization of regular crews in man-hours

R = ratio of reserves to regulars

T = equivalent man-months of training or retraining

V = equivalent man-months of vacation.

By regression analysis, "A" was found to be almost always positive, while "B" was consistently negative. This implied that reserve flying varied in direct proportion to the number of flying hours scheduled, and that average reserve

---

[52] D.R. Bornemann, "A Linear Programming Solution to the Reserve Crew Scheduling Problem," <u>AGIFORS Proceedings</u>, 1968, p. 455.

utilization declined as more reserve bids were published.

An LP formulation arrived at the optimal sets of bids, subject to desired minimum reserves on duty each day for one month. A reserve with only one day of duty remaining, is of limited use. Figure 6 shows how availability constraints ensure that the number of reserves with three or more consecutive duty days remaining, is maintained above a specified minimum for each day of the month.

The problem may be written:

$$\bar{\bar{A}}\bar{x} \geq \bar{b}, \quad \text{minimize} \quad \bar{c}\bar{x} .$$

where $\bar{\bar{A}}$ = matrix of bid parameters

$\bar{x}$ = optimal set of bids

$\bar{b}$ = desired minimum number of reserves on duty

$\bar{c}$ = cost = 1 per bid

$$a_{ij} = \begin{cases} 1 & \text{if holder of bid j is on duty} \\ 0 & \text{otherwise} \end{cases}$$

i = 1, 2, 3, ··· , 30. (days of the month),

but i also has values 31, 32, ·· , 60, corresponding to days (i - 30). For values of i between 30 and 60, a_{ij} has values of 1., .5, .4, or zero, as follows:

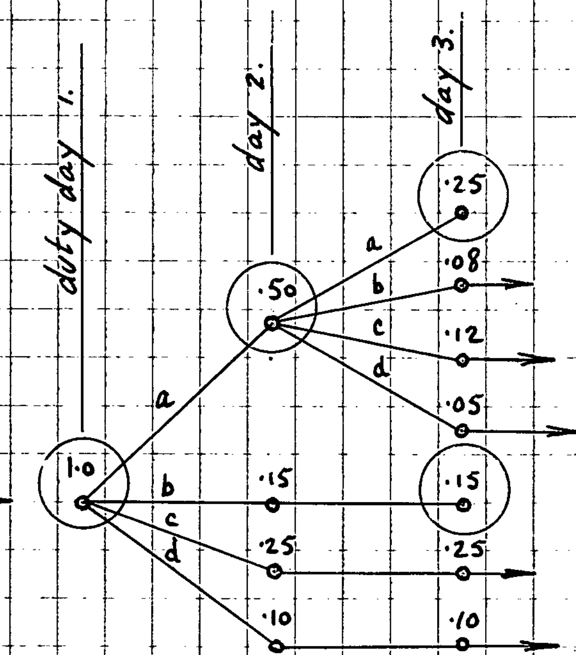
a_{ij} = 1.0 if holder of j is coming on duty on day (i - 30) for three or more days

a_{ij} = .5 if holder of bid j is on second duty day and has three or more consecutive days remaining

ANALYSIS OF RESERVES AVAILABILITY.

Systemwide average of duration of Reserve usage.

Trip Duration	Probability
0 or 1 day	a = ·50
2 days	b = ·15
3 days	c = ·25
4 days	d = ·10



Probability of being @ base: 1.00 ·50 ·40

LP FORMULATION.

Set of bids:		X_1	X_2	...	X_j	...	≥	
day number (i)	1	1	0	...	a_{1j}	...	8	desired minimums on duty each day.
	2	1	1	...	a_{2j}	...	7	
	3	1	1	...	a_{3j}	...	6	
	⋮							
	i	a_{i1}	a_{i2}	...	a_{ij}	...	b_i	
	⋮							
	30							
	31	1.0	0	...	a_{31j}	...	3	availability constraints. b_i = min. reserves with 3 or more consec. days remaining on day $(i-30)$.
	32	·5	1·0	...	a_{32j}	...	2	
	33	·4	·5	...	a_{33j}	...	1·5	
	⋮							
	60	0	·5	...	a_{60j}	...	2	
Cost:		1	1		c_j		Min.	

FIGURE 3·6 RESERVE CREW SCHEDULING.
(From: AGIFORS Proceedings 1968 p. 462)

a_{ij} = .4 if holder of bid j is on his third duty day and has three or more consecutive days remaining

a_{ij} = 0 otherwise.

This system has been used successfully by American Airlines. Benefits resulting from implementation were not stated, but the model was aimed at direct dollar savings in reserve crew costs. Users of this model should consider the assumption that the probabilities of one, two or three day postings were assumed equal throughout the route system. This may not hold true for every airline.

Cargo Scheduling is secondary to passenger flow in airlines with mixed flights. The low priority for belly cargo may be due to the low net return. Ground handling costs were typically 77 per cent of the 1968 revenue for hauling a thousand pounds three hundred miles.[53] A comparison between all-cargo and mixed passenger and cargo operations shows Flying Tiger's all-cargo productivity as 409,000 ton km. per employee versus Air Canada's mixed cargo productivity of 66,000 ton km. per employee.[54]

Air Canada applied an LP approach to cargo scheduling, maximizing revenue subject to delivery performance con-

---

[53] D.H. Maund, Comment on paper by Tennant and Batey, AGIFORS Proceedings, 1968, p. 16.

[54] Airline Management and Marketing, October 1970, p. 57.

straints.[55] The LP was used as a headquarters tool to estimate actual loads in the system formerly a manual calculation. Benefits from the LP were mainly in the reduction calculations, and in giving more evaluations and more rapid assessment of alternative schedules at twice-yearly meetings with cargo service managers. Much more development of solution techniques was needed to arrive at operating programs for weekly or daily schedule response to external conditions.

III. CUSTOMER SERVICE

In this chapter, customer service is activity that requires personal contact between airline and customer, particularly the loading and unloading of passengers and baggage. As the airline product is generally considered to be time, it is mainly in time conservation that efforts toward better service are directed, (always with greater efficiency and lower costs in mind).

In 1969 Pan American planned to spend thirteen million dollars for air freight terminals to accommodate

---

[55] C.J. Tennant and A.T. Batey, "Schedule Evaluation for Air Cargo," AGIFORS Proceedings, 1968, p. 12.

Boeing 747 traffic.[56] Special ground handling equipment expenses for the Boeing 747 tended to offset lower seat mile costs and reduce profit potential. Passenger boarding on the 747 took from ten to forty-five minutes depending on the load.[57] Figure 7 illustrates Pan American's early experience loading the 747.

Airlines sometimes agree to share facilities for baggage handling, for example Finnair and Braniff International at J.F. Kennedy Airport. United developed its own systems at O'Hare airport using Aerojet General high speed equipment.[58] Eastern Air Lines in 1970 were studying "advance baggage" service expansion--sending baggage ahead on earlier flights to improve service at destination. This can be done if baggage is checked in early enough.[59] In 1968, passengers on average checked in 1.3 bags. More than two hundred million pieces of baggage were handled. Evidently more installations for automatic baggage handling were needed. The Docutel system was designed for shock-proof carts travelling fifteen to twenty miles per hour by linear induction motor. In 1970 Pan American planned to be first to install this system. The initial installation, costing more than three million dollars was to be at Kennedy International Airport.[60]

---

[56] Aviation Week and Space Technology, 31 March, 1969, p. 33.

[57] Ibid., 29 June, 1970, p.25.

[58] Ibid., 31 March 1969, p.33.

[59] Ibid., 7 Sept. 1970, p. 33.

[60] Ibid., 6 July, 1970, p. 30.

747 GROUND OPERATIONS

"Ground operations on a New York to London departure take about three hours. Cargo loading, fuelling, systems checking and galley loading take place simultaneously, all within one and a half hours. Time sequence includes:"

Taxi from hangar to terminal	10 to 15 minutes
Cargo loading	60 to 90 "
Fuelling	30 to 45 "
Galley loading	30 to 43 "
Lounge boarding	60 "
Passenger boarding	45 "
Baggage loading	40 to 90 "
Taxi to runway	10 to 15 "
ATC delay (average is 10 min.)	2 to 57 "

Arrival at Kennedy:

Deplaning	10 to 15 minutes
Health and Immigration	10 to 20 "
Baggage unload (biggest problem)	40 to 60 "
Customs	20 to 30 "

Figure 7 Initial Pan American 747 Experience. (From Aviation Week and Space Technology, 2 February 1970, p. 32)

Although Braniff attempted to relieve congestion with a monorail at Love Field, Dallas, conveying passengers from the parking lot to the aircraft, ground transportation and congestion is a problem area that airlines have seldom addressed in the past, perhaps because road systems and surface transportation are outside their control.

In the 1970's cargo may assume a more important role, especially in the jumbo fleets. Cargo volume may increase as a result of lower costs, including pickup and delivery, or through adoption of military airlift systems innovations, standardized containers and handling facilities and through reduction of paperwork and documentation.[61] While passenger traffic has increased, and will continue to increase, freight traffic growth has been more rapid. In 1953, cargo represented thirty-four per cent of air transport services. In 1968 cargo represented forty-two per cent of air transport service.[62]

Improvement of customer service is often a problem of queueing. Three important ways of using queueing models are: (1) for planning new facilities, (2) for seeking best use of existing facilities, and (3) for comparison of

---

[61] B.A. Schriever, and W.W. Seifert, Air Transportation 1975 and Beyond: A Systems Approach, Report of the Transportation Workshop, 1967, MIT Press, pp. 69-83.

[62] George R. Besse, "Some International Aspects of the Demand for Air Transport," Air Transportation--a forward look, Karl M. Ruppenthal (ed.), and Brian E. Sullivan, Graduate School of Business, Stanford University, 1970, p. 18.

alternatives.[63] Queueing theory provides quantitative assessments of specific situations rather than optimal decisions. Present theory accommodates only the simplest queueing situations and these are not the usual real world situations. Simulations provide good answers but are costly. (How good an answer is needed?) Simulations can be used to develop general rules of thumb. Alternatively, more tractable solutions, albeit less accurate, may be found from simplified models of real situations. A third approach is the Poisson Chain technique or imbedded Markov chain technique.[64] This method can handle Erlang series, variable arrival rates and variable service rates, and it is easily computerized.

Check-in Service. Aer Lingus examined manpower needs at its check-in counters. Service standards were set previously by management decision from tabulations of possible levels of service:[65]

---

[63] A.M. Lee, Applied Queueing Theory, London, MacMillan, 1966.

[64] A. Deller, "The Use of Poisson Chain Techniques in the Solution of Practical Queueing Problems," AGIFORS Proceedings, 1968, p. 483.

[65] S. O'Broin, "Manpower Planning for Airport Operations," AGIFORS Proceedings, 1968, p. 245.

Standard	A Mean Waiting Time	B Prob. of wait $\geq$ 10 Min.	C Prob. $\leq$ 5% of waiting
1.	1.5 min.	5%	10 min.
2.	2.0 "	10%	15 "
3.	4.0 "	20%	25 "

In the table above, columns A, B, and C are alternate methods of setting standards. They do not necessarily apply simultaneously, but Aer Lingus decided to investigate A and B. Data required included aircraft schedules, expected passenger loads, arrival pattern by flight, average group size, service time by passenger group and service time distribution. For baggage registration the day is divided into five-minute intervals, "i". The distribution for arrival pattern is given as P(t - i), the proportion of arrivals during interval "i" for departure at time "t". Of those that catch the flight, it was assumed that P(j) is zero where j = 36. (Nobody arrives more than three hours early).

Service time distribution was found by observation. It was well approximated by an Erlang distribution. Similar analyses were made of the ticket desk, and departure gate. Validation was intuitive on the basis of informed judgement. Having thus specified staff requirements through the day for specified levels of service, the next step was shift scheduling in compliance with the union agreement.

Figure 8 shows the staffing process. Some re-allocation of surplus may be possible in order that surpluses be more uniformly distributed across the shift. The second phase of staffing was to make weekly cycles for days off.

$$N = \frac{1}{5} \sum_{j=1}^{7} \sum_{i=1}^{n} N_{ij}$$

where N = staff required

i = shift number

j = day of week.

N_{ij} is the number of staff on shift "i", day "j", N, larger than N_{ij}, includes allowance for working five days out of seven. In the N x 7 staffing array, each column represents a day of the week, and each row represents one staff member. To obtain a legal configuration, one or two staff members may be added. The method need not be described in more detail here. The experienced judgement of operating staff was the main validation of the analysis, and the analysis was considered adequate.

The same problem was studied by KLM at Schiphol Airport, where queues were multi-service, first-come-first-served, with observed Erlang 8 service characteristics.[66]

---

[66]W. Jensema, "Passenger Handling Model," AGIFORS Proceedings, 1967, p. 52.

INDEX	START OF SHIFT	TIME	REQUIRED NO. R	R1	R2	R3 or -S	SURPLUS S	NUMBER REPORT
1	t_1	0800	3	0	0	0	0	3
2	t_2	0900	7	4	-2	-2	2	6
3		1000	7	4	-2	-2	2	
4		1100	9	6	0	0	0	
5	t_3	1200	8	5	-1	-1	1	0
6		1300	7	4	-2	-2	2	
7		1400	5	2	-4	-4	4	
8		1500	3	0	-6	-6	6	
9	t_4 T_1	1600	2	2	-4	-8	8	4
10	T_2	1700	3	3	3	-1	1	
11		1800	4	4	4	0	0	
12		1900	3	3	3	-1	1	
13	T_3	2000	3	3	3	-1	1	
14		2100	2	2	2	-2	2	
15		2200	2	2	2	-2	2	
16		2300	1	1	1	-3	3	
17	T_4	2400	0	0	0	0	0	

Start Times — Finish Times

R(i) max for $t_1 \le i < t_2$, i.e. $1 \le i < 2$, is 3. $N_1 = 3$. For $t_1 \le i < T_1$, subtract 3 from R(i) to get column R1.

R1(i) max. for $t_2 \le i < t_3$, i.e. $2 \le i < 5$, is 6. $N_2 = 6$. For $t_2 \le i < T_2$, subtract 6 from R1(i) to get column R2.

The max. value of R2(i) for $t_3 \le i < t_4$, i.e. $5 \le i < 9$, is -1, which is less than zero. Therefore N_3 is zero.

R2(i) max. for $t_4 \le i < 17$, i.e. $9 \le i < 17$. os 4. $N_4 = 4$. For $t_4 \le i < 17$, subtract 4 from R2(i) to get column R3.

All elements in column R3 are less than or equal to zero, so staffing is complete. R3(i) is the negative of the surplus at time i.

Figure 8 Sample Shift Scheduling Program. (From the <u>AGIFORS Proceedings</u>, 1968, p. 257.

Determination of the inter-arrival time distribution was the key to the solution, and the development was more theoretical than the approach taken by Aer Lingus, but the theoretical development was based on the assumption that inter-arrival times were negative exponential.

The KLM study was made prior to the Aer Lingus study, but M.A. Foley of Aer Lingus pointed out that the assumption of negative exponential inter-arrival time distribution was contrary to Aer Lingus experience. While this did not invalidate the KLM model, Mr. Foley made the point that little is gained by sophistication of a model if a simpler approach gives accuracies in the order of ten per cent. He stated that, " . . . fast simple solutions are quite adequate in practice even if they may not be technically respectable."[67]

Baggage Claim. A simple model for estimation of maximum numbers of passengers waiting for baggage and maximum baggage awaiting passengers has been described for typical airline terminals. Given the arrival rate of passengers, arrival rate of baggage, and the number of passengers, existing facilities can be assessed in terms of a new need--say traffic growth or the arrival of jumbo jets or the effects of cutting-off service at baggage claim for maintenance, or for other reasons.

---

[67] Ibid., p. 57.

This analysis resulted in simple expressions for the inventories of baggage and passengers and respective maxima. The assumptions were based on observations of actual conditions at Kennedy International Airport:

1. Passengers and baggage arrivals are random at uniform rate.
2. Bags and passengers leave immediately there is a matched set.

If a delay of time t is assumed, then the maximum queues are increased by the delay time multiplied by the arrival rate.[68]

Telephone Trunks were studied by Air Canada to evaluate the network capability in terms of service level. A model was developed to analyze any proposed network but not to optimize the system. Estimates of the number of rejected calls were made for networks proposed.[69] Inputs to the model included measured leg-flows and survey samples of calls from any source to its set of destinations.

From these inputs, the origin-destination patterns of traffic were obtained for the entire network. Estimation

---

[68] J.J. Browne, J.J. Kelly, and P. leBourgeois, "Maximum Inventories In Baggage Claim: A Doubled-Ended Queueing System," Transportation Science, Vol. 4, No. 1, February 1970, p. 64.

[69] A.T. Batey, "Some aspects of Telephone Network Design," AGIFORS Proceedings, 1967, p. 311.

of loss, (frustrated calls), was developed from Poisson and Erlang B models and validated by means of recording meters on one of the network points, recording call arrivals, terminations, and rejected calls. Observed hold-time distributions were significantly different from the theoretical.

Perhaps the reason for the difference was that the models were for steady state, while the system was actually subject to traffic fluctuations through the day. The model used only one ratio of source to destination and this too may have varied through the day. While admittedly simple, work sampling studies might provide a good measurement of real conditions in the system. Calls could be originated from any point to any point at random through several weeks, providing a statistical basis for estimation of rejected calls in the system.

Conclusions--Airline Production Models

Airline information systems deal with tremendous volumes of data, particularly in connection with reservations systems. Without computers it is doubtful that large airlines could have grown as rapidly as they did in the years 1945 to 1970.

Some of the largest commercial computer systems in the world in 1971 were operated by airlines. But computers alone do not make a good system. Real world complications may prevent adoption of technically attractive information systems. The United Air Lines on-line check-in proposals provided such an example. Efforts should be made to know *all* the requirements of a system before spending heavily on its development. System design considerations must precede hardware. Operations research models of computer systems can be used for exploration of system operating characteristics and for cost-benefit analyses.

Indirect benefits accrue from the abundance and timeliness of accurate computer output. Operations research can take advantage of reservations data to optimize booking procedures and revenues while maintaining prescribed standards of customer service.

Operations research analyses for manpower and facilities planning are used by several airlines, but much remains to be done. Future information systems should simplify and speed up the reservation process, particularly where information is transferred among different airlines. Integrated information systems, providing unit control packages in 1971 were still in conceptual stages.

The schedule is the heart of the airline, but it is the source of difficult management problems. Assignment problems, travelling salesmen problems and truck dispatch problems are familiar to those engaged in operations research, yet in real applications, solutions seem mainly in the future.

Scheduling by manual methods is "cut and try" until the deadline for implementation is reached. The best feasible solution discerned at deadline is implemented. Small airlines can and do schedule manually. Certain mandatory departure times, fleet size, route configuration, and connections impose binding constraints such that scheduling freedom is limited.

General computer solutions begin with a list of all *possible* solutions and an objective. Reasons for poor success in scheduling by computer have been suggested as one or more of the following:[70]

1. The model contains too many variables. The list of all possible solutions should be reduced. The method suggested: use common sense.

2. The solution method may be too elaborate. Enumeration, integer LP, dynamic programming, branch and bound, Balas' algorithm--are all elegant and adequate for small scale problems, but impractical for larger problems, such as airline schedules involving two thousand variables and one thousand constraints. Spitzer suggests using heuristics or approximation methods, or removing zero-one constraints--at least initially.

[70] M. Spitzer, "The Computer Art of Schedule Making," Datamation, Vol. 15, No. 4, April 1969, p. 84.

3. Solutions are inflexible. Any change of parameters requires a complete reworking of the problem. To reduce the inflexibility of a solution, partition the problem by sensible geographic split of customers. Changes in one area may not affect the rest.

In 1971, schedule building was still mainly a manual task. Many applied models used for scheduling were checking routines for comparison of alternatives, or feasibility checks with respect to maintenance and the like.

Customer service at check-in and at baggage claim has been the object of apparently successful queue analyses. Simplicity and technical imperfections in the models take preference over sophistication and rigor. This was often because precise formulation has led to solutions that in the past were too expensive, particularly when simulation models were employed. As computer and software capabilities improve the cost objections may be swept aside.

CHAPTER IV

AIRPORT OPERATIONS

Airport activities include servicing of arrivals and departures of surface vehicles, passengers, baggage, freight, and aircraft. The airport is a modal interface or a buffer between modes and between connecting flights, providing temporary storage or waiting areas in the intervals between arrivals and departures. Some of the storage is in the air space in the vicinity of the port, used to "stack" arriving aircraft until landing clearance can be given.

Airport operations related to passenger, cargo and baggage services are discussed in Chapter III. In this chapter, the main topics are airport design, air traffic control, and aircraft maintenance. Although all three topics are important to airline operators, generally only maintenance is directly under their control. The Federal Aviation Administration, (FAA), in the United States, and the Department of Transport, (DOT), in Canada, are responsible for enactment and implementation of regulations on safety, ground and air crew certification, navigation facilities, certain airport standards, air traffic control, airport funds for improvements, and sponsorship of research in these areas.

Airport Location

A detailed cost-benefit study should precede implementation of a great project such as a new airport. Research should include consideration of the importance of aviation to the economy of the region, the economic effects of a new airport, effects of the airport on real estate values, future passenger and cargo plane movements and general aviation traffic, airspace and port capacity, airport design, land use and ground transportation, traffic as a function of accessibility, climate, etc.[1]

The proposed Stansted site for the third London airport was found undesirable for six main reasons:[2]

1. Inadequate road and rail access for short haul traffic.
2. Poor situation with respect to passenger and cargo sources and with respect to principal air routes.
3. Air traffic control disadvantages expecially with respect to SST routings to the West.
4. Climate and visibility conditions.
5. Airline operating economy.
6. Conflict with other airports.

---

[1] Studies of the Site for a Third London Airport, sponsored by North West Essex and East Herts. Preservation Association, 1966. Alan Stratford & Associates, Air Transport Consultants Nicholson house, High Street, Maidenhead, Berks.

[2] Ibid.

Information required for analysis of proposed airports sites is largely of a demographic nature and is dependent upon routes and traffic both in the air and on the ground. Technical aspects of design, soil conditions and weather involve specialized engineering and meteorology. Airspace and port capacities involve some forms of queuing models as well as industrial engineering for passenger and freight handling methods and facilities.

In protesting the proposed Stansted site for London's third airport the aim was not to specify the best alternative but merely to show that Stansted was *not* the best site. The fact that this study cost about £25,000 in England prior to 1966 is an indication of the high costs of researching for major airport development. The social and economic consequences of site selection are enormous. It is significant that the Stansted study was financed entirely by voluntary contributions from residents and businesses in the area of the proposed site.

Facilities Design Considerations

Some interesting models and practical discussion of typical airport design considerations are found in Lee's book on Applied Queueing Theory.[3] Such queueing situations

[3] A.M. Lee, Applied Queueing Theory, London: Macmillan, 1966.

as taxiway traffic, terminal traffic, passenger movements, bus traffic, aircraft turn-round (minimum service interval between landing and next take-off), are included. Perhaps the most important message in Lee's book is that queue models are rarely applicable in text-book fashion because most real situations are too complex for convenient mathematical solution.

Simulations are useful for comparing alternatives where analytical models do not exist. Simulation may be the only practical way to model complex problems. The greater the penalty for error, the more valuable simulation becomes. But simulation can suffer from bias or from poor definition caused by oversimplification of the model. Another frequent objection to simulation is cost.

All component variables must be carefully examined. Distributions of arrival and service times must be derived. If these correspond with known distributions such as Poisson, lognormal, or Erlang, so much the better. They can be generated by high-level simulation languages as part of a standard routine. If not, Monte Carlo techniques are used to generate events in the simulation. The high cost of simulation arises from the fact that each run gives answers for a single set of conditions. In order to explore the solution space, many runs are necessary, each run being made under different chosen conditions. Having made several runs for various chosen conditions, the analyst tries to generalize the simulation results by means of empirical (analytic) relationships that will yield approximately the same solutions. This procedure is demonstrated in Chapter 15 of Lee's book.[4]

Approximations may be necessary to keep the costs of solution reasonable, or just to make a solution possible. Three approaches are available:[5]

1. Use oversimplified models. These are imperfect but simple and practical where great accuracy is not required.
2. Use a limited number of fairly elaborate simulations. Find empirical relationships between various factors, for use in general solutions.
3. Substitute an initial set of values in a complex formula and iterate to obtain solutions. Unmanageable functions sometimes may be expanded by power series, ignoring less important terms of higher order.

Avoiding Congestion. The need for solutions to airport congestion became generally apparent in the 1960's. At the large airports, large queues of sometimes as many as twenty-

---

[4] Ibid., p. 185.

[5] Ibid., p. 89.

five planes waited on runways to take-off while other planes circled sometimes for hours, waiting to land. Passengers walked a considerable distance, perhaps three quarters of a mile, from the parking lot to the terminal, and then hundreds of yards to the gate. Airport expansion to relieve existing problems is limited by considerations of finance, high land costs, and social resistance to noise and air pollution. Local, regional, and Federal governments suffer from inertia and from the pressures of lobby groups. Ground congestion can be reduced by limiting the number of vehicles permitted, and perhaps through reduction of airport staff. At large airports there are more than 30,000 employees. Congestion could be reduced by eliminating visitors and sightseers, reducing traffic peaks, improving access, the use of more public and less private transportation.

Another approach to the problems of congestion, is via airport design. Figure 1 illustrates a typical evolution of air cargo terminals. In this evolution, an airline faces two major decisions:[6]

1. To separate air cargo operations from the passenger terminal.
2. To establish one or more off-airport consolidation terminals.

---

[6]Schriever and Seifert, Air Transportation 1975 and Beyond: A Systems Approach, Cambridge Mass., MIT Press, 1968, pp. 376, 377.

1. INTEGRATED
PASSENGER/CARGO
TERMINAL

2. SEPARATE CARGO FUNCTION
AT PAX TERMINAL

3. MULTIPLE AIRLINE
SHARED CARGO TERMINAL

4. INDIVIDUAL
AIRLINE CARGO TERMINAL
ON-AIRPORT SITE

5. OFF-AIRPORT
CONSOLIDATION TERMINAL

6. SEPARATE
CARGO AIRPORT

7. SEPARATE
CARGO AIRPORT
WITH
OFF-AIRPORT CONSOLIDATION
TERMINAL SYSTEM

Figure 4.1 Cargo Airport Evolution.
(from Schriever and Seifert, Air Transportation 1975 and Beyond, A Systems Approach, p. 375.)

If traffic peaking could be eliminated, a certain amount of congestion might be avoided. Preferential fares reduce traffic peaks, but many, if not most travellers are on business trips and are less likely to be influenced by off peak fare reductions.[7] Larger aircraft reduce the number of movements at airports. In the New York area, passenger traffic increased 144 per cent between 1958 and 1967. In the same period, aircraft movements increased by 52% and the schedule day increased on average by more than two hours by operating earlier and later.[8] Rescheduling to avoid peaks is often very difficult. Crew layovers and flight connections may interfere. A typical example was an American Airlines flight leaving New York at 5:45 for Dallas, making connections with 63 other flights in the two cities.[9]

General air traffic, (small private and business aircraft), could be discouraged from using busy airports at peak hours if landing fees were charged in proportion to demand.[10] While this would ease air traffic peaking, it is not a cure for the long-term capacity problem of continued rapid traffic growth. Between 1968 and 1975 passenger

---

[7]Melvin A. Brenner, "Public Demand and Airline Scheduling," Air Transport Association Paper, 1968, p. 9.

[8]M.A. Brenner, op. cit., p.6. [9]Ibid., p. 31.

[10]W.D. Grampp, "An Economic Remedy for Airport Congestion," Business Horizons, Vol. 11, No. 5, October 1968, pp. 21-30.

traffic was expected to grow from 150 million to 300 million passengers carried annually, and by 1980 the figure was estimated to be 450 million.[11]

Living With Congestion. Runway use can be modified by means of priority rules aimed at chosen objectives. A queueing model for runway waiting time has been developed to include consideration of waiting time for different classes of users.[12] For example, priority rules might be variations of the following:

1. First come first served.
2. Landings have priority over departures, but first come first served in both groups.
3. Priority by aircraft type to minimize average delay.
4. Priority to minimize average delay cost.

Average delay is not very sensitive to these rules, but total delay cost can be affected. At a busy period, small aircraft would have to wait until all the larger aircraft had been serviced. Presumably the least cost is a desirable social objective. A discipline other than first

---

[11]S.G. Tipton, "Airline Challenges of the Future," Datamation, Vol. 15, No. 3, March 1969, p. 22.

[12]G. Pestalozzi, "Priority Rules for Runway Use," Operations Research, Vol. 12, No. 6, 1964, pp. 941-950.

come, first served would be required. Complicated service rules would require computer assistance, particularly if queues became large.

Simulation models for airports embrace the main airport operations, many of which are queueing situations.

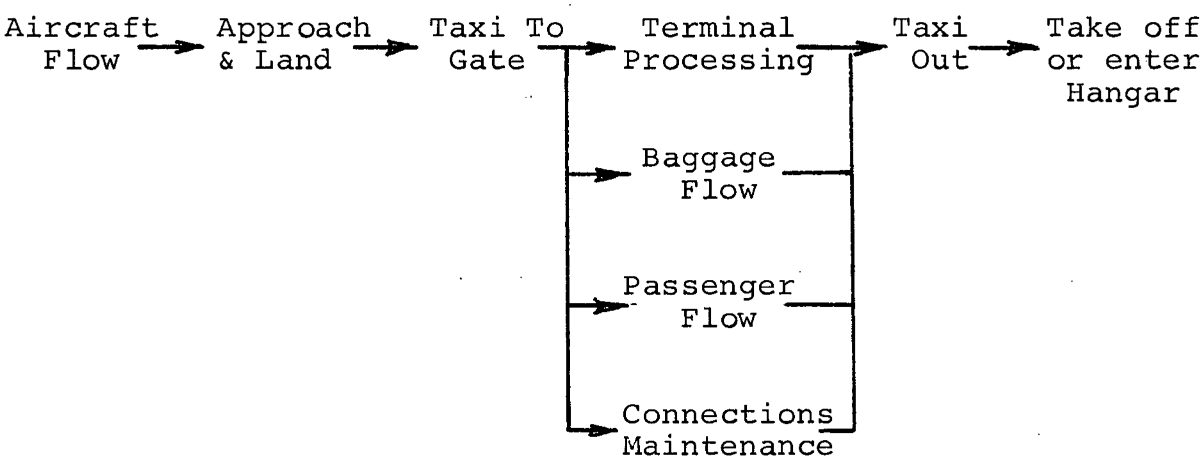


Figure 2 Schematic traffic flows

The difficulty with an overall simulation is the size of program and the computer facilities required.[13] This type of model is practical for a single airline operation at a large airport, but not necessarily for total airport operation. Simulations are used to approximate many operating features such as:

---

[13]K. Mountjoy, Airport Simulation Models, <u>AGIFORS Proceedings</u>, 1969.

- per cent of flights waiting over ten minutes at gate.
- baggage delivery, average minutes.
- per cent of flights missing connections.
- capacity of runways.
- effects of port configuration on taxi times.
- effects of policies, priorities, on waiting time and service.
- effects of increasing traffic volumes.

Individual simulations have been designed to evaluate proposed terminals and tractor allocations. A model for O'Hare airport was made to estimate the number of aircraft waiting in holding areas, frequency distribution of times taken to reach terminal gates, and frequency distributions of ramp times for departing flights.[14]

Models can be built on outputs of other models. Given time of flight arrival, number of passengers deplaning, time of first bag arrival in claim area et cetera, secondary models can represent say, space requirements for specified service levels in baggage claim, baggage check-in, ticket counters and the like. A danger in the profusion of models from a number of original assumptions is that the models may grow further from reality at each stage. However, model

---

[14] Ibid.

outputs, if *consistent*, whether high or low, can provide a means for ordering alternatives. If the model is validated in terms of existing operations, then differences between the model output and reality can be taken into consideration in assessment of outputs for alternatives.

Air Traffic Control

Although operated by government, air traffic control, (ATC), is vital to the airline companies. ATC plays a role that affects the safety of the air traveller. Safety is sometimes given as a reason for *not* flying, despite statistics that show flying to be less risky than highway travel. Books, such as Airport,[15] magazine articles about flying safety and celebrities who refuse to fly, all tend to keep the public aware of the "risk" they take when they board a plane. There are risks in flying, as the records show. In 1959, there were 5,000 aviation accidents that resulted in the deaths of 4,000 pilots and 3,000 passengers. Obviously, these accidents involved few airline incidents, and the causes of the accidents were certainly not mainly due to ATC deficiencies. Nevertheless, in 1961, the U.S. Task Force on Air Traffic Control pointed out deficiencies in the ATC

---

[15] A. Hailey, Airport, New York, Doubleday, 1968.

of that day, due to separation standards (not on radar control), mixtures of instrument and visual flight rules, (IFR and VFR), separation not controlled for VFR aircraft, outmoded radar at terminals, and complex holding, reporting and clearance routines.[16]

Government action to improve ATC is limited by technical obstacles, such as the need for international standards for equipment and procedures and evolutionary conversion standards for equipment and procedures. Noise abatement limitations on airport ingress and egress, human limitations of controllers, and flight crews, weather conditions, snow removal, etc., all add to the difficulties. Satellite weather observation has led to improved forecasting, but improvements are needed in the ability to detect and react to turbulence, icing and poor visibility.[17]

Many of the needs for improved ATC appear to be methods and equipment oriented, yet the continued use of human controllers provides some fruitful areas for operations research. The need for ATC can be forecast in much the same way that total air traffic is forecast. As forecasting models have been discussed in Chapter II, they shall not be discussed

---

[16] Report of the Task Force on Air Traffic Control, 1961.

[17] B.A. Schriever, W.W. Seifert, op. cit., p. 281.

here. Other models have been made to represent collision risks for aircraft and ships.[18] These are not properly airline models because they deal with problems that are the responsibilities of government. Below, two models that deal with controller capacity are briefly described.

A.T.C. Workload Time Model (Enroute).[19] Controllers duties may be considered as *routine* and *conflict* workloads. The routine workload includes acceptance from and handoff to other en route controllers, routine communication with aircraft and related clerical functions. The conflict workload arises from interaction between aircraft in flight.

For a given controller, routine workload time may be expressed as:

$$R_T = \frac{K_1 N}{T}$$

where K_1 = average time spent per aircraft for routine control

N = number of aircraft under control at any time

T = average time that an aircraft is under control

---

[18] L. Stachtchenko, "An Investigation of Collision Risks Over the North Atlantic," Canadian Operational Research Journal, Vol. 3, No. 2, 1965.

[19] M. Rosenshine, "O/R in the Solution of ATC Problems," Journal of Industrial Engineering, Vol. XIX, No. 3 March 1968, p. 122.

Conflict can occur among all possible aircraft pairs, N(N-1)/2, or, more approximately, as a function of N^2. This function could be expresses as:

$$C_T = K_2 \alpha N^2$$

where K_2, α are constants.

Then overall workload time would be:

$$L_T = \frac{K_1 N}{T} + K_2 \alpha N^2 .$$

Since N varies with time a more appropriate expression would be:

$$E(L_T) = \frac{K_1}{T} [E(N)] + K_2 \alpha [E(N^2)]$$

where E(N) = expected value of (N).

Using industrial engineering measurements to establish the constants, and considering the variance of the expression (in this case on assumed normal distributions), the components of workload were combined to yield the required number of controllers. The expected workload is given by:

$$L_T = \frac{N}{30} + .5 \alpha N^2 \quad \text{(minutes/minute)},$$

and $.0008 < \alpha < .0025$, depending on the route airspace structure.

Because of the N^2 term, the conflict component becomes more significant with traffic build-up. This model measured the workload and indicated the number of controllers required under given traffic conditions.

A.T.C. Communication Model (Terminal).[20] At the terminal, aircraft arrive and land, or taxi and tak off. The controller clears a waiting aircraft to land, and notifies other waiting aircraft in ascending altitude sequence to descend by one level. Service times (between release of successive aircraft from the sector) is evidently a function of the number of aircraft in the sector.

If aircraft arrivals are Poisson and the release of aircraft is stochastic, depending on the number of aircraft in the sector the sector can be represented as an imbedded Markov chain.[21] Change of state probabilities are represented mathematically in rather complicated fashion, arriving at a queue model for the controller. For such a model a queue *limit* can be calculated, such that the probability of emptying the queue is kept close to unity, (say $\geq .90$).

[20] Ibid., p. 126.

[21] F.S. Hillier and G.J. Lieberman, Introduction to Operations Research, San Francisco, Holden Day, 1967, p. 438.

This model has been validated by trials based on observed traffic intensity in actual sectors. Effects of tandem queues and extra controllers have also been studied.

Fleet Maintenance

Maintenance planning is an important phase of airline management. Operations Research has been applied to inventory control, workload forecasting, scheduling and shop methods. As a planning tool, simulation has been applied by several airlines.

The development of computer systems for maintenance applications was discussed as an O/R problem in a paper by F.P. Wallace.[22] Typical development is haphazard in the early stages of computer application. "Pet" projects and individual systems proliferate without regard to duplication or general system structure.

Specifications for integrated systems may require detailed knowledge beyond the capability of any individual. A committee may be required but the danger in a committee is that each member will insist upon maintaining his own program in every particular. One aim of integration should be to reduce input by making efficient use of data banks in the

---

[22] F.P. Wallace, An O/R Approach to the Definition of Computer System Requirements in Airline Maintenance, AGIFORS Proceedings, 1969.

system. O/R people with expertise in network theory should be competent to coordinate systems development.

Using CPM/resource Allocation, Wallace states that an integrated system design requires the following inputs:

1. Segments or implementable packages.
2. Activities making up each segment.
3. Manpower resources to make up each segment.
4. Elapsed time estimate for each activity.
5. Sequence relationships between segments.

Instructions based on the above would be subject to errors of judgement because they deal with unknowns that can be over or under-rated. The attempt to take a broad overview is nevertheless worthwhile. It is more characteristic of organizations experienced in computer systems work, that development of systems is planned. For the beginner, who has a completely clear slate, some initial experimentation with "pet" projects is inevitable.

Shop Planning. American Airlines developed a simulation model to predict workforce overtime, inventory levels and backlog under various proposed operating rules. Simulation can evaluate the effects of new facilities, changes in the workforce or in the work load.[23] Simulation is user

[23] F.P. Wallace, An O/R Approach to the Definition of Computer System Requirements in Airline Maintenance. AGIFORS Proceedings, 1969.

oriented. The user may propose policies that are reasonable in the light of experience. By varying the policies and observing the simulated effects, the user has the opportunity to arrive at good rules of operation without the cost and delay of trial and error in the shop.

While simulation can provide good evaluations of alternate policies, it is usually expensive and complicated. Updating for changes in fleet size or composition, shop procedures, collective agreements, shop facilities, can be costly. Despite its tendency to have a limited life, simulation is used by several airlines for maintenance shop planning.

Simulation was used by Air France to find the relationship between technical manpower and regularity of flights as well as to test alternative overhaul structures.[24] Synthetic outputs of operations indicate regularity of operations, per cent cancellations and delayed departures, overhaul duration, maintenance crew utilization, hangar space utilization, and numbers of aircraft waiting for hangar space.

A simulation model for maintenance management information was developed in 1969 by KLM Royal Dutch Airlines to economize maintenance manpower. Using manual solution

---

[24]J. Vautier, Report on the Caravelle Simulation, AGIFORS Proceedings, 1968, p. 426.

methods, each calculation took about two weeks. This was shortened to a few minutes on the computer. Manpower allocations were made from a tremendous range of possible allocations by means of an algorithm that set lower upper bounds for hours worked, on the basis of least sums of squares of hours allocated.[25]

This model, in addition to allocating maintenance man hours could be used to suggest alternate flight schedules. Manual methods were too slow for a feedback to the flight scheduling process but the speed of the computer assessment strengthened the ability of the maintenance group to influence flight scheduling for overall company benefit.

Maintenance Workload Forecast. Maintenance forecasting is easy for scheduled service operations. The intervals between major overhauls and checks are laid down in terms of flying hours. Given the aircraft schedule it is a routine procedure to list these maintenance activities. Non scheduled maintenance is more difficult to forecast. On new aircraft and engines reliability is not known. As experience is gained, reliability data are accumulated.

---

[25] B.J. Verdoes,"Manpower Leveling for Medium and Long Term Planning Purposes, AGIFORS Proceedings, 1969.

Reliability tends to improve with accumulated service experience. Modifications in design are the typical engineering response to repetitive component failure, and pre-failure detection of trouble can sometimes prevent the need for extensive maintenance.

In 1967 Eastern Air Lines in cooperation with IBM were trying to develop a practical system for recording performance data on aircraft in service.[26] A Boeing 707 was suitably wired, a recording system was installed to track 120 engine parameters. A program was developed to convert the recorded data to engineering data for validity checks, and trend analysis. This program encountered difficulties with the recording hardware. Cost information for implementation and for running the system was not given but it appears to be relatively expensive.

United Air Lines attempted originally to forecast, engine repair and maintenance workload by means of simulation.[27] This approach was rejected for several reasons. Long run-times for repeated simulations, the need for large computers, extensive reprogramming for maintenance policy changes, and tedious input preparation--all tended to make simulation

---

[26]V.D. Mackle,"Airborne Integrated Data System (AIDS)," AGIFORS Proceedings, 1967, p. 320.

[27]F.S. Nowlan,"Some Topics Pertaining to Engine Management, AGIFORS Proceedings,"1967, p. 171.

unattractive for engine workload forecasting. A mathematical programming approach was taken instead.

Intervals between overhauls increased as experience was gained with an engine type. United Air Lines' Turbine Engine Reliability Program, (TERP), selected sample engines from among the oldest engines in service. The sample engines were closely inspected and repaired as necessary. The aim was to extend the interval between overhauls as long as reliability indications continued favorable. TERP samples were taken at a specified annual rate that allowed fluctuation in the number of engines selected month by month. There was no hard overhaul time limit; samples could be chosen from engines that were within 200 hours of the oldest. Some prematurely removed engines were thus allowed as TERP samples.

Engine removal frequency gradually declined as reliability data accumulated from TERP sampling. Reasons for removal were grouped. By projecting the engine age distribution for future twenty-eight day periods, the number of removals were forecast as a function of engine life in service. Forecasts for 1967 through 1980 for twenty-one fleets and twenty-eight day intervals ran twenty-six minutes on the computer.

United Airlines' approach was installed because it worked. It was not a sophisticated development, but it appeared to do the job reasonably well. The overhaul interval was gradually extended, and the overhaul workload was smoothed because of the flexibility of the TERP program.

A different approach is seen in Air Canada's maintenance simulation.[28] The aims of the simulation were to forecast material usage and to evaluate maintenance policy in terms of material usage.

The model simulated inherent performance characteristics of 118 assemblies and 6,000 individual components. Five-year runs replicated ten times ran three to five hours on an IBM 1410 computer. Results included: average number of components accepted and repaired, number of components scrapped and reasons for same, number of replaced components, and engine events summarized by month.

This simulation presumably suffered from the inadequacies mentioned above in the discussion of United Air Lines' engine workload forecasting. It appears that very little is constant in engine reliability expectations, (except that there tends to be a long run improvement).

Informed opinion is divided on the suitability of simulation as a maintenance forecasting method. Unless the objections have been considered, a decision to simulate could lead to disappointment.

---

[28]A. Bodnarchuk, Jeanniot, P.J.,"A Maintenance Simulation for Complex Assemblies", AGIFORS Proceedings, 1968, p. 373.

Maintenance Shop Scheduling

Repair work may be divided into priority classes according to the need for the item being repaired. If the repair is holding up a higher assembly, (for example an aircraft is waiting for an engine), the repair would be assigned a higher priority than repairs going to stores inventories.

Queue discipline affects the length of the waiting line. Three examples of queue discipline are as follows:

1. Jobs are sequenced according to process time, shortest first (SPT).
2. Jobs are sequenced in order of arrival (FIFO).
3. Jobs are sequenced with Longest process times first (LPT).

SPT leads to the shortest queues and the shortest average waiting time. LPT leads to the longest queue and the longest average waiting time. The SPT rule has a large variance in waiting time that will be unacceptable in some cases because of due dates. Providing that due dates constraints are binding in a *small* proportion of cases, two priority classes will serve to meet the due dates without causing large increases in mean waiting times.

To minimize the dollar investment in the queue, the jobs should be scheduled in increasing order of the index P_i processing time per dollar value of item.

Queues at individual work stations may be studied independently if they have Poisson inputs. The inputs to a particular work station are the cumulative outputs of other work stations, and for practical purposes the assumption that the cumulative outputs are Poisson is often justified.[29]

Simulation studies have been used to evaluate scheduling rules with respect to per cent of late jobs, lateness variance, mean lateness, and mean shop time. Scheduling to due dates, the objective is to minimize the overdue total. An example of such a rule is the SLPO, (slack per operation), given by:

$$\text{SLPO} = \frac{D_i - T - \sum_{k=G}^{g_i} p_{i,k}}{g_i - G + 1}$$

where D_i = due date, job i

T = present date

g_i = total number of operations in job

$p_{i,k}$ = process time for operation k

G = number of present operation (in process).

This rule minimizes the operating risk by scheduling jobs according to due dates. A comparison between SPT and a 50/50 combination of the two are shown in the following table:

---

[29] J.A. vanHamel, B.J. Verdoes, "Maintenance As A Cybernetic System and Application to Shop Scheduling," <u>AGIFORS Proceedings</u>, 1968, p. 281.

	% of Late Jobs	Lateness Variance	Mean Lateness	Mean Shop Time
SPT	5.0	2878	44.9	34.0
SLPO	3.7	226	12.8	66.1
SPT/SLPO	1.5	232	14.0	57.6

Improved performance to due date is at the expense of increased shop time with SLPO rule. Doubt is cast on the whole table because of the results given for the SPT/SLPO. The objective of SLPO is to minimize the percentage of late jobs. It has been pointed out that the combined rule, SPT/SLPO, can not provide better operating risk than the pure SLPO rule because the objective of the SPT rule is *not* to reduce operating risk, but to minimize investment in the queue.[30] However, if more than one job is late, then it is conceivable that an SPT schedule for late jobs would reduce the number of late jobs just as it reduces the number waiting in any queue.

The SLPO rule minimizes risk in a sense, but it does not weigh jobs according to importance. Assume there are two late jobs, A and B. Loss per day associated with delay of B is greater than for job A. It may be better to let job A finish later if this allows job B to be completed earlier, even though job A has a prior due date.

[30] M. Etschmaier, Comments on the paper "Maintenance as a Cybernetic System and Application to Shop Scheduling," AGIFORS Proceedings, 1968, p. 368.

Because job arrivals and job durations are probabilistic, simulation appears to be the most practical method for checking out a proposed shop scheduling policy.

Many objectives are desirable in job shop scheduling. P.Mellor lists twenty-seven.[31] No one has attempted to solve a problem that contains all these objectives. Even the priority of objectives varies with circumstance. Most of the real-life complexities are excluded from existing models. Blind adherence to a scheduling rule is therefore impractical. Production smoothing is one objective that seems out of place for an airline maintenance shop although United Air Lines' TERP program is a step in the direction of more uniform shop loading. Traffic varies by factors of about 3 to 1, between busy months and off-season months. During the busy summer period the aircraft are all in service. Maintenance is minimal. Most maintenance and repair work is done in the off season. Because a total systems approach is beyond the capability of present day computers, airline systems are built around the focal point of operations--the flight schedule. Other planning is peripheral to the flight schedule. An assessment of flight schedule requirements is made by the following formula for engine maintenance.[32]

---

[31] P. Mellor, "A Review of Job Scheduling," Operational Research, Vol. 17, 1966, p. 161.

[32] F.S. Nowlan, op. cit., p. 184.

$$IN = \frac{SS + IP - EI}{\sqrt{EI}}$$

where IN = index number

SS = the number of serviceable spare engines

IP = the number of engines (of a type) in process

EI = engines of one type/average shop cycle time for that type

A high index number signifies a strong inventory position. A low number corresponds to a need for replenishment. Each day, by calculating the index number for each engine awaiting overhaul, the schedule sequence is found. This rule is simpler than the SLPO sequence mentioned above, in that it selects an inputting sequence, but is not dependent upon detailed knowledge of every engine in the shop.

Empirically, it has been found that the average index number indicates the overall capability of the maintenance facility. A given number of spare engines will result in a certain average index number. If the number of spares is increased then the average index number is increased. The desired average index number was found by experience. At United, it was about 3.[33]

---

[33] Ibid.

Application of the index number can be particularly beneficial during a conversion program--as for example, in the introduction of a new engine, or for some general modification to a large number of engines. By reducing the index number to a safe minimum, on all *other* types of engine, a maximum effort can be applied to the conversion program, without disrupting necessary service elsewhere.

Engine Provisioning should minimize the sum of the following costs:

- stockouts or unfilled demand costs
- system management costs
- spare engine ownership costs.

To build a provisioning model, an evaluation of annual volume of overhauls, costs and flow times is essential:

- the number of scheduled and non-scheduled engine removals
- the time required to prepare, ship, repair and return engines sent for maintenance
- shop capacity constraints - (men or facilities)
- costs of owning spares
- costs of unfilled demand
- costs of overtime work
- costs of expediting in shop, or in transit.

A dynamic programming approach was developed by United Air Lines for maintenance of engines for its fleet of Boeing 727 aircraft.[34] The dynamic programming method is well described in the book by Hillier and Lieberman.[35] The engine logistics cycle at United is represented by Figure 3. Stages were numbered in reverse order. (The last stage of maintenance is Number 1). Stage 1 is defined by optimal allocation of serviceable engines for any number (between zero and twenty-one) of such engines and the cost of unfilled demand associated with each number of serviceable spares (between zero and twenty-one). Zero and twenty-one were considered to be the likely limits of numbers of serviceable spares.

Stage 2 does not affect costs and is resolved subject to criteria other than costs.

Stage 3 weighs the costs of overtime against the benefits of more serviceable engines, and reduced unfilled demand. As the stock of serviceable engines increases, the probability of unfilled demands decreases.

Stage 4 decides which type of engine goes next into the repair shop. This decision is based on the index number discussed above.[36]

---

[34]F.S. Nowlan, "Application of Dynamic Programming Techniques to the Management of the Engine Logistics Cycle and to the Determination of Spare Engine Requirements", AGIFORS Proceedings, 1969.

[35]F.S. Hillier and Lieberman, G.J. Introduction to O/R, San Francisco, Holden Day Inc., 1967, pp. 243-244.

[36]F.S. Nowlan, AGIFORS Proceedings, 1967, op. cit.

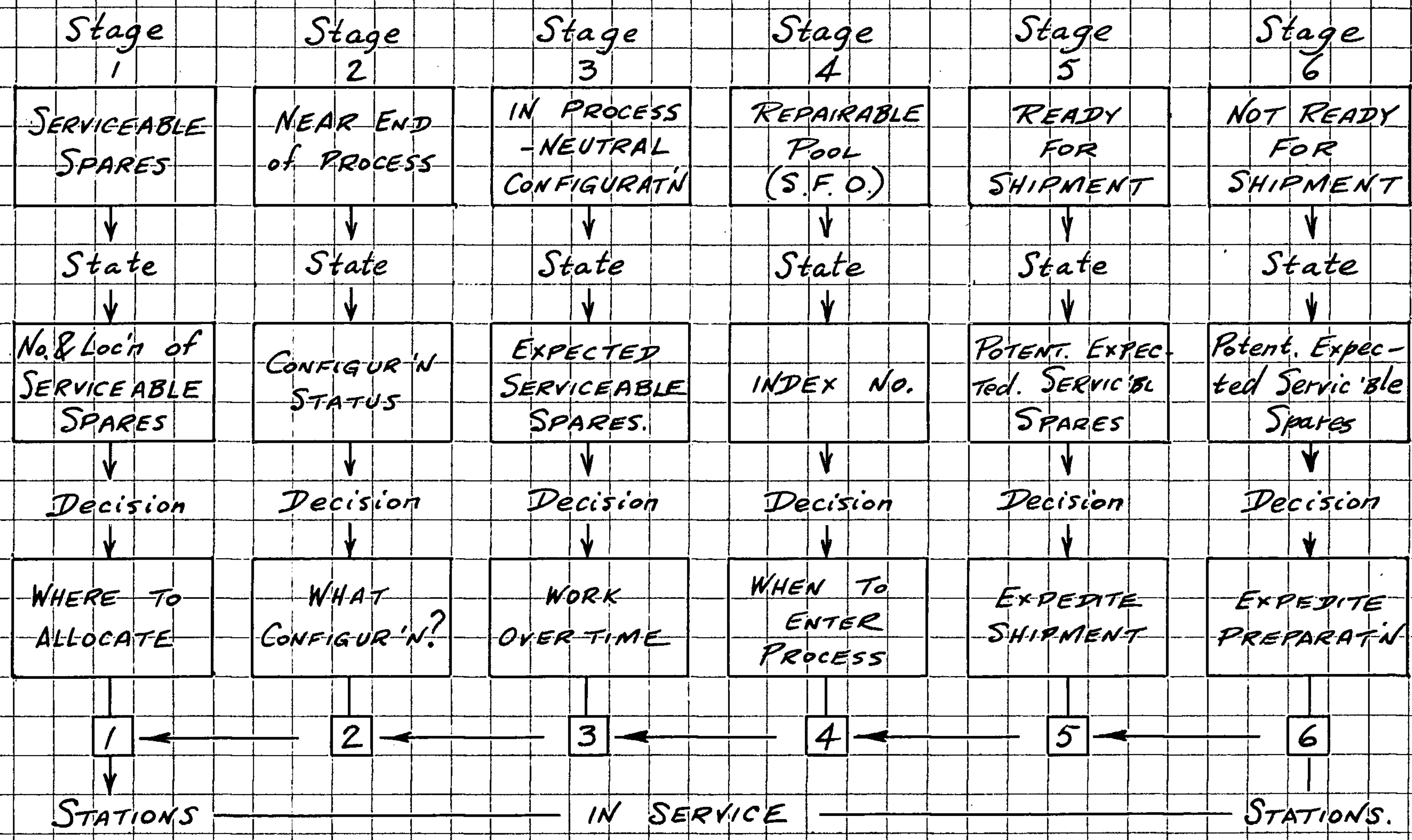


FIGURE 4.3 ENGINE PROVISIONING BY DYNAMIC PROGRAMMING.
(From F. S. Nowlan, AGIFORS Proceedings 1969.)

Stage 5 and Stage 6 weigh costs against benefits of expediting engines to the maintenance base.

Calculated total costs (of ownership and shortage) increased about 3 per cent if the actual number of spares was 7 per cent over or under the optimum. This programme was introduced by UAL in 1969. The approach was a practical illustration of dynamic programming in a day to day schedule operation.

An approach similar to the index number for engine sequencing was applied to Lufthansa's electrical shop scheduling. The objective was to minimize the risk of a stockout.[37] A variety of two-bin reordering was used such that when the reorder point was reached, a priority tag was generated for each item withdrawn from stock. The tags were attached to the most advanced spares in process in the repair shop so that these were completed with high priority and placed in stock as serviceable spares.

O/R In Shop Methods

Not many examples are available to illustrate the use of O/R in shop methods. Statistical quality control and programs such as TERP for evaluation of engine conditions

---

[37] M. Etschmaier, "Optimal Scheduling of Rotables Through the Electronics Workshop," AGIFORS Proceedings, 1968, pp. 516-533.

were, of course, shop uses of O/R, but these did not directly affect shop methods.

In some assemblies such as turbine blade sets there may be combinatorial problems created by strict design specifications. Nozzle guide vanes direct engine exhaust through the turbine. A set of vanes may be worth $8,000, (or $100 per vane). Depending upon certain measurements, vanes have a "value" that is subject to five conditions in an assembled set.

1. average set value must be within specified limits
2. maximum and minimum values per vane are specified
3. number of vanes per set is explicit
4. difference in adjacent vane values must be less than a specified maximum.
5. variations in a set should be uniformly distributed around the circle.

O/R investigation of this problem was invited by the materials planning department because of a growing inventory of vanes.[38] Despite large stocks of vanes, new vanes had to be supplied to match sets being assembled. To satisfy the five assembly conditions the easiest method was to choose

---

[38] J.C. Abbinck, "Nozzle Guide Vanes - a case study," <u>AGIFORS Proceedings</u>, 1967, p. 283.

vanes with values close to the average required for the set.

Details of the method need not be discussed here. A computer program was devised to compose the stock of vanes into sets that met all requirements. There was a time interval between stocktaking and computer output. The shop exchanged good vanes in order to build sets as dictated by the computer. This caused extra work because each vane had to be wrapped and boxed separately.

The solution was to stop regarding vanes as rotables. Instead, *complete sets* were rotated and the sets were matched as a stores function. The shop turned in a set with approved and rejected vanes and the store provided a matched set completely ready for assembly. The store was responsible to have one matched set available at any time.

"O/R is the art of giving bad answers to problems to which otherwise worse answers are given."[39] The dynamic inventory problem here was solved by a static solution. From the stock position at any moment, a number of possible set combinations were calculated. Only one set was made up. Whenever changes occurred in the stock, the calculations were repeated. One set was released and one more set was matched up for assembly.

---

[39] Ibid., p. 290.

Inventory Control Applications of O/R

Inventory control is aimed at the least total cost of procurement, holding, and stockout. The procurement interval or lead time, (the time elapsed between ordering, and receipt of order from the supplier), is not known with precision, and is generally variable. "Lead time usage" is the quantity required during the lead time. In practice, lead time usage is known only approximately. Ordering costs may be calculated, but the stockout costs are generally less well known.

An investigation of inventories of expendable parts at Swissair revealed that fifty per cent of the 61,000 items in stock had not moved in the preceding three years.[40] Consumption of many items was low and erratic. The natural question was whether or not rules could be found to reduce the total cost. If service could be improved without raising investment in inventory, or if the investment could be reduced without impairing service, an overall improvement would be attained.

Lead time usage may be distributed in almost any fashion. Variance of lead time usage is likewise of wide latitude. Target stockout frequency can be defined in terms

---

[40] W. Grassman, "The Calculation of the Reorder Level of Expendable Parts," AGIFORS Proceedings, 1968, p. 500.

of a specific time period, say, one stockout in ten years, or in terms of lead time, or order cycle. Computer systems such as IBM IMPACT automatically recalculate mean and variance of lead time consumption and aim at a percentage of demand met without delay, rather than a specified interval between stockouts.

At Swissair, a simulation was used to test proposed ordering rules. Consumption during a one-year period served as input and the simulation tested the proposed rules. Results indicated that the proposed rules would lead to a reduction of inventory while providing a very high service level.

Long engine overhaul cycles of 5,000 hours or more, indicate that a one-year history is too short a validation period. A single ordering rule, based on dollar value of items used, is probably unsuitable for some items in a complete range of stock. The consequences of stockout vary from trivial to disastrous, and other considerations such as fleet and schedule changes may affect the ordering rule. If such real factors are kept in mind, there is less danger of placing too much confidence in the specific output of the inventory model simulation.

Initial Provisioning. Initial provisioning for a new aircraft type is more difficult than inventory maintenance for a fleet with a reasonable service history. For each part, the manufacturer should specify price, delivery, usage rate, shelf life, mode of usage (during overhaul, during maintenance, etc.), end usage ("goes into"). The customer or user, in this case the airline, should estimate or specify fleet size over time, scheduled flying hours, abnormal overhaul rates during early months of operation, and locations of spares inventories.[41]

Overall fleet requirements may be broken down for spares allocations between the overhaul base and the field stations. A two-echelon model was used by American Airlines for rotable spares. (Rotables are normally reconditioned and re-used). This model was analytic and was predicated upon availability criteria set by airline policy.[42]

Sensitivity analyses of the models indicated that minimum stocks could be reduced without serious penalty to availability standards. Introduction of the new initial provisioning system, called RACE, was expected to reduce initial investment by 22 per cent on rotables and by 7 to 13 per cent on consumables (consumables are replaced, not repaired) while saving 30,000 man hours by means of automatic performance of previously manual functions.[43]

---

[41] H.E. Norwood, "An Initial Provisioning System and its Decision Models," AGIFORS Proceedings, 1969.

[42] Ibid.

[43] Ibid.

These forecasts were made prior to operating experience with the program. The assumptions made by the manufacturer and by the airline were fundamental to the prediction of savings, yet these assumptions, of necessity, had to be made without operating experience. This could invalidate the sensitivity analysis. About all that can be said here is that judgement errors should be documented as they become apparent, so that errors can be reduced in future programs.

Stocks may be divided between maintenance base and field stations. Two-echelon inventory models distribute stock among stores with the objective of minimizing total costs of: (1) ownership and (2) delays due to shortages.[44] The two-echelon model can be used to redistribute existing stock to achieve maximum item service level. Item service level and ownership level can be related for various transit times (between stores) and for various mean shop overhaul times. The two-echelon model optimizes item service level by seeking the best allocation of inventory among the various stores at the overhaul base and at the field stations. The solution was found by means of discrete optimization techniques.[45]

---

[44] NN. Amin, K.C. Khanna, "Sensitivity Analysis of Optimal Allocation of Rotable Spares," AGIFORS Proceedings, 1969.

[45] B. Fox, "Discrete Optimization via Marginal Analysis," Management Science, Vol. 13, No. 13, pp. 210-216.

"Item service levels" (or Item availabilities) vary according to (a) the total inventory level and (b) the inventory at the central (overhaul) base. TWA costs of overhaul, transportation and delays due to parts shortages were not available. The problem then was to solve for the most economic way to increase item service level. The alternatives available were (a) increase stocks, and (b) reduce replenishment time. The cost of increasing stocks by one unit was easily estimated. The two-echelon model could predict service level improvement resulting from such an increase. The model could also predict the reduction in replenishment time for the same increase in service level. It is a matter of judgement whether or not the reduced replenishment times could be achieved at less cost than increasing inventory, but for expensive items, with long overhaul times, this judgement should be made.[46]

Insurance Spares are aircraft surface, components stored as a safeguard against damage to airworthiness. Small airlines operating limited fleets can not afford to keep full sets of insurance spares. Instead they can buy access to spares. Arrangements vary, but spares may be available from the manufacturer, from other airlines, or from an airline pool.

---

[46] N.N. Amin, K.C. Khanna, *op. cit.*

The propability of damage requiring insurance spares has been found to fit the Poisson distribution:[47]

$$p(x) = \frac{\lambda^x}{x!} \cdot e^{-\lambda}$$

where λ = average rate of damage occurrences

x = (0,1,2,3,....), the number of occurrences.

Occurrence of damage has been historically confirmed as a regression of the form:

$$x = K_o + K_1F + K_2L$$

where the K's are constants

F = hours flown

L = number of landings.

Conceptually, two policies can be compared: Strategy (1), to buy a full set of spares or, strategy (2), to buy access to spares. Let A and B be fixed costs associated with the strategies respectively. If the expected average rate of damage is less than the breakeven rate of damage, μ, then strategy (2) is the more economical.

---

[47] J. Byrne, "A B747 Insurance Spares Strategy," AGIFORS Proceedings, 1969.

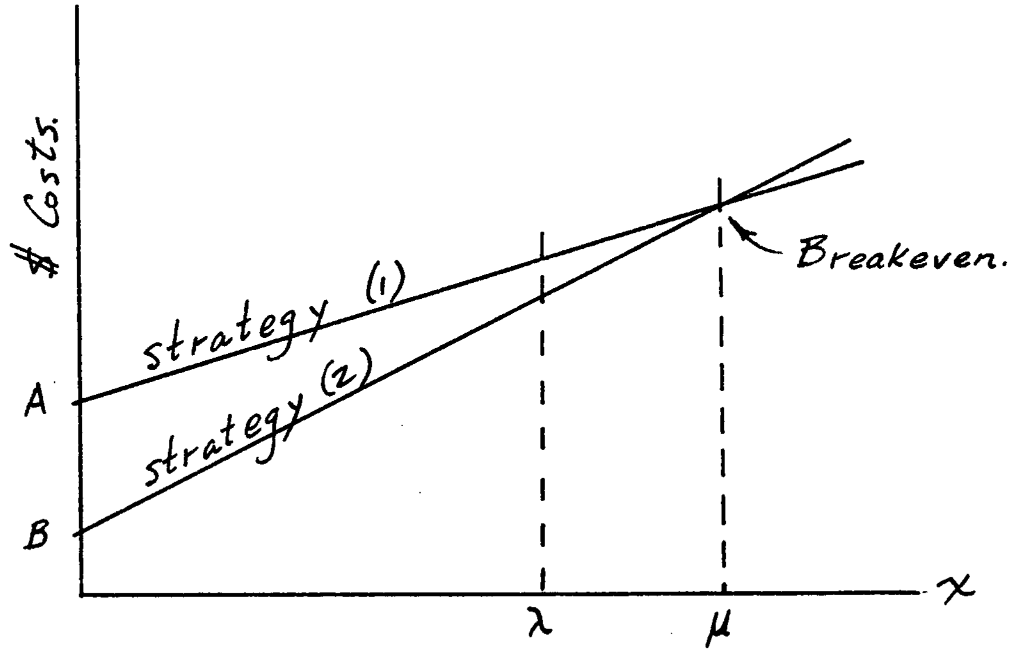


Figure 4 Insurance Strategies

The problem is to assess costs relative to the strategies. Factors that affect this assessment are fleet size and utilization, maintenance policy, route structure and frequencies, location of maintenance base. A factor favoring non-ownership is that damage may occur away from the maintenance base, in which case the spares might have to travel to the aircraft. In such a case, the advantage of ownership boils down to marginal cost of transit delays (between stores and repair sites).

Historical information on types and causes of damage and geographic occurrence of damage would help to quantify expected costs and benefits of alternative strategies. A simulation is conceivable as a solution approach. Intuitively a pooling arrangement with spares conveniently allocated to main ports of call should provide participating airlines with more insurance than they could provide individually. The problem then becomes a decision rule for the sharing of pool costs. Keeping such rules perfectly impartial would be difficult if routes and schedules were subject to change. However, as long as individual airlines gained from pool membership, the arrangement could be satisfactory.

Expendable Inventories present a somewhat different problem. Overhaul times do not affect the size of inventory required. The items are supplied by others. Economic order quantities can be found by means of the Wilson formula,[48] but the objective was to find the safety stock that maximized the service level over all items subject to:

- specified minimum service level for each item
- given total safety stock investment.

The dual of this problem is to minimize the total safety stock investment subject to:

- a given system service level
- a given minimum item service level.

---

[48]K.C. Khanna, A.V. Bhatia, Optimal Decision Rules for an Expendable Inventory System, AGIFORS Proceedings, 1967, p. 215.

The latter problem may be stated symbolically as follows:

$$\text{Min.} \sum_{i=1}^{N} R_i \qquad \text{(total safety stock investment)}$$

subject to: $\sum f_i(R_i, Q_i) \geq$ SSL (system service level)

$$R_i \geq 0$$

$$f_i(R_i, Q_i) \geq M_o \qquad \text{(minimum item service level)}$$

where R_i = dollar value of safety stock - item i

Q_i = Economic Order Quantity - item i

Care should be taken to observe the nature of the function f_i. If f_i is a non-linear function then the "dual" above is not a dual, but a related problem.

Service level can be expressed in several ways, for example:

A. Item: per cent of periodic item demand that is supplied without delay.

System: per cent of periodic system demand supplied without delay.

B. Item: -as for A. above.

System: an average of the item service levels in the entire system.

C. Item: probability of item demand satisfied during lead time cycle.

System: average of item service levels in the entire system.

Safety stocks exist to cover variations of requirements during the lead time interval, caused by high usage or longer than average lead times. Unlike economic order quantities that optimize gradually from both directions, the loss function associated with too small a safety stock is subject to an abrupt increase at the occurrence of a stockout.

The advantages of sophisticated inventory control systems may not be evident in the record of any single item. Over thousands of items in stock, however, good rules result in high performance per dollar invested. The effectiveness of rules depends upon the extent to which usage patterns are known. Because the future is uncertain, there is a tendency to under-rate advanced inventory control methods. Like the slot machines at a gambling club, individual winnings are impossible to foretell. The long run laws of chance on the other hand, are known with precision.

CHAPTER V

AIRLINE FINANCE

The Current Financial Picture

Adverse financial trends for airlines began in 1966. Revenue Passenger Miles, (RPM), increasing annually at a rate of 22.2 per cent in the second quarter of 1966, were still increasing, but at only 13.6 per cent per annum by the first quarter of 1969. The decline in the rate of increase in traffic was steady through this period. In 1969, it was expected to remain at about 11.1 per cent per year in the years 1969 - 1973.[1]

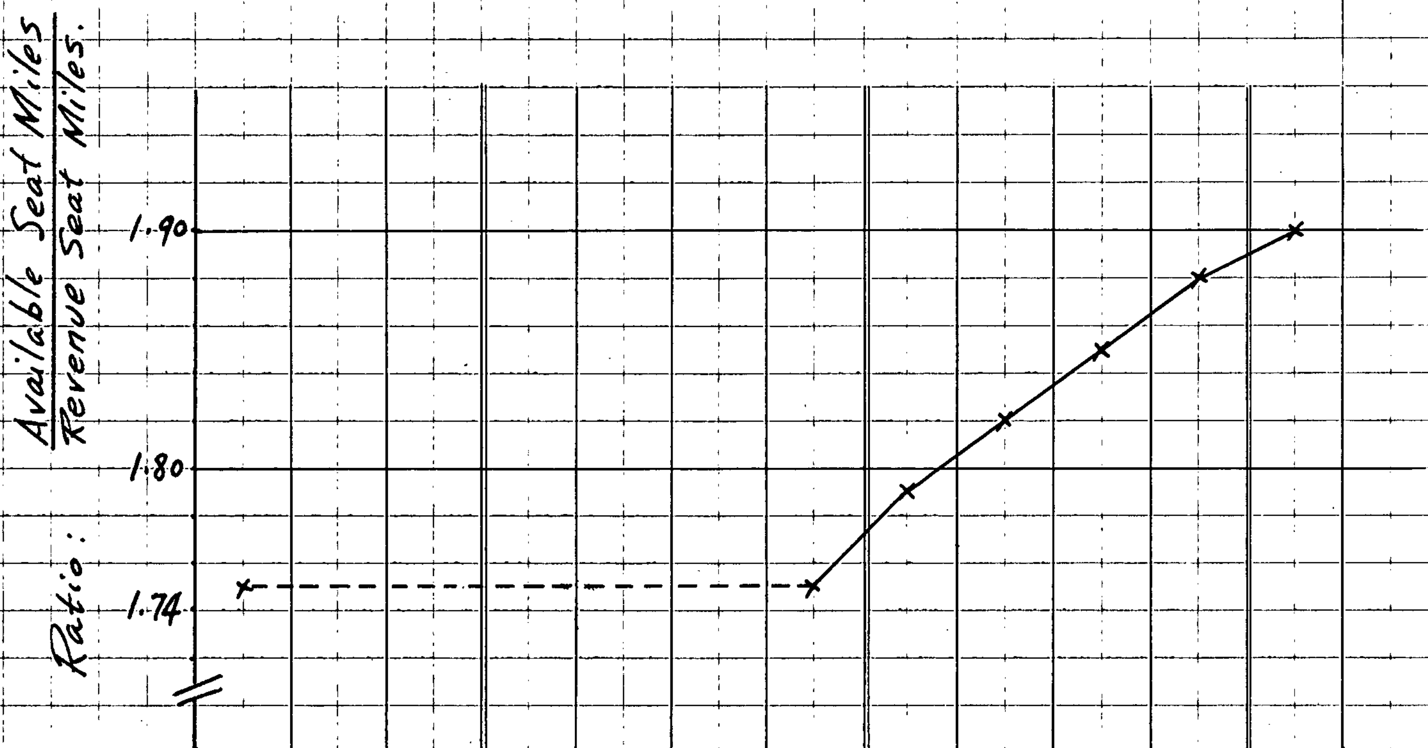
During the same period, available seat miles increased at an annual rate of 19.0 per cent initially, and grew to a rate of 24.6 per cent per annum in the first quarter of 1969. Earnings peaked at $412 million in 1967, then fell. Earnings in 1969 were $219 million.[2] Figure 1 illustrates how capacity grew faster than revenues.

At the end of 1970, airline costs were climbing annually at an estimated 8.6 per cent on average. About 8,000

---

[1]Major U.S. Airlines Economic Review and Financial Outlook 1969 - 1973, Air Transport Association of America, June, 1969.

[2]Ibid.



YEAR	1966			1967				1968				1969
QUARTER	II	III	IV	I	II	III	IV	I	II	III	IV	I
% ROI	12						7.8	7.1	6.4	6.1	5.3	4.7
A.S.M.	127.2						163.8	173.2	182.7	192.7	201.6	208.0
R.S.M.	72.6						93.4	96.5	100.4	104.1	107.1	109.6

FIGURE 5.1 CAPACITY Vs. Revenue Growth.
(From: Air Transportation Association of America: Major U.S. Airlines - Economic Review and Financial Outlook 1969 - 1973).

employees were laid off from scheduled U.S. airline payrolls in 1970 and there were 658 fewer flights in December 1970 than there were twelve months earlier. The Air Transportation association of America forecast $192 million loss for the twelve major U.S. carriers in 1971.[3] "In retrospect, it is difficult to understand why the manufacturers believed the airlines could absorb hundreds of expensive new aircraft within a relatively short period."[4]

How did the 1970 losses come about? Hardship seems particularly unnecessary in an industry that has prospered only recently, and that has enjoyed continued growth. Relative to the economy as a whole, the growth picture for airlines appears good for an unlimited future.

Did the 1970 airline situation have parallels in railways or in water transport? Evidently it did. In the 1800's railroad expansion in the United States was rapid and sometimes murderously competitive. Government intervention was necessary in the public interest because of "gouging" where railroads held monopolies.[5] In shipping world tonnage grew from 79 million in 1939 to 147 million in 1960,[6] and in the process, American shipping lost most of its dry cargo

---

[3] Aviation Week and Space Technology, Vol. 94, No. 2, 11 January 1971, p.

[4] Dan Cordtz, "The Withering Aircraft Industry," Fortune, Vol. LXXXII, No. 3, September 1970, p. 117.

[5] A.S. Boyd, "Government's Role in Transportation," Perspectives in Transportation, K.M. Ruppenthal, (ed.), Stanford, California, Stanford University Graduate School of Business, 1963, pp. 44-54.

trade to foreign competitors with lower costs.

Strong competition in fast growing capital intensive industries leads to some misallocation of resources. The airlines provide an example of growth industry competition subject to government restrictions. Three main interests are involved: the airlines in competition with one another, the government on behalf of the public served by air transport, and the financial interests supporting development of the industry. The financial interests are probably the most neutral. If their conditions are met, they can generally be counted upon to lend support.

> Banks look upon airlines with considerably more kindliness for short-term borrowings. One reason is that many of the larger banks have substantial loans out to the airframe manufacturers, and the health of the latter is closely dependent upon that of their customers. 7

Government, particularly in the united States appears more afraid of monopoly and excess profits or bureaucracy (in private enterprise) than it is afraid of excess competition and contingent industrial recessions. Airlines,

---

[6] S.B. Turman, "The Challenge to the American Merchant Marine," Challenge to Transportation, K.M. Ruppenthal, (ed.) Stanford California, Stanford University Graduate School of Business, 1961, pp. 161-169.

[7] Tom Alexander, "Is there *Any* Way to Run an Airline?" Fortune, Vol. LXXXII, No. 3, September 1970, p. 211.

realizing that the market is growing, are concerned with their long-run share of the market, and are inclined to fight a hard battle in order that they will ultimately survive.

Whether the existing arrangement is satisfactory is a question that involves tremendous study. No attempt will be made to answer this question here.

Factors Affecting Money Supply to Airlines

In the United States, federal controls of air transport cover entry, profit level, issue to securities, rates and fares, freight classifications, mergers, controls and directorate interlocks, service authorization and obligations, (use it or lose it), subsidies, equipment design, safety, working rules and other more technical matters.[8] An example of the Civil Aeronautics Board's pervasive control was order ER-586, that called for collection of traffic and capacity data on a flight stage basis and transmittal on magnetic tape or punched cards for use by the Board.

Airport expansion has been constrained by limited and undefined sources of financing, by rising land costs and social revulsion for airports in metro areas. Bureaucracy, weak local governments and local regional conflicts, lobby groups versus the "general good" and inertia--all tended

---

[8] K.M. Ruppenthal, Issues in Transportation Economics, Columbus, Ohio, Charles E. Merrill Books Inc., 1965, p. 3.

to impede development.[9] The new airport and Airway Development Act was expected to improve this situation in the United States by spending $840 million on airport improvements during 1971-1973. Forty five million dollars were slated for the planning effort.[12]

Ownership of the airlines was not precisely known. Holders of 5 per cent or more stock in major airlines were listed, but holder were often owners' representatives. Speculative swings in airline stocks in the 1960's, contributed to the difficulty in attracting equity capital.[11]

On two points, any company must guard against financial vulnerability. Firstly, excess investments in fixed assets will reduce current assets to the danger point--where it is difficult to meet current obligations. Secondly, the debt-to-equity ratio should not be allowed to grow beyond a safe limit. Creditors must be paid, but proprietors are entitled only to profits earned. In bad times, high debt capital means vulnerability. Liquidity was not considered a near-term crisis for U. S. airlines in 1970, but signs of potential capital problems were looming unless earnings were to improve. The long term airline debt in comparison with net worth grew

---

[9] B.A. Schriever, W.W. Seifert, Air Transportation 1975 and Beyond: A Systems Approach, Report of the Transportation Workshop, 1967, pp. 337, 355.

[10] J.E. Skinner, "Airport Development Money is Here," AirLine Management and Marketing, August 1970, p. 14.

[11] Airline Management and Marketing, June 1970, p. 32.

for U. S. airlines over the 1960's, and prospects for improved earnings in 1971 were not encouraging.[12]

Investment Decisions

Before financing an airline service, or making financial contribution toward the improvement of existing services, there should be some assessment of expected market and expected costs. Marketing, in response to management intuition or initiative, locates and assesses the market size. Cost estimates often come from experience. Airline accounts would be studied if the project were to increase or improve an existing service. If the service were to be started from nothing, check-lists of costs could be obtained from some reference on airline management.[13]

To test the projected cost estimate, comparison can be made with airline cost models. A paper by Eads, Nerlove and Raduchel,[14] demonstrates the extensive analysis necessary for a generalization of airline costs. A description of the model formulation is too long for presentation here. An analytic model is developed in detail for local service airlines, giving equations for: fuel costs, short-run

---

[12] A. Altschul, "Liquidity," Airline Management and Marketing, October 1970, p. 37.

[13] W.S. Barry, Airline Management, Geo. Allen and Unwin, London, 1965, pp. 203, 204.

[14] G. Eads, M. Nerlove, and W. Raduchel, "A Long Run Cost Function for the Local Service Airline Industry: An Experiment in Non-lenear Estimation," The Review of Economics and Statistics, Vol. LI, No. 3, August 1969, pp. 258-270.

variable costs, all other long-run costs, long-run total costs and a production function.

Cost analyses such as the study by Eads, Nerlove and Raduchel demonstrate the gulf between the analytic and the practical approach. While this study was not tremendously difficult from a mathematical standpoint, it nevertheless exceeds the grasp of many operating managers whose abilities grew from long experience in the industry, and who generally might not have the time to acquire in-depth familiarity with sophisticated mathematical models. If therefore, the model output were at variance with the judgement of experience, it becomes the analysts' task to reconcile the difference and to ensure that appropriate corrections are pointed out to the model builders or to the practical managers as required.

Fleet Planning, from the airline point of view begins with a choice of aircraft available. New aircraft types result from airline needs as seen by aircraft manufacturers. This is a circle of interacting industry needs. The manufacturers are concerned with needs of the airline industry as a whole, but each airline is faced with making decisions based on the needs of its own market and the limitations of its own financial resources.

Figure 2 is a very schematic illustration of the Lockheed Airline System Simulator.[15] The simulator "flies"

[15] Lockheed Airline System Simulation, Burbank, Lockheed publication CTR 2007, 1970.

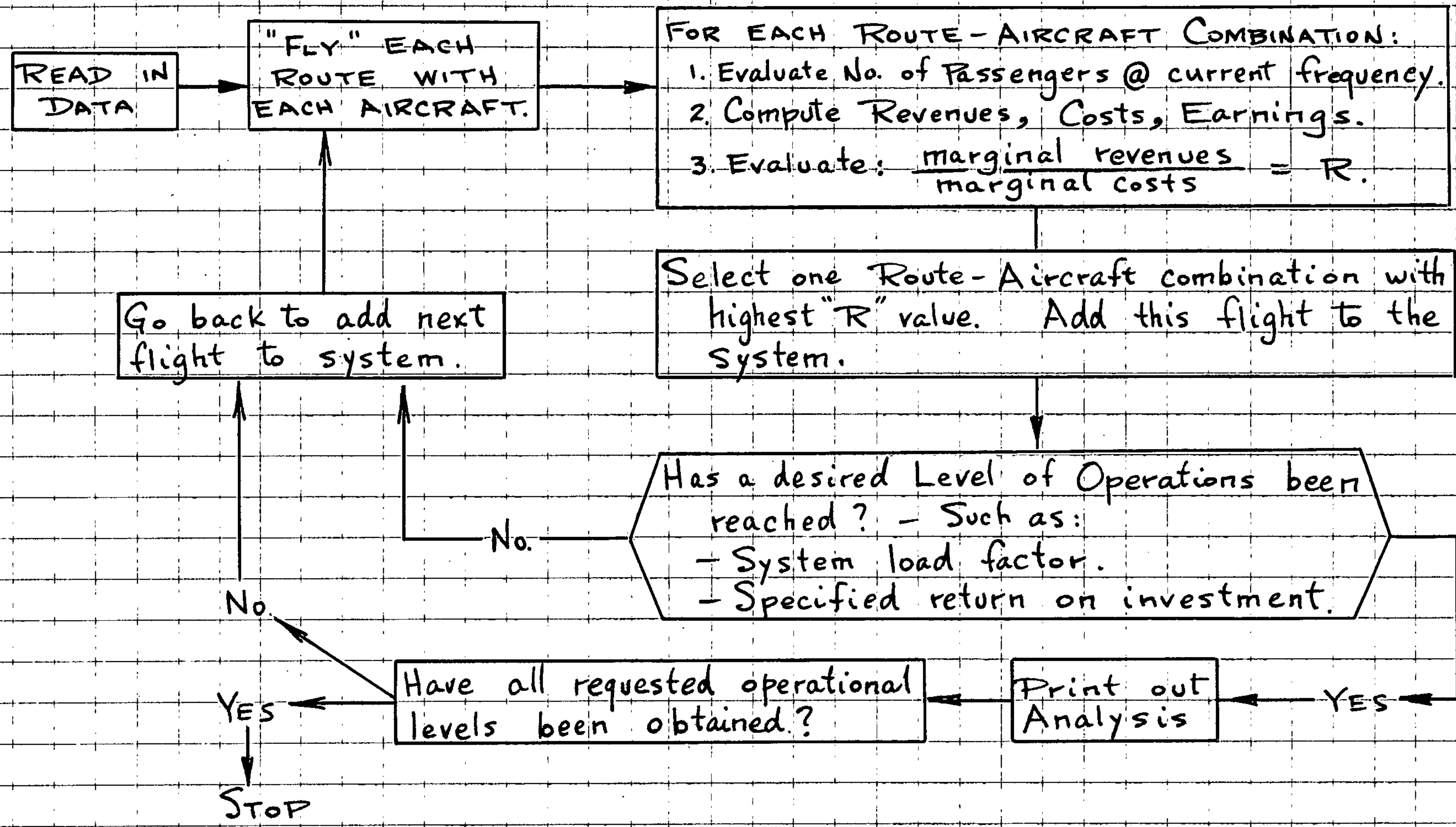


FIGURE 5.2 LOCKHEED AIRLINE SYSTEM SIMULATION.
(From "Lockheed Airline System Simulator," Lockheed Publication CTR 2007, 1970).

each aircraft within a given airline fleet over each route available to the airline, assigning the most profitable aircraft/route combinations. New flights are assigned until specified levels of operations are reached. The process normally continues beyond the point of maximum system earnings, because specified levels of operations are usually forced by regulation and by competition to yield no more than about a ten per cent rate of return. Input data are as important as the model itself. These data include aircraft operating characteristics, maintenance costs, capital costs, airline ground rules for maintenance, indirect costs such as landing fees, meals and handling costs, estimated wind conditions, all flying costs, taxi times, revenues, traffic forecasts, allowable load factors, and competition factors from other airlines, automobiles, etc.

The addition or removal of routes must be considered in terms of route interaction. Additional routes provide additional paths between origins and destinations. Profitability on a proposed new route may result in profit losses elsewhere in the system. On the other hand, the addition of unprofitable segments may augment profits on other segments, and evaluation should be made for the whole system rather than for its individual parts.

Competitive factors will affect market share and three approaches to market share analysis are as follows:

1. market shares are fixed
2. market share factors are variable for the airline under study.
3. market share factors are variable for the airline and for its competitors.

The Lockheed simulation uses assumption 2 and rejects 3 on the grounds that 3 would result in higher average load factors and more unserved demand in peak periods than would be the case using assumption 2. This is probably correct, but from the point of view of the airline industry as a whole, it could lead to overcapacity due to assumed benefits of expansion by the individual airlines. All competing airlines may try to enhance their own market shares by improving facilities and service. If competitors' actions are ignored, the airline under study may get an overoptimistic view of benefits from expansion. Model outputs are shown in Figure 3.

Purchase of new aircraft typically precedes delivery by two years. If an airline buys one large jet too many, cash flow and other investment activities are impaired. Douglas Aircraft Company sells aircraft with the help of an operations and planning model comprising of a number of sub-models dealing with aircraft performance, route performance, airport take-off analysis, schedule planning and evaluation, airline operating cash flow, econometric forecasting, economics,

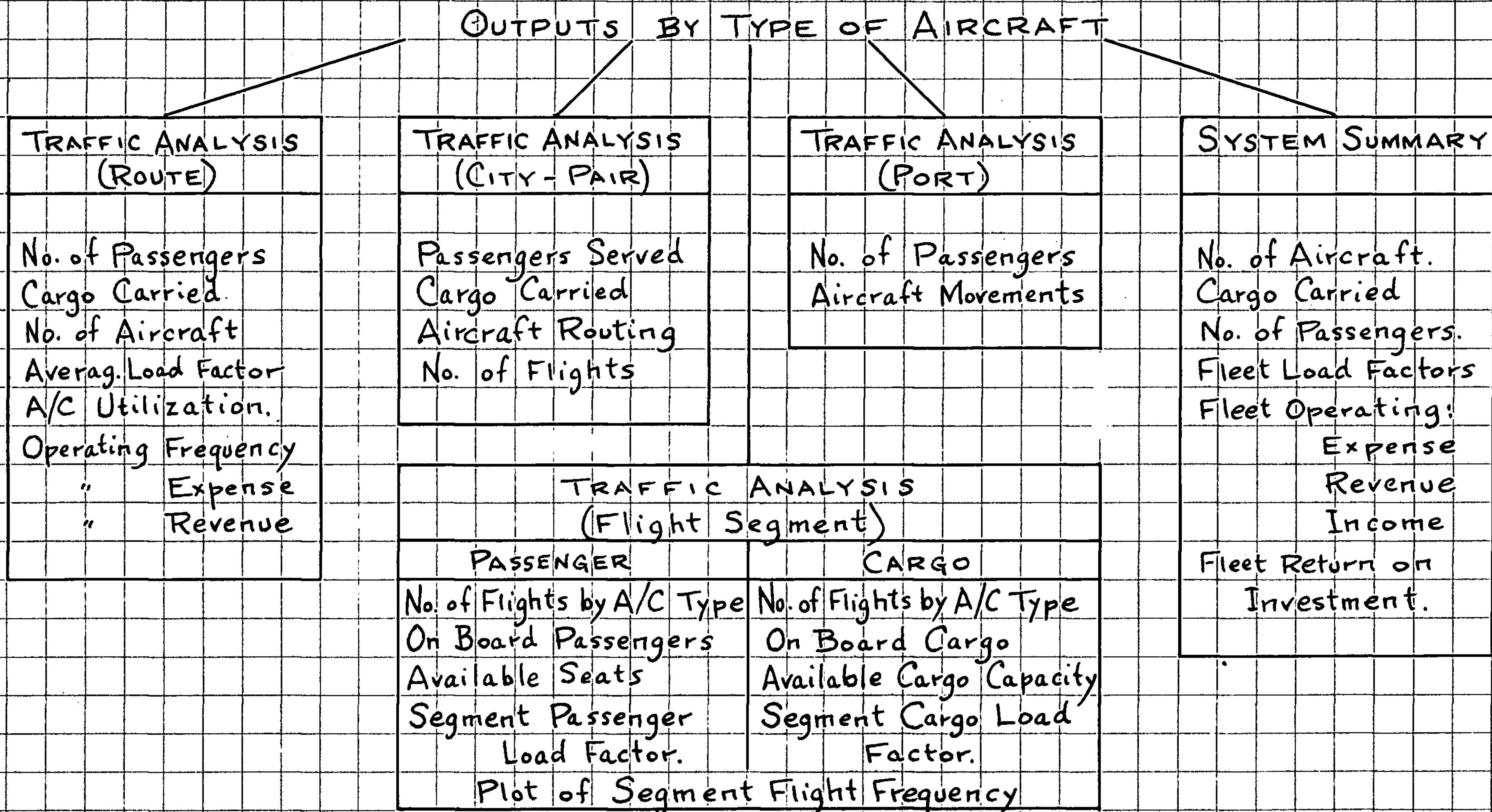


FIGURE 5.3 LOCKHEED SIMULATION OUTPUTS.
(From: Lockheed Publication CTR 2007, Burbank Calif. 1970.)

and return on investment.[16]

Fleet planning involves a great deal more than selecting types and numbers of aircraft to satisfy demand economically. Airlines must guard against buying what is known as a "transition" aircraft that has a temporary advantage when introduced into service. When more efficient aircraft are developed, the transition aircraft is not suitable for downgrading. It should be realized that aircraft manufacturers' strategies are to develop designs that capture a large portion of the market, trapping competitive aircraft into transition categories. An airline that has purchased transition aircraft is going to be faced with the need to replace the transition fleet at some point in the relatively near future, when the market value of transition aircraft is low. An example of this was the DC-7. DC-7's were phased out while DC-6's (that had been replaced by DC-7's), were downgraded and continued in service.[17]

Aircraft productivity can sometimes be enhanced by mixing aircraft types. This is particularly evident in cargo operations of a military nature. In an example given for a strategic fleet of transport aircraft consisting of various

---

[16] J.D. Kingsley, "Airline Operations and Planning Model," Long Beach, Douglas Aircraft Company paper 5058, 1968.

[17] M. Gurel, and L.A. Vargha, "Airline Fleet Planning - Restricted Models," Boeing Company Paper, Commercial Airplane Division, 1968.

proportions of C141 and C5A machines, productivity of both types was improved when they were used together as a mixed fleet.[18] The optimum ratio or mix was dependent upon the type of cargo as well as upon the amount of cargo. As the productivity was a function of mix, ordinary LP methods were ruled out. Piecewise linear approximations relating productivity to aircraft mix led to series of LP problems. Branch and bound methods were used to reduce the amount of calculation for an optimal solution.[19] The method appears to be unwieldy for an airline situation, typically more complex than strategic problems.

The savings inherent in the use of optimally designed aircraft must be weighed against the investment in mixed fleets. Expensive logistics backups, ground equipment and spares should be included in the calculation.[20]

Capacity Expansion. Several models of optimal capacity expansion have been developed. In the expansion problem the objective is to control the level of *production capacity* through a series of time periods, minimizing the

---

[18] D. Gross, and R.M. Soland, "A Branch and Bound Algorithm for Allocation Problems in which constraint coefficients depend on Decision Variables." Research Analysis Corportaion paper RAC-TP-327, 1968.

[19] Ibid., p. 10.

[20] J.G. Abert, M. Kamrass, J.A. Navarro, "Evaluating Aircraft Requirements in the Light of Varying or Uncertain Mission Mixes, Operations Research, Vol. 15, No. 4, 1967, p. 738.

composite cost of investment and capacity shortage. Owing to the complex manner in which extra capacity affects airline productivity, expansion of capacity for airlines is not capable of simple formulation. The most practical models for airline expansion are probably those of the aircraft manufacturers.[21]

Cash Flow Models

Given a proposed addition to the fleet, return on investment calculations are obtainable from the Douglas model.[22] Input includes assumed operating conditions and costs, startup costs, tax considerations, and particulars of the financing agreement. Output itemizes cumulative cash flow and profits for each year over the life of the investment, and return on average investment over the same period. There is nothing very novel in this model. It uses standard present value concepts. In this case the relationship of the output to the input assumptions is the main point of interest. Because Douglas set up the program with cathode ray tube display facilities, it was an easy matter to plug in ranges of assumptions to observe the effects on output. Models

---

[21] G.T. Howard, and G.L. Nemhauser, "Optimal Capacity Expansion," Naval Research Logistics Quarterly, Vol. 15, No. 4, December 1968, p. 535.

[22] B.J. Heap, "Return on Investment Program," Long Beach, Douglas Paper, No. C1-806-1316, 1968.

of this type are particularly convenient for answering questions of the type, "What if . . . .?" This model was easily set up on the users premises and did not require a large computer installation.

Cash flow is subject to a number of input probability distributions. Return on investment models will calculate cash flows for specific input assumptions, but to know the distribution of cash flow possibilities, a more general model is required.[23]

The projected cash flow model generates output probability distributions resulting from the input distributions. Input probability distributions, unfortunately, must be obtained from a barrage of questions of the type shown below:

Which do you prefer?

1. Win the 50/50 chance of $100 on the toss of a coin.
2. Receive $100 if RPM growth exceeds x per cent.

When probability distributions for all the important input parameters are generated in this fashion, random selections of inputs are made and substituted in the cash flow formulae. The outputs are distributed in some manner characteristic of the input.

---

[23] P.T. Glascall, "Probability - An Application to Projected Airline Cash Flow," Douglas Paper 5052, 1968.

The Airline Operating Cash Flow Model[24] is intended to provide more accurate financial and operating data in less time than say, repeated use of the ROI model. It enables managers to consider only specific inputs to the cash flow problem rather than the imponderable problem as a whole, and it produces a statement of cash flow in the form of a probability distribution covering the entire range of likely outcomes. If rethinking leads to a change in a subjective input distribution, it is possible to weigh the effects in the revised output distribution.

In 1967 the manufacturers' fleet planning models were criticized for not including time of day effects and not reflecting market share as a function of frequency.[25] However, system simulations for many years to come will operate on judgemental interpretation.

Financing Alternatives . . . should be considered before an investment decision is taken. In particular, the lease or lease purchase arrangements may prove attractive when tax considerations are included. This decision involves no more than normal evaluation by discounted cash flow methods.

If forecasts of income and acquisitions were certain, optimal financing becomes an LP problem:[26]

---

[24] Ibid., p. 1.

[25] W.G. Williamson, "Computer Programs for Fleet and Schedule Planning, AGIFORS Proceedings, 1967, pp. 11-22.

$$\text{Min} \begin{bmatrix} \text{Present value} \\ \text{after tax cost} \\ \text{of purchases.} \end{bmatrix} + \begin{bmatrix} \text{Present value} \\ \text{after tax cost} \\ \text{of leases.} \end{bmatrix} - \begin{bmatrix} \text{Investment} \\ \text{tax credits.} \end{bmatrix}$$

subject to $V \cdot T_x \cdot INC_j(IBT_j, P_{1,8}, P_{1,9} \cdots\cdots P_{2,8} \cdots\cdots, P_{j,8})$

$$\geq .07 \sum_{y=j-7}^{j+3} T_{jy} + \sum_{z=1}^{z=8-j} U_{jz}$$

where V = proportion of gross taxes eliminatable by tax credits

T_x corporate tax rate

INC_j income as a function of IBT_j and purchases

IBT_j income before interest, rent and depreciation of acquisitions in the period covered by the analysis

P_{jk} purchases in year j with depreciable life of k years

$T_{j,y}$ purchases in year j, tax credits for which apply in year y. ($y= j-3 \rightarrow j+7$)

U_{jz} unused tax credits earned z years before the period of analysis, used in year j.

---

[26] J. Slade, "Efficient Financing of Equipment Acquisitions," AGIFORS Proceedings, 1969.

This model as it stands is of little general use, firstly because earnings and acquisitions are *not* certain, and secondly because the tax picture depends upon location of the firm. Just as a deterministic prediction of return on investment or cash flow represents only *one* point in the distribution of possible outcomes, this LP represents one point on the distribution of optimal financial strategies. By taking the distribution of possible profits, this LP could be run for various outcomes *as if* the outcome were certain. Points to watch are sudden or large changes in financing strategy caused by variations in corporate income. If income variations are present, financial decisions should be kept open for optional flexibility until the future becomes more certain.

Mathematical programming can be applied to the problem of selecting an optimal combination of investments where the budgets are limited in a series of time periods. The Lorie-Savage model for two periods has been elaborated by Weingartner. The dual variables in this formulation are "shadow prices," that indicate the marginal rate of return on each of the constraints of the primal problem. For example, a budget constraint that limits investment, might be increased. The benefit of a unit increase in the constraint is given by the value of the corresponding dual variable.

For a warehousing operation, the investments may be divisible from an allocation point of view. In the case of major capital investment, the decision is all-or-nothing. Weingartner developed an integer program to make the "either-or" decisions and to take account of mutually exclusive projects. Weingartner's models have been extended by Quirin to handle other constraints such as labour.

The difficulty with mathematical programming approaches to capital budgeting is the assumption that future investment opportunities are known. Programming models are based on expected values that are treated as certainties. Risk may be programmed into the model by means of chance constraints and quadratic programming.[27]

Mathematical programming has been applied to the raising of external capital but the models were crude and unrealistic.[28] The methods are systematic and comprehensive, and with further sophistication may become more applicable to real situations.

---

[27] J. Van Horne, *Financial Management and Policy*, Englewood Cliffs, Prentice Hall, 1968, p. 56.

[28] *Ibid.*, p. 57.

Financial Control

Accounting ratios are used conventionally to indicate liquidity or solvency, earning power and the operating condition of business in general. Apart from conventional ratios used by accountants around the world, there are specific ratios that are peculiar to specialized needs of individual firms. Operations research in finance could start with Tucker's approach in the search for ratios that do more than indicate financial status.[29] For day by day control of factors affecting finance, ratios should be constructed as to suggest specific remedial actions that benefit the firm.

Aer Lingus proposed a financial plan in 1968 to allocate annual aircraft dependent costs and overhead costs.[30] Figures of merit were devised to compare route profitabilities, gross profits and profits of marginal service. Aircraft dependent costs are allocated on the basis of aircraft block hours. Overhead costs are allocated by judgemental weighting of traffic volume, revenue, etc. Profitability indices are functions of load factors on the various routes.

As indicated by the Lockheed Airline System Simulation, profitability on a given route does not tell the whole story if there is route interaction. An "unprofit-

---

[29] S. Tucker, Successful Managerial Control by Ratio Analysis, New York, McGraw Hill, 1961.

[30] R.H.W. Johnston, "A Computerized Capacity Plan and Budget System," AGIFORS Proceedings, 1968, p. 77.

able" route may enhance profits on other routes. Allocation of overheads appears to offer no contribution to the improvement of overhead management, and the same can be said for allocation of aircraft dependent costs.

It has become traditional to "absorb" costs on a basis of hours worked and then to compare "budget" versus "actual" costs to make year-end corrections and lists of variances for management review. Perhaps a more fruitful approach would be to review the costs themselves in the hope of making improvements. Elimination of allocation effort would represent initial savings.

Aer Lingus benefits from the speed of its computerized financial plan. Until 1968 the procedure had been to develop a schedule plan as the first step in elaborating the financial predictions. The financial plan evolved by Dr. Johnston was an iterative procedure that started with an original schedule plan and indicated actions that would lead to improved profitability. Using the former manual procedure, there was not time to change the schedule plan in response to financial analysis.

The Aer Lingus plan might prove unwieldy in a large airline system where many iterations would be required. It did not include allowances for competitors' actions that would affect total service, and it lumped together frequency and aircraft capacity in an overall measure of capacity.

In the long run this might lead the airline toward larger aircraft and reduced frequency whereas frequency may be the main determinant of market share.

In 1968, Air France was developing its TARAGE plan that brings together various O/R studies. "There is absolutely no question of finding optimal schedules, the meaning of optimality being difficult to specify."[31] But given a schedule it should be possible to calculate expenditure automatically. Revenues are more difficult . . . still in the future.

Air France's Economic Model was used to evaluate combinations of borrowing, amortization, financing and capital investments.[32] Inputs were: initial state of fleets, balance sheet, expenditure and cash flow and ratios from which simulated policy would be judged. The simulation suffered from difficulties in finding laws obeyed by revenue and expenditure once a production schedule was given.

Accurate measurement of policy impact is limited by the necessity for aggregation and by assumptions of linearity in revenue and expense. Any model, manual or computer, is subject to error--but what accuracy is required? American Airlines and McDonnell Douglas worked to develop a more

---

[31] J. Agard, "The Air France TARAGE Plan," AGIFORS Proceedings, 1968, p. 223.

[32] J. Agard, "Air France Economic Model," AGIFORS Proceedings, 1969.

comprehensive financial model, but much will be learned before human experience, judgement and intuition can be replaced by decision rules and equations.[33]

Interline Sampling schemes were introduced by European airlines in the fifties to relieve the tremendous clerical task of keeping track of interline accounts. Each airline sells and receives payment for coupons that may be honoured by other airlines. (Certain legs of the route are flown by two or more airlines and the passenger travels part of his journey on airlines other than the one from which the ticket was purchased). Complicating this, the local fares in most cases add up to more than the total fare from origin to destination, so a prorating system must be used to calculate amounts owing. F. Van Dam[34] illustrates how the estimators in the original fare sampling scheme were biased, and describes the development of unbiassed estimators.

Swissair in the late 1960's received up to 13,000 billings per month per airline, and even the 10% sampling precedure was becoming a large clerical problem.[35] The

---

[33] J.E. Wells Jr.,"Comments on J. Agard's paper", AGIFORS Proceedings, 1969.

[34] F. Van Dam, "Application of the Unbiassed Ratio Estimator to the Interline Sampling Scheme," AGIFORS Proceedings, 1969,

[35] M.L. Siegwart, "Simulation to Evaluate Sampling Methods in Interline Accounting," AGIFORS Proceedings, 1969.

question therefore, was, "Can the sample size be reduced?"

Actual (used) punched cards, already prepared for prorated coupons were collected. Thus an exact distribution was obtained. The punched cards were supplied by some of the participating airlines over a period of several months. The simulation verified that the unbiassed estimator would result in more precise allocations. For a given accuracy, the sample could be reduced, but the unbiassed estimator was not confirmed as a cost reduction because of its added complication. Assuming that computer facilities were available for accounting purposes, this objection appears relatively trivial.

Future Financing

Commercial aviation is only one mode of transport. Other main alternatives are: highway, rail, barge and pipeline transport. Past developments has been piecemeal in air transport, with many problems on the ground. The Transportation Research Foundation proposed that a study (to cost $900,000) be launched to determine future trends in requirements and sources of funds up to the year 1990.[36]

Such a study would attempt to evaluate future developments in all areas of transport, a difficult task even for

---

[36] E.G. Plowman, "Feasibility Report of the Transportation Research Foundation on the Proposed Study to Evaluate Transportation Capital Requirements and Investment Sources," Washington, 1968.

a static technology. Modal development costs and intermodal dependencies would have to be estimated. Rates of return would affect the sources of funds, and perhaps non-government sources would prove inadequate.

Where facilities are used by many, for example networks of public roads or telephone central office equipment, a "fair" system of charges is impractical or impossible. On large individual projects such as tunnels, turnpikes, or bridges, tolls may be charged, but the cost of toll collection and the minor delay involved in paying tolls--tend to reduce the social benefits of the projects. On the other hand, some routes are so crowded that those who are in a hurry are quite prepared to pay for the exclusion of those who are not in a hurry.

Whether long-range nation wide studies can be effective is a moot point. Studies can be made of individual developments, ports or urban road systems et cetera, but whether or not funds are government supplied, right of way often requires expropriation, and this will remain a government prerogative. Evaluation of individual developments in terms of cost benefit will use the tools of operations research. Government sources and applications of funds however, fall more into the field of economics.

CHAPTER VI

CONCLUSION

By 1971 extensive applications of Operations Research had been made in airline management and operation. In addition, fleet simulation and planning models were developed by airframe manufacturers. Airlines and airport authorities have used O/R models to study airport operating characteristics under various conditions of traffic. The literature associated with these applications has grown tremendously since the early 1950's. The chapters above refer to a fragment of the literature published prior to 1971, and give only a general impression of problems and solution approaches developed to date.

Any of the chapters on Marketing, Production, Airports, or Airline Finance could be developed into broad thesis topics. Scheduling itself provides a wide range of problem situations and a considerable variety of models and solution methods. In researching O/R applications in any of these areas, excellent bibliographic data is available in the International Abstracts in Operations Research, published by the International Federation of Operational Research Societies, (IFORS).

Successful Applications of O/R. To 1971, perhaps the most successful airline applications of O/R were in various queueing situations, for example, in baggage handling, and in passenger service at ticket counters, at check-in and at departure gates. Some examples were discussed under *Customer Service* in Chapter III. Queueing models have also served well in the analysis of runway utilization, airport design, and Air Traffic Control.

O/R models have been used successfully in evaluating airline information systems, and in the design of booking procedures consistent with required standards of customer service.

Several maintenance shop scheduling models appear to have been effective in providing specified supply reliability from relatively small stocks of rotable spares. *Engine Provisioning*, in Chapter IV is a good example of practical application of dynamic programming. Spares inventories pose special problems, particularly for small airlines operating new aircraft types. However, inventory models appear to have resulted in good spares inventory management.

O/R solutions to problems of airport manpower planning have been implemented with evidently satisfactory results. This is not to say that further improvements will stop.

Areas for Further Development. Slow developments in some problem areas may be partly due to a lack of analysis. Many problems of airport access, (such as ground congestion and bottlenecks), appear soluble. In some cases route authorizations, particularly in the United States, may have been ill-considered. While *optimal* solutions to ground congestion and route authorizations are yet in the future, existing O/R methods could yield significant improvements.

In other areas, developments seem to be impeded by lack of technical knowledge. Scheduling and crewing problems were still in experimental stages of solution in 1971. While much work had been done on various mathematical programming approaches, schedule solutions by O/R were generally partial and not necessarily optimal. Aircraft rotation was still largely a manual calculation.

In the more subjective problems of marketing and financial decisions, good O/R solutions appear dependent upon deeper understanding and knowledge of factors external to the airlines.

Does O/R Pay? In objective problem situations, such as inventory control and manpower planning, where measurements of cost-benefits are easily made, O/R should generally yield savings to the airline. In other areas such as marketing, benefits may be less tangible and difficult to measure with precision. This might also be the case in repair shop scheduling where O/R leads to improved reliability of supply. In passenger queues, benefits may take the form of improved customer service. In booking policy, O/R might lead to some combination of improved revenues to the airline while giving improved service to the customers.

O/R staffs at airlines are typically fewer than ten. If projects are selected to yield short-term payoff, then O/R groups ought to be self-supporting. If difficult long-range projects are undertaken, the payoff will be further in the future.

Installation of a New O/R Group. Probably the group should start with a small number of engineers or mathematically oriented people with several years of company experience. An O/R library should be started at the outset, and all O/R members encouraged to keep up to date with the library materials. A survey of the literature should be made to find out what has been done, but there should be immediate problem assignments and target dates from the start. Otherwise the group loses coherence and sense of purpose.

For quick results initially, early projects should be simple copies of successful applications elsewhere (modified as necessary). Inventory control, maintenance shop scheduling, or passenger queue models might be suitable choices.

Gradually, after several simple problems are solved, more attention could be devoted to difficult and long-range projects.

A Final Comment. O/R departments tend to assume an esoteric nature because they deal with *mathematical* representations of the world. The details of the mathematics, however, need not obscure the general solution approach nor the assumptions inherent in the solution. Judgement in making assumptions is generally more relevant to model output, than model structure. Management skill and competent executive judgement have not been replaced by O/R, nor is this anticipated. Implementation of O/R programs often requires support from management who are aware of the objectives, the costs, and the risks involved.

BIBLIOGRAPHY

Abbink, J.C. "Nozzle Guide Vanes - A Case Study." AGIFORS Proceedings. 1967, pp. 283-310.

Abert, J.G., Kamrass, M., & Navarro, J.A. "Evaluating Aircraft Reg'ts in the Light of Varying or Uncertain Mission Mixes." Operations Research. Vol. 15, No. 4, 1967, p. 738.

Agard, J. "The Air France Tarage Plan." AGIFORS Proceedings. 1968, pp. 223-237.

________. "Air France Economic Model," AGIFORS Proceedings. 1969.

AGIFORS Proceedings: Proceedings of theAirline Group; International Federation of Operations Research Societies. Published annually since 1961.

Air Transport Association of America. "Major U.S. Airlines Economic Review & Financial Outlook 1969-1973." ATA Economics & Finance Department, June 1969.

Airline Management & Marketing. General Reference.

Alexander, Tom. "Is there *Any* Way to Run an Airline?" Fortune. Vol. LXXXII, No. 3, September 1970, p. 117.

Altschul, S. "Liquidity," Airline Management & Marketing. Vol. 2, No. 10, October 1970, p. 37

Amin, N.N., and Khanna, K.C. "Sensitivity Analysis of Optimal Allocation of Rotable Spares." AGIFORS Proceedings, 1969.

Amstutz, Arnold E. Computer Simulation of Competitive Market Response. Cambridge, Massachusetts, The M.I.T. Press, 1967.

Aviation Week & Space Technology. General Reference.

Barry, W.S. Airline Management. London: Allen & Unwin Limited, 1965.

Bass, F.M. (eds.). Mathematical Models & Methods in Marketing. Homewood: Irwin, 1961.

Bass, F.M. & Lonsdale, R.T. "An Exploration of Linear Programming in Media Selection." Journal of Marketing Research. III, May, 1966, pp. 179-187.

Batey, A.T. "Some Aspects of Telephone Network Design." AGIFORS Proceedings. 1967, pp. 311-322.

Beale, E.M.L., Hughes, P.A.B., Broadbent, S.R. "A Computer Assessment of Media Schedules," Operational Research Quarterly. Vol. 17, No. 4, December, 1966, pp. 381-411.

Belgray, D.C. "The Israeli Air Force, The Six-day War & Their Relevance to Airline Management," AGIFORS Proceedings. 1968, pp. 464-482.

Benjamin, B., Jolly, W.P. & Maitland, J. "Operational Research & Advertising: Theories of Response," Operational Research Quarterly. XI, No. 4, December, 1960, pp. 205-218.

Benjamin, B., Maitland, J. "Operational Research Quarterly & Advertising: Some Experiments in the Use of Analogies," Operational Research Quarterly. IX, No. 3, September 1958, pp. 207-217.

Besse, George R. "Some International Aspects of the Demand for Air Transport," Air Transportation - a forward look. (ed.) by Karl M. Ruppenthal & Brian E. Sullivan, Stanford, Graduate School of Business, Stanford University, 1970, pp. 10-20.

Bindler - Gaspard, D. "Spare Aircraft - A Necessity or A Superfluity?" AGIFORS Proceedings. 1969.

Bodnarchuk, A., & Jeanniot, P.J. "A Maintenance Simulation for Complex Assemblies." AGIFORS Proceedings, 1968, pp. 373-407.

Bornemann, D.R. "A Linear Programming Solution to the Reserve Crew Scheduling Problem," AGIFORS Proceedings. 1968, pp. 455-463.

Boyd, Alan S. "Government's Role in Transportation." Perspectives in Transportation. edited by Karl M. Ruppenthal, Stanford, California, Graduate School of Buriness, Stanford University, 1963, pp. 44-54.

Brenner, Melvin A. "Public Demand and Airline Scheduling," Air Transport Association Paper, 1968.

Brewer, Stanley H. Air Cargo - The Gold is in the Terminals. Seattle, Faculty of Research & Publications, College of Business Administration, University of Washington, 1962.

________. The Complexities of Air Cargo Pricing. Seattle, Graduate School of Business Administration, University of Washington, 1967.

________. The Environment of International Air Carriers in The Development of Freight Markets. Seattle, Graduate School of Business Administration, University of Washington, 1967.

Brewer, Stanley H., Decoster, Don T. The Nature of Air Cargo Costs. Seattle, University of Washington, Graduate School of Business Administration, 1967.

Brewer, Stanley H., Kast, Fremont E., Rosenzweig, James E. The Europe - Asia Market for Air Freight. Seattle, College of Business Administration, University of Washington, 1963.

Brewer, Stanley H., Rosenzweig, James E., Warren, James, B. British Columbia's Need for a Unified Regional Air Transportation System. Vancouver, University of British Columbia, 1965.

Browne, J.J., Kelly, J.J., le Bourgeois, P. "A Double Ended Queueing System," Transportation Science. Vol. 4, No. 1, February 1970, pp. 64-78.

Buchanan, G.A. "The Outlook for Improved Passenger Systems," Datmation. Vol. 15, No. 3, March 1969, pp. 24-25.

Burck, G. "A New Flight Plan for the Airlines," Fortune. Vol. LXXIX, No. 4, April 1969, p. 206.

Byrne, J. "A B747 Insurance Spares Strategy," AGIFORS Proceedings. 1969.

Cardwell, J.J. "Marketing and Management Science - A Marriage on the Rocks?" California Management Review. Vol. X, No. 4, Summer 1968, pp. 3-12.

Chestnut, Harold. Systems Engineering Methods. New York, Wiley, 1967.

Corbett, David. Politics & the Airlines. London, Allen & Unwin Limited, 1965.

Cordtz, Dan. "The Withering Aircraft Industry," Fortune. Vol. LXXXII, No. 3, September 1970, p. 117.

Dantzig, George B. Linear Programming & Extensions. Princeton, N.J., Princeton University, 1966.

Deller, A. "The Use of Poisson Chain Techniques in the Solution of Practical Queueing Problems," AGIFORS Proceedings. 1968, pp. 483-499.

Eads, G., Nerlove, M., & Raduchel, W. "A Long Run Cost Function for the Local Service Airline Industry,: An Experiment in Non-Linear Estimation." The Review of Economics & Statistics. Vol. LI, No. 3, August 1969, pp. 258-270.

Etschmaier, M. "Optimal Scheduling of Rotables Through the Electronics Workshop," AGIFORS Proceedings. 1968, pp. 516-533.

Foley, Maurice A. "Operations Research in Aer Lingus," The Aeronautical Journal. Vol. 72, No. 691, July 1968, pp. 596-602.

Foreman, C.W. "The Hidden Benefits of Air Freight," Business Horizons. Vol. 11, No. 6, December 1968, pp. 27-34.

Fox, Bennet. "Discrete Optimization via Marginal Analysis," Management Science. 1967, Series "A", Vol. 13, No. 13, pp. 210-216.

Friedman, L. "Game Theory Models in the Allocation of Advertising Expenditure," Mathematical Models & Methods in Marketing. ed. by Bass, F.M., et al., Homewood, Irwin, 1961, pp. 271-301.

Gagnon, G. "A Model for Flowing Passengers over Airline Networks," AGIFORS Proceedings. 1967, pp. 29-47.

Gallagher, J.D. "Management Information Systems and the Computer," New York: American Management Association, Inc., Research Study Series, No. 51, 1961.

Glascall, P.T. "Probability - An Application to Projected Airline Cash Flow," Douglas Paper 5052. Long Beach, 1968.

Grampp, W.D. "An Economic Remedy for Airport Congestion," Business Horizons. Vol. 11, No. 5, October, 1968, pp. 21-30.

Grassman, W. "The Calculation of Reorder Levels of Expendable Parts," AGIFORS Proceedings. 1968, pp. 500-515.

________. "The Intricacies of Forecasting," AGIFORS Proceedings. 1967, pp. 379-386.

Griesshaber, R. "A Heuristic Model for the Impersonal Phase of Crew Scheduling," AGIFORS Proceedings. 1968, pp. 534-549.

Griffiths, B., & Taylor, J. "Mathematical Formulation of the Sector Control Problem," AGIFORS Proceedings. 1967, pp. 436-450.

Gross, D., & Soland, R.M. "A Branch and Bound Algorithm for Allocation Problems in which Constraint Coefficients Depend on Decision Variables," McLean Va., Research Analysis Corporation paper, RAC-TP-327, 1968.

Grumbridge, J.L. Marketing Mgm't in Air Transport. London, Geo Allen and Unwin Limited, 1966.

Gunn, William A. "Airline System Simulation," Operations Research. 12, 1964, pp. 206-229.

Gupta, S.K., & Krishman, K.S. "A Differential Equation Approach to Marketing," Operations Research. Vol. 15, No. 6, 1967, p. 1030.

Gurel, M., & Vargha, L.A. "Airline Fleet Planning - Restricted Models," Renton, Washington, Boeing Company Paper. Commercial Airplane Division, 1968.

Hailey, A. Airport. New York: Doubleday, 1968.

Hammarskjold, Knut. "Economic Implications of High Capacity Jets and Supersonic Aircraft," Financial Analysts Journal. Vol. 23, No. 2, March-April, 1967, pp. 67-70.

Heap, B.J. "Return on Investment Program," Long Beach, Douglas Paper. C1-806-1316, 1968.

Hertz, D.B., Schaffir, K.H. "A Forecasting Method for Management of Seasonal Style Goods Inventories," Mathematical Models & Methods in Marketing. edited by Bass, F.M. et al., Homewood, Irwin, 1961, pp. 461-481.

Hillier Frederick S. & Lieberman, Gerald J. Introduction to Operations Research. San Francisco, Holden Day, 1967.

Howard, G.T. & Nemhauser, G.L. "Optimal Capacity Expansion," Naval Research Logistics Quarterly. Vol. 15, No. 4, December 1968, pp. 535-549.

Howard, L.R. & Eberhardt, D.O. "Airline Simulation for Analysis of Commercial Airplane Markets," Transportation Science. Vol. 1, No. 3, pp. 131-157.

Jacks, R.E. "passenger Check-in & Information System," AGIFORS Proceedings. 1969.

Jackson, R.R.P. & Longton, P.A. "An Introduction to Operational Research," Journal of the Royal Aeronautical Society. Vol. 69, No. 656, August 1965, pp. 543-552.

Japan Air Lines. "Operations Research Organization, Functions and Activities," AGIFORS Proceedings. 1967, pp. 387-391.

Jenkins, W.E. "Airlines Reservations Systems," Datamation. Vol. 15, No. 3, March 1969, p. 29.

Jensema, W. "Passenger Handling Model," AGIFORS Proceedings. 1967, pp. 52-80.

Johnston, R.H.W. "A Computerized Capacity Plan and Budget System," AGIFORS Proceedings. 1968, pp. 77-96.

Judge, J.F. "MASSOP - A New Cost Weapon for Management," Airline Management and Marketing. Vol. 2, No. 10, October 1970, p. 96.

Kendall, Maurice G. & Stuart, Alan. The Advanced Theory of Statistics. Vol. 1, 3rd ed. London: Charles Griffin & Company, Limited, 1969, pp. 156-163.

Khanna, K.C. & Bhatia, A.V. "Optimal Decision Rules for an Expendable Inventory System," AGIFORS Proceedings. 1967, pp. 215-240.

Khanna, K.C. & Takamori, H. "Optimal Staff at Airline Terminals," AGIFORS Proceedings. 1969.

Kingsley, Joe D. "Airline Operations and Planning Model," Long Beach California, Douglas Paper 5058. May 1968.

Klingen, L.G. "Control of Materials Costs by Ratio Analysis," AGIFORS Proceedings. 1967, pp. 364-377.

Langhoff, Peter, (ed.). Models, Measurement & Marketing. Englewood Cliffs, Prentice Hall, 1965.

Lee, Alec M. "Applied Queueing Theory," London: MacMillan, 1966.

Linder, R.W. "Models for Planning and Control," AGIFORS Proceedings. 1969.

Little, J.D.C., Lodish, L.M. "A Media Selection Model & Its Optimization by Dynamic Programming," Industrial Management Review VIII. No. 1, Fall, 1966, pp. 15-24.

Lockheed Airline System Simulator Burbank California, Lockheed Publication. CTR2007, 1970.

Longton, P.A. "Mathematical Models of the Human Controller," Journal of the Royal Aeronautical Society, Vol. 69, No. 658, October 1965, pp. 699-709.

Longton, P.A., & Williams, A.T. "Procurement & Capital Investment Programs," Journal of the Royal Aeronautical Society. Vol. 69, No. 657, September 1965, pp. 601-610.

Mac Airt, J.G. "Estimation of the Financial Advantages of Eliminating Error No Shows in a Real Time PNR Reservation System," AGIFORS Proceedings. 1967, pp. 271-281.

MacIntyre, M.A. "Managerial Initiative and Government Regulation," Perspectives in Transportation. edited by Karl M. Ruppenthal, Stanford, California, Stanford University Graduate School of Business, 1963, pp. 1-8.

Mackle, V.D. "Airborne Integrated Data System," (AIDS), AGIFORS Proceedings. 1967, pp. 324-339.

Mellor, P. "A Review of Job Shop Scheduling," Operational Research Q'ly. Vol. 17, No. 2, 1966, p. 161.

Mercer, A. "Operational Research in Marketing," Operational Research Quarterly. Vol. 17, No. 3, September 1966, pp. 235-236.

Mills, H.D. "A Study in Promotional Competition," Mathematical Models & Methods in Marketing. Edited by Bass, F.M., et al. Homewood, Irwin, 1961, pp. 271-301.

Montgomery, David B., & Urban, Glen, L. Management Science in Marketing. Englewood Cliffs, Prentice Hall, 1969.

Mountjoy, K. "Airport Simulation Models," AGIFORS Proceedings. 1969.

North West Essex & East Herts Preservation Association. Studies of the site for a Third London Airport. Maidenhead, Berks, Alan Stratford & Associates, July 1966, 114 pp.

Norwood, H.E. "An Initial Provisioning System and its Decision Models," AGIFORS Proceedings. 1969.

Nowlan, F.S. "Application of Dynamic Programming Techniques to the Management of the Engine Logistics Cycle and to the Determination of Spare Engine Requirements," AGIFORS Proceedings. 1969.

________. "Some Topics Pertaining to Engine Management," AGIFORS Proceedings. 1967, pp. 170-207.

O'Broin, S. "Manpower Planning for Airport Operations," AGIFORS Proceedings. 1968, pp. 245-267.

O'Carroll, J.A. "Note on a Computer Simulation Used to Evaluate Pilot Seniority and Salary Systems," AGIFORS Proceedings. 1968, pp. 552-559.

Palda, K. "The Measurement of Cumulative Advertising Effects," Englewood Cliffs, Prentice Hall, 1964.

Parsons, R.B. "Microfilm Retrieval in an Airline Reservation System," Datamation. Vol. 15, No. 9, September 1969, p. 103.

Pestalozzi, G. "Priority Rules for Runway Use," Operations Research. Vol. 12, No. 6, 1964, pp. 941-950.

Plowman, E.G. "Feasibility Report of the Transportation Research Foundation on the Proposed Study to Evaluate Transportation Capital Requirements and Investment Sources." Washington, Transport Research Foundation. 1968.

Presley, S.G.N. "Control Information Distribution," Vancouver, Canada, C P Air paper, (unpublished), 1969.

Reddick, H.W. & Miller, F.H. Advanced Mathematics for Engineers. New York, John Wiley & Sons, 1948.

Reeher, D.H. "Air Freight Has Problems on the Ground," Business Horizons. Vol. 11, No. 1, February 1968, pp. 33-38.

Richter, H. "Optimal Aircraft Rotations Based on Optimal Flight Timing," AGIFORS Proceedings. 1968, pp. 36-39.

Rosenshine, M. "Operations Research in the Solution of Air Traffic Control Problems," Industrial Engineering. Vol. XIX, No. 3, March 1968, pp. 122-129.

Rothstein, M., & Stone, A. "Passenger Booking Levels," AGIFORS Proceedings. 1967. pp. 392-435.

Ruppenthal, Karl M. Air Line Management. Published in Draft Form by the School of Business, Stanford University, 1968.

________. Challenge to Transportation. Stanford, Graduate School of Business, Stanford University, 1961.

________. Issues in Transportation Economics. Columbus Ohio, Charles E. Merrill Books, Inc., 1965.

________. Perspectives in Transportation. Stanford, California, Stanford University, Graduate School of Business, 1963.

Schmidt, R.J. "Econometric Passenger Demand Forecasting Model," Long Beach California, Douglas Paper 5057. May, 1968.

Schriever, B.A., & Seifert, W.W. (Co-chairmen). Air Transportation 1975 & Beyond: A Systems Approach. Report of the Transportation Workshop, 1967, Cambridge Mass., The MIT Press, 1968.

Shapiro, M. "Shop Planning Simulator," AGIFORS Proceedings. 1969.

Shaw, G.C. "The Schedule - Its Effect on Passenger Volume," AGIFORS Proceedings. 1968, pp. 102-155.

Siegwart, M.L. "Simulation to Evaluate Sampling Methods in Interline Accounting," AGIFORS Proceedings. 1969.

Simon, J. "A Simple Model for Determining Advertising Appropriations," Journal of Marketing Research. Vol. II, No. 3, August 1965, pp. 285-292.

Simpson, R.W. "A Review of Scheduling and Routing Models for Airline Scheduling," AGIFORS Proceedings. 1969.

Skinner, J.E. "Airport Development Money is Here," Airline Management and Marketing. Vol. 2, No. 8, August 1970, p. 14.

Slade, J. "Efficient Financing of Equipment Acquisitions," AGIFORS Proceedings. 1969.

Spitzer, Murray. "The Computer Art of Schedule Making," Datamation. Vol. 15, No. 4, April 1969, pp. 84-86.

Stachtchenko, L. "An Investigation of Collision Risks Over the North Atlantic," Canadian Operational Research Journal. Vol. 3, No. 2, 1965, pp. 55-72.

Steiger, F. "Activity Report of the AGIFORS Study Group - Crew Scheduling," AGIFORS PROCEEDINGS. 1967, pp. 120-134.

Taylor, C.J. "The Determination of Passenger Booking Levels," AGIFORS Proceedings. 1962.

Tennant, C.J., & Batey, A.T. "Schedule Evaluation for Air Cargo," AGIFORS Proceedings. 1968, pp. 12-26.

te Winkel, D. "An Algorithm for Aircraft Scheduling in a Radical Network," AGIFORS Proceedings. 1969.

Tipton, S.G. "Airline Challenges of the Future," Datamation. Vol. 15, No. 3, March 1969, p. 22.

Tucker, S. Successful Managerial Control By Ratio Analysis. New York: McGraw Hill, 1961.

Turman, Solon, B. "The Challenge to the American Merchant Marine," Challenge to Transportation. ed. by: Karl M. Ruppenthal, Stanford California, Graduate School of Business, Stanford University, 1961, pp. 161-169.

Van Dam, F. "Application of the Unbiassed Ratio Estimator To the Interline Sampling Scheme," AGIFORS Proceedings. 1968, pp. 443-454.

van Hamel, J.A., & Verdoes, B.J. "Maintenance as a Cybernetic System and Application to Shop Scheduling," AGIFORS Proceedings. 1968, pp. 280-363.

Vautier, J. "Report on the Caravelle Simulation," AGIFORS Proceedings. 1968, pp. 426-432.

Verdoes, B.J. "Manpower Levelling for Medium and Long Term Planning," AGIFORS Proceedings. 1969.

Walker-Powell, A.J. "Aircraft Scheduling by Computer," AGIFORS Proceedings. 1969.

Wallace, F.P. "An O/R Approach to the Definition of Computer System Requirements in Airline Maintenance," AGIFORS Proceedings. 1969.

Webber, R.A. "Innovation and Conflict in Industrial Engineering," Journal of Industrial Engineering. Vol. XVIII, No. 5, May 1967, pp. 306-313.

Webb, M.H.J. "Advertising Response Functions & Media Planning," Operational Research Quarterly. Vol. 19, No. 1, March 1968, pp. 43-59.

Weinberg, R.S. "The Uses & Limitations of Mathematical Models in Marketing," Mathematical Models & Methods in Marketing. Bass, F.M. et al., (eds.) Homewood, Irwin, 1961, pp. 3-34.

Weingarten, A. "Response Time in a Total Airlines Computer System," AGIFORS Proceedings. 1969.

Whitin, T.M. "Inventory Control and Price Theory," Management Science. Vol. II, No. 1, October 1955, pp. 61-68.

Williams, A.T., & Longton, P.A. "The Interaction of Demand & Supply," Journal of the Royal Aeronautical Society. Vol. 69, No. 659, November 1965, pp. 777-786.

Williamson, W.G. "Computer Programs for Fleet & Schedule Planning," AGIFORS Proceedings. 1967, pp. 11-22.

Winters, P.R. "Forecasting Sales by Exponentially Weighted Moving Averages," Mathematical Models & Methods in Marketing edited by Bass, F.M. et al., Homewood, Irwin, 1961, pp. 492-512.

Wozniuk, V.K. "Airport Manpower Planning System," AGIFORS Proceedings. 1969.

Yamane, Taro. Statistics: An Introductory Analysis. New York: Harper & Row, 2nd edition, 1967.