DISCLAIMER OF QUALITY

Due to the condition of the original material, there are unavoidable flaws in this reproduction. We have made every effort possible to provide you with the best copy available. If you are dissatisfied with this product and find it unusable, please contact Document Services as soon as possible.

Thank you.

Some pages in the original document contain pictures, graphics, or text that is illegible.
A MICRO COMPUTER BASED
AIRLINE SCHEDULE PLANNING AND CONTROL SYSTEM

by

MORDECHAI PORATH

B.Sc., Industrial Engineering
Tel Aviv University, Israel
(1976)

Submitted to the Department of
Civil Engineering
in partial fulfillment of the
requirements for the degree of
Master of Science in Transportation
at the
Massachusetts Institute of Technology

May 1982
[ie. June 1982]
© Mordechai Porath 1982

The author hereby grants to MIT permission to reproduce and to distribute copies of this thesis document in whole or in part.

Signature of Author ____________________________

Department of Civil Engineering
May 20, 1982

Certified by ____________________________

Antonio L. Elias
Thesis Supervisor
May 18, 1982

Certified by ____________________________

Clifford Winston
Thesis Reader

Accepted by ____________________________

Nigel H.M. Wilson
Chairman, MST Program Committee

Accepted by ____________________________

Francois Morel
Chairman, Departmental Committee

Archives

Massachusetts Institute of Technology

JUL 26 1982
LIBRARIES
A MICRO-COMPUTER BASED
AIRLINE SCHEDULE PLANNING AND CONTROL SYSTEM

by

MORDECHAI PORATH

Submitted to the Department of Civil Engineering
on May 20, 1982 in partial fulfillment of the
requirements for the Degree of
Master of Science in Transportation

ABSTRACT

A study was carried out to understand the organizational and
technical processes of airline schedule planning and control. Current
schedule planning and control practices have been investigated and
related to models of decision-making.

The conclusions drawn from the study suggest that the schedule can be
viewed as both the product the airline offers to the public and the
operating plan the airline establishes to achieve the corporate
objectives. In order to maintain independence of the schedule planning
function within the airline organization, the process of schedule
planning must take place within an independent planning unit.

The nature of the scheduling decision problem has been investigated
and it is concluded that schedule planning is a semistructured problem,
meaning that the use of entirely structured normative models for schedule
planning is inappropriate. As an outcome of the above analysis, a
microcomputer-based planning and control system is developed in this
thesis.

The system has been designed to support schedule planning decisions
within the schedule planning unit. The support is provided by an easy-
to-use, friendly system and a set of models to validate the operational
feasibility of the schedule, evaluate the proposed schedule, and to
control the schedule operation in case of schedule disruption. Part of
the user interface and the evaluation functions were implemented and
tested on a current technology 8 bit 64K RAM microcomputer. The implemen-
tation showed the feasibility of using microcomputers for this type of
planning problem. The system's environment proved to be efficient in
both communicating with the user and response time.

An analysis was carried out to investigate the use of schedule
evaluation measures as decision support tools. It was concluded that, in
order for the measures used to be of any value for the evaluation process,
they have to comply with the principles of air transportation economic
theory, and that a schedule has to be evaluated not as a whole, but
at some level of disaggregation.
The overall system design considers trends in microcomputer technology, and issues such as use of hard disk and the introduction of demand paging in microcomputer systems are explored.

Thesis Supervisor: Dr. Antonio L. Elias
Title: Assistant Professor of Aeronautics & Astronautics
עוקב לзвонת, סופי ונויה
סנהדר

322

יונ 1982
שת"ם ה'תשפ"ב
ACKNOWLEDGMENTS

A great number of people have provided assistance to me in the course of this study. Professor Antonio L. Elias served as my thesis supervisor and gave valuable advice on various aspects of this work. In addition, professor Clifford Winston who served as my academic advisor, and Professor Steve Lerman who provided me with financial support through my course of study at MIT, deserve mention.

A number of professional colleagues contributed to this thesis. In particular, Michael Meyer, who first taught me the practical aspects of air transportation and computers. Dr. Ramon Harel, from whom I learned the political aspects of air transportation planning, and Rafi Herzog, who initiated the idea of this thesis.

A number of fellow students also provided advice and assistance during the course of this research. In particular I would like to thank Peter Belobaba and Patrick Little for reading the drafts and correcting my English and Anne Herznberg for interesting discussions and English correction.

Finally, I wish to acknowledge the intangible contribution of my wife Bonit and my children Omri and Noa,

*to whom this thesis is dedicated.*
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Abstract</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedication</td>
<td>4</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>5</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>6</td>
</tr>
</tbody>
</table>

### 1 THE SCHEDULING FUNCTION WITHIN AN AIRLINE

1.1 Introduction                 | 9  |
1.2 A Definition of an Airline Schedule | 10 |
1.3 Current Institutional and Technical Aspects of Schedule Planning and Control | 13 |
1.4 Description of the Current Short-Range Planning Process in Airlines | 17 |
1.5 Conclusions                  | 22 |

### 2 A CONCEPTUAL FRAMEWORK FOR SCHEDULING PLANNING AND CONTROL

2.1 Introduction                 | 24 |
2.2 Problems in the Current Scheduling Practice | 24 |
2.3 The Nature of the Scheduling Process -- An Organizational Approach | 26 |
2.4 The Scheduling Decision-Making Process -- An Organizational Approach | 29 |
2.5 Scheduling Within the Planning and Control System | 33 |
2.6 Summary                      | 36 |
Table of Contents (continued)

3 SYSTEM DESIGN

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Introduction</td>
<td>37</td>
</tr>
<tr>
<td>3.2 Overall Philosophy and Guidelines for Design</td>
<td>37</td>
</tr>
<tr>
<td>3.3 Functional Components of the System</td>
<td>40</td>
</tr>
<tr>
<td>3.4 Technical Structure of the System</td>
<td>44</td>
</tr>
<tr>
<td>3.5 Software Design and Flow of Control</td>
<td>52</td>
</tr>
<tr>
<td>3.6 Conclusion</td>
<td>56</td>
</tr>
</tbody>
</table>

4 THE PROCESS OF AIRLINE SCHEDULE EVALUATION

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 The Role of Schedule Evaluation</td>
<td>57</td>
</tr>
<tr>
<td>4.2 Evaluation Criteria</td>
<td>58</td>
</tr>
<tr>
<td>4.3 The Economics of Air Transportation and its</td>
<td>60</td>
</tr>
<tr>
<td>Effects on Schedule Evaluation</td>
<td></td>
</tr>
<tr>
<td>4.4 Schedule Evaluation Measures</td>
<td>71</td>
</tr>
<tr>
<td>4.5 Summary</td>
<td>75</td>
</tr>
</tbody>
</table>

5 SAMPLE USAGE

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Introduction</td>
<td>77</td>
</tr>
<tr>
<td>5.2 Generation of the Supportive Data Base</td>
<td>77</td>
</tr>
<tr>
<td>5.3 The Process of Schedule Generation</td>
<td>82</td>
</tr>
</tbody>
</table>

6 CONCLUSIONS AND RECOMMENDATIONS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Introduction</td>
<td>92</td>
</tr>
<tr>
<td>6.2 The Planning Process Within an Airline</td>
<td>92</td>
</tr>
<tr>
<td>6.3 The Planning Methodology for Airline Scheduling</td>
<td>93</td>
</tr>
<tr>
<td>6.4 System Design Concepts: Compatibility with the User Environment, and Compatibility with Current and Future Technologies</td>
<td>94</td>
</tr>
<tr>
<td>6.5 Schedule Evaluation Methodology</td>
<td>95</td>
</tr>
</tbody>
</table>
Table of Contents (continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6 Recommendations on Future Steps in the Development of Decision Support Systems</td>
<td>96</td>
</tr>
<tr>
<td>6.7 Future Steps in the Development of the Decision Support System</td>
<td>97</td>
</tr>
<tr>
<td>6.8 Future Steps in the Development of a Schedule Control System</td>
<td>98</td>
</tr>
<tr>
<td>6.9 Conclusion</td>
<td>98</td>
</tr>
<tr>
<td>References</td>
<td>100</td>
</tr>
<tr>
<td>Appendix A: Data Base Record Structure and Formats</td>
<td>103</td>
</tr>
<tr>
<td>Appendix B: Description of Procedures and Calling Sequence</td>
<td>109</td>
</tr>
</tbody>
</table>
CHAPTER 1
THE SCHEDULING FUNCTION WITHIN AN AIRLINE

1.1 Introduction

In recent years, the United States airline industry has gone through a major change in its operating environment. From a regulated industry, operating under relatively steady state conditions, it went in 1978 into a far less stable operating environment. The introduction of heavy competition (sometimes too heavy) forced the airlines to start looking for more reliable and sophisticated tools for their planning processes.

Also, a major revolution has recently taken place in the area of computer hardware, and the microcomputer, once only a computer scientist's toy, has become a powerful data processing tool, with a wide range of software and devices. The price of this type of microcomputer has become so low that it is within the budget of department heads, and needs not be approved by the board of directors, or another highly-ranked figure in the organization's echelon.

In this work, the use of microcomputers as a planning support tool for airlines is examined, and the use of software especially developed for microcomputer, as a basis for a decision support tool for airline schedule planning and control, is explored.

Before dealing with direct technical issues, this chapter analyzes two issues which are of basic importance in understanding the use of microcomputer-based systems for airline planning and control:
1. Understanding the notion of an airline schedule and precisely defining it

2. Understanding the current institutional and technical aspects of schedule planning and control, especially the distribution of responsibilities, channels of information, and implementation practice.

1.2 A Definition of An Airline Schedule

Although the term "schedule" is used often, its meaning and its role is not simple.

The schedule is both the product offered by the airline to the public, and the production plan for that product. What the airline produces is an explicit origin-and-destination set which is defined over time and space. The operating plan that is conducted to execute this job is the schedule.

The schedule presents the prospective passenger with information about flights from an origin to a destination, at a given time, for a given fare, and provides him with some idea about the levels of service offered on each flight. With this information, the prospective passenger will eventually make a decision about the flight he/she is going to take.

From the airline's point of view, the schedule is also its operating plan. The airline is striving to achieve, through the operation of its schedule, certain economic objectives. In the theoretical sense, these objectives are usually related to maximum profits, but in reality the objective set is much more complex, interrelated, and difficult to define, as will be shown later.
The schedule is an operating plan which is the outcome of an attempt to achieve efficient utilization of resources, namely manpower, airplanes, and airports, and a good level of service offered to the public under the commercial and physical constraints the airline faces.

The legal binding agreement between the airline and the passenger with respect to operating a flight in a given schedule is the flight ticket purchased by the passenger.

The above definition of a schedule could be expanded to a market plan definition if a seat management strategy is revealed to the public, but since in most cases this is not the common practice, the published schedule is not a complete picture of the airline marketing plan. The major components that characterize the schedule as a product are:

-- origin-destination pairs
-- technological components: aircraft type, capacity, seat configuration, speed
-- level of service components: price, frequency offered, departure time, flight time, passenger services
-- hedonic characteristics: punctuality, reliability (not observed by the passenger, but embedded in the schedule).

The aggregation of these unit products establishes several measurements of output with which we can physically "measure" the output of a schedule. Denote

\[ Y = \sum_{ij} y_{ij} \]  \hspace{1cm} (1.1)

where \( y \) is the mean flow intensity of passenger type \( k \) between
origin \( i \) and destination \( j \) over a time period \( t \).

Vector (1.1) represents an aggregation of the different elements of output embedded in the schedule. Depending on the level of aggregation over the different elements of the vector in (1.1), the degree of aggregation of \( y \) will vary. For example, we can describe the schedule as capable of carrying 1000 passengers from Los Angeles to Boston during the summer season between 5 p.m. and 6 p.m. on Fridays. Similarly, we can measure the overall productivity in terms of total passengers from Los Angeles to Boston over the whole season. While in the first case the aggregation is over a short period of time, in the second case the level of aggregation over time is for the whole season. We can aggregate over type and number of passengers, over time, and over space.

Only total aggregation over the three dimensions generates a single unified output in common units times distance per period of time -- the passenger-mile measure. The existence of a unique measure for the aggregate product provides an overall single measure for total output. This might be useful as a policy indicator, but as we show later, should not be used as a sole measure for airline schedule output.

---

1 This definition is based on Galvez (1978), as it appears in Jara Diaz and Winston (ref. 1, p. 3).
1.3 Current Institutional and Technical Aspects of Schedule Planning and Control

The definition of a schedule, presented in the previous section, leads us to two conclusions about the organizational nature of the scheduling process.

1) The scheduling process in an airline is the process in which, at the same time, the airline makes decisions about its operating plan, its product and its marketing plan.

2) By being both the product and the operating plan, there exists a very close relationship between the scheduling process and the process of preparing the major plans in an airline. The maintenance plan, budgeting, market plan and major strategic planning decisions are tightly coupled to the process of scheduling, and dynamic feedback of information and decisions is occurring constantly over the airline organizational channels.

Exhibit 1 illustrates a schematic diagram which describes the fundamental nature of the schedule planning and control process, and its cyclic nature.

In Exhibit 1, it is evident that the planning process receives information from three sources: (1) corporate objectives; (2) operational bounds which are determined by the output upper bound, the market limitations, the input upper bounds and resource availability; and (3) cost revenue data. The operational bounds and corporate objectives are highly correlated, and are constantly providing feedback to each other. Both obtain their inputs from the long-term planning process through the process of evaluating the current and the future environment.
Exhibit 1. The planning process in an airline.
The planning system creates three outputs, each of which is tightly coupled and practically create a cyclic process of decision making. These are the schedule plans, resource plans, and the process of control and evaluation which constantly feeds back into the planning process.

Exhibit 1 represents a simplified model that describes the nature of the planning process in an airline in terms of input, output and channels of information on one hand, and the resultant action and feedback channels on the other hand.

Organizational changes over the course of the turbulent 1970's were symptomatic of gradual evolution in the concepts of how planning fits into air carrier organization. A gradual shift of management emphasis from operations to marketing in the 1960's subsequently brought scheduling under the control of the latter function during the following decade. Long-range corporate planning ranging 5, 10 or more years into the future became a fad among airlines in the 1960's because it had become formalized in many companies in other industrial sectors.

A survey of the planning practice in airlines conducted by Speyer [2] in 1978 revealed some very clear trends in both the nature of the planning process and the organizational nature of this process. Based upon the above survey and information about current practice in the U.S. airline industry, the following conclusions about the nature of planning in U.S. airlines can be made:

1) Recently, there has been a gradual organizational reconcentration of the planning process in both corporate planning and medium range-short range operations planning. This is the
situation observed at United, American, Trans World, Eastern, Western, Texas International and Hughes Airways, where the planning process is completely the responsibility of a single unit, usually under the vice president for planning.

2) Personal leadership in the airline's chief executive office leads to a situation where the CEO himself makes planning decisions, down to a level that planners are actually localized problem solvers, as has been the case at Braniff International until its shakeup in early 1982. This style of leadership is currently developing at Pan Am.

3) Top management style also has an influence on the planning process. For example, at Delta Airlines, there is no comprehensive planning organization at all. Senior and top management is very involved in all levels of planning.

4) There does not seem to be a unique planning model which characterizes the airline industry. Some airlines, such as Pan Am, have a dispersion of planning activities in its corporate staff organization, while others have tightly organized corporate planning departments which are in charge of coordinating the planning activities as they are dispersed through the organization (this is the case with Continental Airlines, for example). In some airlines, there is a dual planning organization, such as in the case of Frontier Airlines, where there is one planning unit in finance focused on short-range planning, and another in marketing concentrating on long-range planning.

5) In terms of the organizational units in which schedule planning is located, we can identify four major groups:
Schedule planning as part of a formal corporate planning department:
United, Eastern, Western, Continental, Hughes Airways

Schedule planning as part of the marketing department:
TWA, American, Texas International, Frontier, National

Schedule planning as part of the finance department:
U.S. Air, Northwest Orient

Schedule planning dispersed among central staff departments and/or task forces, but reporting directly to the Chief Executive Officer:
Pan American, Delta, Braniff

1.4 Description of the Current Short-Range Planning Process in Airlines

In order to understand the nature of the planning process and its importance to the process of developing an airline schedule planning and control system, the actual planning process in several airlines is described in this section. This survey is based on the work done by Speyer [2] and AGIFORS proceedings [3]. The material is compiled in a manner that allows us to propose a planning system which complies in a reasonable way with the planning needs of the industry, as they are reflected by the above surveys.

1.4.1 U.S. Air's Short-Run Planning Practice

Marketing plans at U.S. Air are developed with financial plans during the annual short-range planning process. The process of

2 American has recently put more emphasis on a centralized schedule planning process.
producing the plan is not as sophisticated as that of some of the largest trunks, but it is obviously more flexible and much less cumbersome.

The first part of the planning process is carried out in the Marketing Department. Segment-by-segment traffic forecasts are developed at headquarters, with little or no bottom-up field input, nor top-down statistics; equipment is accepted as a short-term constraint. A tentative schedule is derived, only to be tested again for potential traffic generation. When the iteration is completed, the preliminary schedule is evaluated by finance for its revenue/expense potential. This process is iterated several times until a final mutually-accepted plan is formulated.

1.4.2 American Airlines

American Airlines went through a management shakeup in 1974, which led to its present planning organization. The current practice is that the planning unit formulates schedules and reports directly to Marketing.

Short-range planning at American Airlines is a four-stage process: The first two stages are preparatory, and their main product is the final step of transforming the corporate objectives into principal operating plans. For example, alternative strategies are analyzed in the transcontinental markets. These relate to capacity, frequency, widebody versus narrow-body aircraft, and so on. The third phase is the actual schedule development process: aircraft types, capacity, frequency, departure and arrival times are produced for the whole operations system.

The fourth phase consists of detailed analyses by Forecasting
and Research to estimate the potential impact of the schedule. Various tests of reasonableness are performed to check the forecast. The group ultimately evaluates the product, the schedule, and how it is likely to be perceived by the public.

1.4.3 Braniff International

Although Braniff's corporate planning process has been dominated by the Chief Executive Officer, the short-range planning process is extremely structured, and very much stresses budgeting and efficiency. The process is a one-year plan, labeled the Profit Plan, and is very decentralized.

The process starts with the development of a schedule, which is followed by several iterations, on both formal and informal bases, between Market Planning and the various operations units (i.e., flight operation). A tentative schedule which is a result of this iterative process is then presented to the top executive committee. The next step in the process is a budgeting iteration where the economic results of the proposed schedules are estimated. The financial results and the tentative scheduling are then passed to Corporate Planning for development of the final version of the schedule. The profit plan is, however, not a fixed plan, and is reviewed at least once a month, and sometimes more.

1.4.4 Eastern Airlines

Eastern Airlines is representative of the formal planning approach. The short-range planning process at Eastern produces the
Corporate Profit Plan, which consists of three parts:

-- the Resource Utilization Plan, pertaining to flight equipment, finance, facilities, and personnel
-- the Operating Plans, comprising flight schedules, service sales, employee training, service standards, programs and projects, cost levels and profit generation
-- the Growth Plan, concerning market penetration, market stimulation and route development.

The short-range plan is aimed at producing a final plan for the following year and a preliminary plan for the second year in the future. The process consists of five distinct steps, altogether producing the Resource Utilization Plan, the Operations Plan and the Growth Plan. The first two steps are macroanalysis, resulting in macroforecasting, and definition of a tentative level of operations, in terms of block hours, airborne hours, revenue aircraft miles, available seat miles, etc. The above two steps are iterated after the tentative plans are presented to top and senior management.

The third and fourth steps involve detailed departmental analysis of the operations plan. This output is submitted to Corporate Planning, it is analyzed and results in the fifth step, which is the final operating plan -- the schedule.

1.4.5 British Airways

One of the most interesting and enlightening case studies of schedule planning is the case of British Airways, described by Loughran and Cocks in the 1976 AGIFORS symposium [3]. In 1975, British Airways went through a major organizational and a technical
change in its scheduling planning process. British Airway's practice
before the change was to propose provisional schedules and then
undertake various evaluations. When the evaluations produced
unsatisfactory results, remedies might not have been apparent, or
it might have been too late to change the plan. Each element of the
planning process was separately managed within a distinct unit in the
organization. For example, the traffic planning branch calculated
revenues and load factors; the schedule planning branch maintained the
timetable. Neither had relevant cost information continuously updated.
Other sections prepared fleet plans, route and frequency derivations
and capacity estimates. Finally, another section combined the elements
with a financial assessment for product coordinators, who were
responsible for geographical groups of routes. Each element of the
planning process used a set of computer programs of its own, and plans
could not be rapidly related to objectives; the profit usually could
only be estimated after a two-month delay. Schedule changes occurred
so rapidly that, by the time an economic assessment was available,
it would bear little relation to the up-to-date plans.

Difficult competition and the awareness that the planning
procedure in the airline has to improve if new market segments were to
be profitably developed, brought the British Airways planning team
to set out to design a new generation planning system.

The main strategy of BA's new approach was to establish a
centralized, single on-line computer program called PAM (Profit
Analysis Model) that had the following four objectives:
1) Make economic evaluations of alternative route schedules
2) Maintain a feasible, punctual schedule for the whole network
3) Establish the maximum achievable levels of program-related objectives
4) Develop new schedules in response to new estimates of future markets and/or corporate resources.

Many facets of airline planning were integrated, with the major organizational difference between the previous practice and the current practice being that the process has been centralized and planning objectives are designed into the schedules, in an on-line process, by the team of planners who have undertaken the economic evaluation.

The schedules and accounting data derived from PAM are automatically transferred to the airline information system, to provide the productivity plans and the public timetable. The revenues and market share estimation form targets for the revenue monitoring system, which in turn feed back the actual sales results.

1.5 Conclusions
The basic notion that schedule planning in airlines is the art of matching markets and objectives under a set of input constraints is expressed by the description of the planning process for the above representative airlines. The planning system gets its input from three major sources:

--- the corporate objectives as they are set by the board of directors
--- the upper bounds for input resources as they are set by
current and future availability of those resources, mainly capital assets (fleet), airports, and manpower

-- the output opportunities, in terms of potential markets and expected demand.

The planning system, independent of the particular application, produces a final product -- the schedules -- and creates feedback for its own previous output. Usually these feedbacks provide post-mortem performance indicators that can be used to monitor current performance against targets. In addition, the planning system feeds back to the resource plans. Airlines have multitudes of potential market segments, a wide range of resources, and usually many objectives, and yet, the fundamental purpose of a successful planning process is to achieve the corporate objectives with minimum organizational friction, which means basically to avoid duplication and overlap in the process of planning on one hand, and to avoid ignoring planning issues on the other.

All airlines consider speed of reaction as an important factor in the planning process. The planning system must match the speed of information, to react to actual performance, and to react to actual changes fast enough to influence future actions. The planning process described for the above representative airlines does not seem to fulfill this fundamental demand. In the next chapter, a detailed analysis of this phenomenon and some organizational solutions to overcome this problem are introduced.
CHAPTER 2
A CONCEPTUAL FRAMEWORK FOR SCHEDULE PLANNING AND CONTROL

2.1 Introduction

As an outcome of the organizational and technical review presented in the previous chapter, a conceptual framework for the schedule planning and control process is suggested here.

This chapter deals with the following issues:
1. The problems in the current scheduling practice.
2. The nature of the scheduling problem.
3. Scheduling as a decision-making process.
4. The role of scheduling within the planning and control system.

2.2 Problems in the Current Scheduling Practice

2.2.1 Generation of Input Data

The current practice in airlines is characterized by a variety of non-standard schedule data bases. The process of schedule data base development has been evolutionary in its nature. The information contained in it has been expanded periodically, according to increasing sophistication of the users. The issue of standardized data bases has generally been neglected, due to the non-centralized nature of the current scheduling practice.

Schedule data bases are used extensively to perform task-oriented functions, for example:
1. A schedule data base which constitutes the source input for the Official Airline Guide (OAG) publication.
2. Maintenance schedule data base for purposes of issuing
maintenance programs, or a station schedule for manpower schedules, all of which are developed and used for administrative purposes only.

3. Schedules for use as part of the reservation system.

None of the above has been intended to serve as a data base for planning purposes.

2.2.2 Selection and Evaluation of Alternatives

In all airlines observed, the process of alternative selection and evaluation appeared to be cumbersome. The relatively slow process of iteration practically limits the number of alternatives that can be evaluated, and the response time, which is relatively slow, does not allow an exhaustive process of alternatives selection and evaluation.

2.2.3 Real-Time Response

In the more sophisticated airlines, such as American and Eastern, there is frequent use of online programs to permit entry, manipulation and analysis of schedules as well as access to pertinent traffic and revenue data. Unfortunately, these programs have not been a substitute for the current manual schedule development process. The reasons for this include organizational drawbacks, poor command languages and computational capabilities, the limited number of factors that are considered during the process of schedule development, and the fact that recognition of the decision-maker's judgment is neglected.

Currently, two major online systems are widely recognized in the industry:

SPS -- Developed by Potomac Scheduling, Inc., which provides online access to an extensive service, traffic and operating statistics data
base, as well as models for forecasting the impact of schedule modification.

CASS -- Competitive Airline Strategy Simulation, developed at the Flight Transportation Laboratory at MIT, which contains a powerful scheduling tool known as PFP, as well as highly-disaggregated traffic allocation and operational forecasting capabilities.

Both systems are powerful, but even so, they cannot deal with an operational schedule (i.e. a schedule that is already operating), and they have no mechanism to deal with schedule disruptions, which could be a very important real-time support tool for schedule control purposes. In addition, they require large mainframe computers, and at the same time use traditional line-by-line terminals, allowing only modest user/machine data exchange rates.

The rest of this chapter explores the nature of the scheduling process as an organizational process and the nature of the scheduling decision-making process.

2.3 The Nature of the Scheduling Process -- An Organizational Approach


2.3.1 Fully-Structured Problems

Fully-structured problems are those for which algorithms or decision rules can be specified in such a way that would allow us to find the problem, design the alternative solutions, and select the best solution. An example of a structured problem is the game of tic-tac-toe,
where we can specify rules for play that will give the user, whether a computer or a person, a draw at worst, or, if the opponent blunders, a win. In the business world, the inventory reordering problem is an example of a structured problem which can be put into simple decision algorithms, that can easily replace the person responsible for this operation.

2.3.2 Unstructured Problems

An unstructured problem is one for which we are unable to define the conditions that allow us to recognize the problem, and in the design phase of the problem solution process, we are unable to create methodologies to solve the problem that has been defined. In the choice phase of the problem process, we do not have clear criteria for choosing the best solution from those we created. An example for the unstructured problem is deciding upon a cover design for a new book.

2.3.3 Semi-Structured Problems

Semi-structured problems are ones in which one or two stages of the problem-solving process might be left in the manager's hands because we are unable to define it precisely enough. However, the remaining phases of the problem-solving process, especially the design and choice process of alternatives, have enough structure to permit us to effectively use computer support because managerial judgment alone will not be adequate, due perhaps to the size of the problem or the computational complexity and precision needed to solve it. On the other hand, using the data in a computerized model alone for solving the problem is inadequate because the solution involves some judgment and subjective analysis. Under these
conditions, the manager plus the system can provide a more efficient solution than either one alone.

The scheduling decision-making process at each level of decision is by nature semi-structured. Information regarding markets, demand, cost, performance and vehicle characteristics is multidimensional and complex, and it is almost impossible to systematically handle all the information in a way that the design of alternatives and the choice of alternatives could be exhaustive and effective.

A fully-structured process, on the other hand, is not adequate because there does not exist any complete structured model that can consider all the possibilities, or that is able to employ past experience for better design and choice of alternative schedules. Any operations research type of model will be inadequate, especially when the level of detail required is high and many unstructured, ad-hoc events have to be considered.

The strategy that focuses on supporting the human decision-maker is very different from that which aims at replacing him, and it can be strongly argued that airline scheduling belongs to a class of problems that focus on support, an approach that is likely to be much more effective than that of replacement of the human decision-maker.

To support this statement, a further look into the nature of the decision-making process in airlines is needed, in order to understand how different basic concepts of decision-making fit into the schedule planning and control framework.
2.4 The Scheduling Decision-Making Process -- An Organizational Approach

G.T. Allison, in his book *Essence of Decision* [5], defines three basic conceptual models of decision-making: the Rational Actor, the Organizational Process, and the Bureaucratic Politics decision-making models. These definitions have been expanded, and currently we can observe five major viewpoints explaining the decision-making process.

1. The Rational Manager view
2. The Satisficing Process-Oriented view
3. The Organizational Procedures view
4. The Political view
5. The Individual Differences perspective

2.4.1 Scheduling as Rational Decision-Making

Under the assumptions of a rational decision-making process, the following steps would comprise the schedule planning process:

-- the scheduler is confronted with a number of different specified alternative courses of action

-- to each of these alternatives is attached a set of consequences (in terms of contribution, profit, traffic volume, etc.) that will ensue if the alternative is chosen

-- the scheduler has a system of preferences that permit him to rank the consequences according to these preferences, and to choose the alternative schedule that has the preferred consequences, usually in terms of higher profit.

The conceptual process described above provides for virtually no descriptive support whatsoever. The concept above defines the logic
of optimal choice; it remains theoretically true, even where it is descriptively unrealistic. No scheduler can take into account the random behavioral effects on demand patterns, and there is no practical way of comparing the second-best solution to the "optimal" one. Furthermore, the addition of a few probabilistic elements into the model tends to create, over time, a very large and complex model, with little or no practical value at all.

The above does not mean that rational decision-making models are not part of the scheduling process. The normative stance defines for the scheduler the upper bounds on a system and creates for the scheduler the theoretical criteria for a good schedule and a comprehensive framework for problem definition, and furthermore, consistent relationships among the different elements in the scheduling process.

2.4.2 Scheduling as Process-Oriented and Satisficing Decision-Making

The satisficing view of decision-making is an attempt to move closer to reality and to understand the process as it actually exists, under the notion that it is better to produce a feasible solution that is not optimal, rather than an optimal plan that is not feasible.

Most formal operations-research-type scheduling models are feasible within the framework of their own boundaries (not necessarily the real-world boundaries). Thus, we can optimize under feasible conditions that are not always realistic. For example, an optimal solution might suggest the following flights departing within a range of 45 minutes:

(1) BOS-NYC-ATL-DVR-LAX
(2) BOS-LAX

This solution might be feasible under the model assumption, but unrealistic
from a practical point of view. Passengers will take the first flight to Denver and Los Angeles only under very rare circumstances, and these flight segments will in most cases go empty. Some problem-solving strategies that are based on heuristics might produce more adequate solutions to this kind of problem.

To understand a manager's (or scheduler's) decision-making process, one must know and understand the heuristics the manager uses. Heuristics reflect bounded rationality, that is, they are a compromise between the requirements of the problem and the capabilities, commitments and time constraints the decision-maker operates under.

In making strategic decisions, the manager has more flexibility in defining the scope of feasible solutions, than in the case of short-run scheduling decisions. Using heuristics as part of the short-run decision process might be adequate, and in some cases might be as effective and less costly than a formal large-scale optimization program.

2.4.3 The Organizational Process View

The first two concepts of decision-making put emphasis on the issue of goals vis-a-vis practicality of solutions that the scheduler is producing. An intermediate conclusion from the above discussion is that combined use of formal normative models and heuristic-descriptive models can produce a better final output than might have been obtained by using only one concept of decision-making. But the scheduler is also confined to the organizational decision-making process where formal and unformal structures can heavily affect the standard operating procedures and the channels of communication in the organization. Each subunit in the airline (operations, maintenance, marketing, etc.) relies on programs and
procedures that in a sense constitute the corporate memory and store of learning. If, for example, the maintenance people know that the standard practice of engine change does not hold in several airports, or that an equalizer procedure takes longer time than is expected, they will adopt some different compatible procedures.

The scheduler, while making his decisions, needs to be familiar with the subunits and their standard pattern of decision-making. In most cases, however, it is very difficult within an airline to institutionalize an information system that cuts across the different major units -- operations, marketing, finance, and maintenance -- in a way that intrudes on territorial rights or that is inconsistent with the organization's structure and lines of communication.

For airlines with a stable and reasonably-effective set of standard operating procedures for schedule planning, it is reasonable and effective to develop support packages that permit the scheduling procedure to be executed more efficiently with less organizational friction and to provide more rapid modification tools.

Cyert and March [6] stress the compartmentalization and specialization of the various units in any organization. In the case of the airline industry, some non-commercial subunits have an almost-unlimited veto power in determining the resource availability for a given schedule: maintenance and crew assignment are an example, where flight safety arguments can dominate all other arguments. Usually, disagreements arise on fringe problems, and unless an agreed-upon procedure exists to handle such problems, the solution has to be negotiated at top management level.

Dearborn and Simon [7, pp. 307-314] point out that even senior
executives tend to view the total market from their own functional perspective. This specialization of effort and attention is generally more efficient for solving local problems, but impedes integration, modification, or evolution of the creation of the schedules, which represents a broader view of the airline product.

The solution for achieving efficiency in the process of integrating the subunit goals and expediting the process of frequent changes in the schedule is an independent scheduling unit, independent in both the organizational and technical sense, at each level of planning within the airline.

2.5 Scheduling Within the Planning and Control System

We need a framework in which to position the various scheduling functions. For this purpose, we need to map the process of scheduling decision-making in airlines in a way that will allow us to differentiate between organizational activities in terms of the types and levels of decision involved, and perhaps more important, the information characteristics needed for each level of schedule decision-making.

In Planning and Control Systems: A Framework for Analysis [8], Anthony views managerial activities as falling into three categories, and argues that they are sufficiently different in type to require distinct planning and control systems. We adopt Anthony's framework for our analysis, with some fairly marginal changes to fit the airline industry framework.
2.5.1 Strategic or Corporate Planning

Strategic or corporate planning is defined as "the process of deciding on objectives of the organization, on changes in those objectives, on the resources used to attain such objectives, and on the politics that are to govern acquisition, use, and deposition of resources" [8, p. 24]. In the case of the airline industry, definition of objectives implies an emphasis on scanning current markets and evaluating new market strategies, and scanning the current and future technologies that are adequate to accomplish the market objectives.

2.5.2 Management Control

Management control is defined as "the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives [8, p. 27]. Anthony stresses three key issues in management control:

-- the activity involves considerable interpersonal interaction
-- it takes place within the context of the policies and objectives developed in the strategic/corporate planning process
-- its permanent aim is to assure effective and efficient performance. For the airline industry, this is the stage where actual schedules are produced by combining the supply and demand information into the two-stage supply function introduced by Simpson [9]:

(1) The first stage, the Transportation Production function, converts inputs consisting of Labor, Fuel and Capital facilities, such as aircrafts, stations, airports, ATC, etc., into a set of intermediate outputs consisting of vehicle trips, station operations, etc.

(2) The second stage of the supply process is called the
scheduling function, where intermediate inputs and their cost, along with forecasts for demand and prices for all markets, produce the final output, which is the service schedules to be offered over some time period in the multiple markets of the network.

We can see that the term "management control" is not totally adequate to describe the managerial activities taking place in the airline industry at this stage. The term "operations planning" is more appropriate for describing the actual nature of this process. The term "planning" emphasizes the fact that we are dealing with future activities, and the term "operations" points out that the planning process at this stage is done under predefined objectives and is no longer at the conceptual level.

2.5.3 Operations Control

Anthony's third category is Operations Control, the process of assuring that specific tasks are effectively and efficiently carried out. Operations control in the airline industry is concerned with operationalizing a predefined schedule, whereas operations planning more often relates to an airline's policies. In the classic (manufacturing organization) case, there is much less judgment required in the operations control area than in airlines. The reason for this is that for production systems, tasks, goals and objectives have already been carefully defined, automation is involved in the process, and usually there is independence between sequential processes.

In the case of airlines, operations control has both time and space dimension, and the judgment required at this level is as important and complex as the one required at the operations planning stage.
While the boundaries between strategic/corporate planning and operations planning are clear in the airline industry, the boundaries between operations planning and operations control are often not clear. The volume of work and the information requirement for each level can determine for an airline whether both levels could operate under the same organizational roof, or function as separate independent subunits.

The system presented in this work is aimed mainly at supporting the operations control decision process, but the design principles will enable airlines of small size to adapt the system as a tool for operations planning.

2.6 Summary

This chapter establishes the framework for the scheduling system design. Four principles that characterize the scheduling system are presented:

-- the semi-structured nature of the scheduling problem

-- the need for a system that has both descriptive and normative capacities, and considers the importance of the organizational nature of scheduling decision-making process

-- the importance of the operations control process in the airline industry

-- the conditions under which operations planning and operations control could be joined together.
3.1 Introduction

This chapter describes and analyzes the overall system design. The chapter has four sections:

1. Overall philosophy and guidelines for design
2. Functional components of the system
3. The technical structure of the system
4. The software design and flow of control.

3.2 Overall Philosophy and Guidelines for Design

3.2.1 Potential Users

The system is intended to support two planning functions within the airline organization:

-- the operations planning level, where optional test schedules are produced periodically. These are the sets of alternatives that are evaluated later through the planning process.

-- the operations control level, where "real time" decisions regarding the operation of the schedule are made.

The overall design of the system, in terms of characteristics of information and operation, is motivated by the above two planning functions. For airlines with relatively simple networks (i.e., no more than 100 flight segments a day), the system is capable of doing both planning and control. For airlines with more complicated networks, only partial or local analysis can be performed using the system (i.e. planning a subnetwork or analyzing a limited group of isolated links).
3.2.2 Decision-Making Function

The designed system is micro-computer-based and it intends to support schedule operation decisions. The system will provide the user with the data management support, computation handling and structural evaluation. In other words, all the parts of schedule planning which are structured will be done using the computer. The non-structured part of the planning process is left to the decision-maker's judgment.

This provides the decision-maker with a supportive tool, under his own control, which does not attempt to substitute for human judgment in the decision process, predefine objectives or impose solutions.

3.2.3 Levels of Support

Four levels of supporting tools are offered by the designed system:

1. The first level of support provides access to data and information retrieval. The decision-maker can retrieve information on the total schedule for a given period of time, all the flights operating a route, etc. This information is helpful in cases where a decision-maker is looking for total number of services, or in situations where manual evaluation is to be performed.

2. The second level of support involves the addition of data access filters and pattern recognition to identify basic trends in the schedule data. This level of support provides the decision-maker with the ability to selectively ask for information and to give conceptual meaning to the schedule information. Two examples are: (a) aircraft patterns on the network map, which are useful for operational followup;
and (b) cost fluctuations on a given flight segment for the entire fleet of type X aircraft, which are useful for cost performance followup.

3. The third level of support adds more sophisticated computational facilities to the first two levels and it permits the scheduler to ask for quantitative analysis, comparisons, and performance evaluation of the schedule. It is based upon both existing state-of-the-art evaluation techniques and newly-developed evaluation criteria. As an example, the scheduler could ask for cost revenue analysis and compare the performance of alternative schedules.

4. The final level of support is a set of decision models to support ad hoc problems through the schedule decision-making process (for example, a model for rerouting aircraft in the case of schedule disruption). The emphasis is on non-sophisticated mathematical models, using heuristics, that could be easily applied and provide immediate and adequate answers to problems raised through the schedule planning and control process.

3.2.4 The Software Interface

To make an efficient use of the computer resources, the system's designer is usually looking for clear coding, hierarchical structuring, keying techniques for data access, table-driven commands, etc. The user, on the other hand, is not interested in all the techniques used to provide him access to the computer, but rather views the system through the interface that provides him access to the data, the application software and the hardware.

The design of the interface attempts to achieve the following guiding principles:
1. **Communicability**: The system is genuinely conversational, with a well-defined, simple process of menu-driven commands for submitting requests, switching to new data sets or performing different functions. Thus typing is almost avoided and all requests are English-type or simple numbers.

2. **Robustness**: The system contains internal checks, both at the logical level and at the structural level, to prevent users from making mistakes or presenting nonessential output. Each check is performed as early as possible throughout the session, in order to correct for errors as soon as possible.

3. **Ease of Control**: This is an extension of communicability, in which the system attempts to maintain a standard sequence of operations by employing a menu-type approach. Thus, the user is not forced to employ a vocabulary which is unnatural to him.

3.3 **Functional Components of the System**

As we have seen in earlier chapters, the scheduling decision-making process is a very complex one, and different levels of decisions regarding the schedule need different support in both the type of information (details and nature) and type of computational details and complexity required. Regardless of the particular computational level needed, there are several key functions which are common to all levels of analysis.
3.3.1 Data Base Generation

This function provides the tools to create a new schedule, namely the insertion of relevant data for a single flight segment or a complete set of flight segments which establish a network of airline services. In addition to creating the schedule itself, the generation function must have the capability of creating the support information for the operational plan: aircraft data, station data, city pair data, cost and income data and a set of miscellaneous data, all of which are crucial for establishing a complete picture for scheduling decision-making (see Appendix A for a detailed description of the data base files).

3.3.2 Data Base Updating

This function provides the tool for updating existing flights within an existing schedule (i.e., modifying information, or completely deleting a flight or a flight segment) and to add new additional flights or additional segments to the schedule. This process of updating is also applied to the support information.

3.3.3 Information Retrieval

Information retrieval should be available at different logical levels according to the ad hoc needs of the decision-maker; thus, the schedule information should be available for retrieval on a time basis (periodical schedule), station basis, city pair basis, aircraft basis (individual or a fleet) or market area basis. This means, of course, a sophisticated direct access method must be used to increase the retrieval speed on one hand and system utilization on the other (i.e., fewer input/output oriented transactions and better use of the processor).
3.3.4 Manipulation of the Schedule Information

The manipulation function provides a tool for the schedule decision-maker to perform basic changes in the schedule during the planning process, or during the control process without affecting heavily the existing schedule. This operation is especially effective and powerful throughout the process of "sliding", or varying the operating times of a flight, while keeping the rest of the flight structure unchanged. A detailed analysis of this function appears in Lubow (17, p. 70-74). The primary goal of this function is to get immediate response to local changes in the schedule, allowing these changes to be tested in a simple and easy-to-apply way.

3.3.5 Schedule Validation

While the basic logical check regarding individual items of the schedule takes place during the generation process, there are checks which must be performed at the global level (i.e. after all pertinent data has been entered). There are two levels for this process:

1. Logical validation (legality of the schedule) -- At this level we check issues such as duplicate flight numbers, legality of arrival or departure (availability of time), availability of aircraft to perform a given flight, etc.

2. Operational validation -- This set of validation checks notify the decision-maker about phenomena within the schedule that although operationally feasible, might be unacceptable from a performance point of view. Examples include extremely low
load factors, unbalanced use of a fleet, station or city pair without service, etc. The purpose is to make the scheduler aware of these effects. The decision-maker will decide whether the phenomenon that was encountered was intended or a simple mistake in the planning process took place. One can describe the validation process described here as a zero-order approximation of the schedule's basic attributes, before the actual process of evaluation takes place.

3.3.6 Schedule Evaluation Function

Schedule evaluation is the process of reviewing the consequences of alternative schedules to determine whether they meet a set of goals the scheduler and the decision-maker are striving for, and to provide the decision-maker with a set of common criteria to compare and scale alternative schedule options. A detailed analysis of the evaluation function, its role and the problem it presents to the analyst appears in Chapter 4.

3.3.7 Schedule Disruption Handling

Schedule disruption handling is the last functional component of the scheduling planning and control system and it is the most important tool for schedule control. Schedule disruption as a result of unexpected changes within the scheduled pattern of operation can be grouped into the following basic categories:
1. Unexpected availability of aircraft: maintenance problems, grounding or permanent loss
2. Ground delays
3. Inflight delays
4. Cancellation/adding a flight
5. Station closed
6. Flight rerouting

The system should provide the decision-maker the tools to decide promptly on the next event of the operations process, or provide management with a set of feasible alternatives, including their economic value, to be considered for decisions on the next step to be taken. The common base objective of those alternatives is to minimize the interruption of the regular flow of the system that has not been affected by the unexpected change in the schedule pattern.

3.4 Technical Structure of the System

This section describes in detail the technical framework of the computerized system: hardware, software and data structures. To accomplish this task, we perform a functional decomposition; the components of the management information system are itemized and grouped into distinct levels, such that each level uses functions of the level below.

3.4.1 Level 1: Bare Machine

The issue of what type of machine to use for schedule planning and control is of major importance. Airlines are usually "computer-
intensive' organizations: the reservation system, interline accounting and other large-scale, highly-distributed operations, demand large mainframe computers with sophisticated operating systems, large main memory and vast amounts of secondary storage.

The question of whether the schedule planning and control process should take place within the mainframe, sharing its resources or on a smaller independent computer with an option to be connected to a mainframe via a telecommunication system, is always an important issue in computer system alternatives evaluation. Even though there is no clear answer to this question, the following points should be considered during the decision implementation strategy:

1. If current and future capacity of the data processing system and response time is below acceptable standards, then an airline should consider upgrading the current capacity of the mainframe, purchasing or renting a bigger, faster and more powerful mainframe, or adding an independent, task-oriented processor that will take over some of the tasks currently executed in the mainframe.

The new microcomputer technology provides very powerful and efficient computing and data processing capabilities, at a relatively low cost. The current costs are actually low enough that most micro systems can be purchased for prices that are within the budget of a department head.

2. For airlines with a relatively low level of operation, a microcomputer-based planning system can provide a low-cost and low-risk data-based processing tool, with a variety of options for future upgrading, both by upgrading existing hardware at low cost, or by adapting advanced technologies upon availability.
3. Current technology for microcomputers is based on standard 64K RAM memory complement. This is the minimum memory size that can be effectively used for the type of functions presented earlier. This is also the minimum memory required to develop software utilizing high-level, object code creating languages (FORTRAN, PL1 and PASCAL). In the near future, the standard will be a 256K machine, for prices around $8000, with vast amounts of fast access secondary storage for data storage.

4. Current technology (8 bit, 16 bit and 32 bit machines) provide a relatively large number of machine instructions (the variety of options and instruction grows as processor size grows from 8 bit to 32 bit). The technology is also marked by efficient architecture, the use of advanced memory management technology, I/O management, bus structure, and high resolution screens. These offer the user very fast payoff in terms of response times, throughput, and productivity: To implement a test version of our design we selected a machine with an 8 bit Z80A processor with 64K RAM. The Z80A is one most extensively used 8 bit microprocessor. The code is extremely machine-independent, which allows easy transfer of software among different processors (including of course, mainframes).

3.4.2 Level 2: Operating System

The operating system is the major device for managing the computer resources (mainly hardware). It controls all the computer resources, thus making the application code machine-independent. The result is a code that can be applied on any machine that supports the particular high-level language. Although the system has been developed and tested
under the CP/M operating system, it can easily run under any other micro-oriented operating system (DOS, RMOS, UNIX).

3.4.3 Levels 3,4,5,6: File System, Primitives for Fields, Records, and Structures

The file system consists of the physical manner in which data is stored in the system, and the logical and physical structure by which data is stored, updated, and retrieved.

The Physical System -- The current implementation of the system needs a minimum of two 8" floppy disk drives with disk capacity of about 1 million bytes in double density. This space is adequate for the operating system components, an editor, the language compiler, the application software and approximately 500,000 bytes of data. The ultimate size of the physical system depends very heavily on the level of sophistication of the complete scheduling system. Two statements, however, can be made:

1. The system with minimum operational development (see 3.4 for details) needs only the above disk capacity.

2. In the future the physical system can be increased to 10 million bytes, by using a Winchester-type disk, which will also provide faster access to information.

Logical File System

1. Data redundancy and consistency -- The system is designed so that every data item appears only once in the entire data base. The major motivation for this policy is to reduce the
need for space, both in primary and secondary memory, and to make the updating process easier and more reliable (maintain consistency). In addition, only relevant data resides in main memory at one time.

2. Retrieval speed -- Retrieval speed of the information is a major consideration for the schedule evaluation and schedule control process. Using automatic keying methods while maintaining the relevant keys in core is an important feature for achieving high information retrieval speeds and efficient use of main storage.

3. Update speed and data integrity -- Maintaining the integrity of a single user system is mainly achieved by manually maintaining logs of the data in case the system crashes. Unfortunately, this is hard to achieve in micro systems; standard backup files are produced to obtain some degree of integrity. Update speed is achieved by use of automatic keying methods.

4. Level of Information Details

There exists a conceptual conflict between very detailed data items and the amount of main storage available. The data structures have been designed in such a way that the smallest unit of analysis comprises an atomic unit data record. For example, the flight segment is the smallest unit of analysis; aircraft costs are individually treated,
while aircraft speeds are aggregated into groups. The same is true of station costs, which are a function of aircraft type.

5. Time horizon -- In order to comply with the industry standards, the user can choose either a day as the time unit of planning or the entire week. The only difference as far as the system is concerned is that in the weekly case, an automatic date generator is operated. When the evaluation process takes place, the user has to input whether the schedule currently evaluated is weekly or daily.

6. Source of information -- Information can be supplied to the file system manually by using a terminal or by means of distributed processing. All the information is available from within the airline itself.

The system's logical files

1. Schedule file -- Direct access keyed file, contains the schedule information; the basic logical record in the flight segment. The logical file contains flight number, time information, aircraft information, passenger and cargo loads and information on continuing segments.

2. Station file -- Direct access keyed file, contains information about the stations in the airline network; the basic logical record is the individual station. Each
record contains geographical data of the station, cost data, and operational restrictions.

3. Aircraft file -- Direct access, keyed file, contains information about the airline fleet; the logical record unit is comprised of the individual aircraft. Information includes identification data, cost data and performance data of each individual aircraft (i.e. speed, fuel consumption, weight, seat capacity, etc.).

4. City pair file -- Direct access, keyed file, contains information about the airline available direct links; the basic logical record is comprised of the individual city pair. Information contained in the record includes flight time for various groups of aircraft, cost over the link, tariffs for the various passenger types (first class, coach and economy) and fare structure.

5. Market file -- Direct access keyed file, contains information about designated market areas; basic logical record unit is a market area. It contains information about stations included, combined cost and tariff structure, and operational restriction for the area.

For a detailed description of each file, see Appendix A.

Besides the operational files, two additional miscellaneous files are included in the system.
1. File containing synthetical\(^1\) data, mainly on per-unit cost, for use in cases where individual data is not available. It functions also as a default file.

2. Aircraft type table is a list of most of the commercial aircraft in service. This is maintained for conversion purposes (aircraft type is maintained in the schedule file only as a two-digit data item, which can be converted to a specific type by using the aircraft type table).

3.4.4 Level 7: Data Security

Issues of security in microcomputers is not as crucial as it is in the case of a mainframe multiprogramming environment, because the user himself loads and unloads his disks, and he protects his own data and software. Features such as passwords to data are included in the system design.

3.4.5 Level 8,9: Source Programs and Query Language

The decision about what type of programming language to use, and the type of query language, is usually a hard one, and any decision taken can not reasonably expect common agreement. Many high-level languages are available for microcomputer applications, the most common being BASIC and PASCAL. Both languages have many versions which can make the code incompatible among different microcomputers. In addition, upward compatibility is also a problem due to the difference in versions

\(^1\) By synthetical, we mean aggregate data indifferent of aircraft type, market type, etc.
between the microcomputer versions of these languages and mainframe versions. PASCAL and BASIC carry out some memory management functions within the application program which makes the code even less machine-independent.

PLI-80, which is a subset of standard PL/I-G level (currently supported by main vendors such as IBM, Honeywell, Prime and recently, DEC) is easily upward-compatible. The language is structured, source code is compiled and partially optimized, and applications run on object code, which makes response time much faster than interpreter-oriented language.

All the queries are menu driven, thus no prior knowledge of the system's operating procedure is required. Each time the designed system is looking for a user response, it will prompt him with the appropriate set of options available for him at this particular stage. Internally, each option is a simple procedure call which makes it very easy to add or update features in the programs themselves.

3.5 Software Design and Flow of Control

The system has a main program (the ROOT) that is loaded by the user upon his request, and which prompts the user to seven functional blocks. Each block can be called by the ROOT upon his request. Each block is an overlay which has been defined during the linkage process. The use of overlays is the prime tool to overcome the problem of a relatively small amount of core storage. Taking advantage of this method of fixed memory allocation is currently the most-advanced feature for memory management in microcomputer systems. Currently it
is available only by using PLI-80 under the CP/M operating system, but the code is independent of this tool. Furthermore, the code is designed in such a way that if demand paging arrived as a new technology in microcomputer operating systems, it can still be run efficiently.²

The following are the system's functional blocks. Those which have been starred have been completely or partially implemented.

1. ENTER*

This block executes the process of data entry, mainly schedule generation, through an online conversational process. The user is prompted by the block's procedure to enter schedule information. Upon completion of entering information about a flight segment, the data is transferred to the ERROR procedures which check for the legality of the user's data. The user is prompted again to correct data in case of errors, or for entering passenger loads in case flight information has been successfully generated (see Chapter 5 for a detailed example).

² The following principles were adopted to achieve this goal:

a. Reduce the number of start I/O for sequential data sets (i.e. key files)
b. Modular programming
c. The mainline of the system contains the most frequently used subroutine in the sequence of most probable use
d. Frequently-used subroutines are closed to each other
e. Data fields are initialized as close as possible to the time they are used to avoid paging in and out between initialization and first use of the data
f. Structure of data are defined in such a way that order is kept according to sequence of reference.
2. UPDATE

This block executes changes in an existing schedule, the user can add new flights using the ENTER block capabilities and error utilities, or can change or delete existing flights. Updated data is kept in temporary files, in order not to alter the existing schedule, and the existing schedule is changed only upon the user's request.

3. VALIDATE

This block performs a set of legality and reasonability checks on the schedule and reports to the user any irregularities in the schedule. The block is basically composed of a set of checking and testing algorithms.

4. EVALUATE*

This is the major planning decision support tool of the system. It uses a set of measures and indices about the performance of the schedule to generate reports on the schedule's performance. A detailed analysis of these measures and indices appears in Chapter 4. Upon request for evaluation, the user is prompted to decide what level of evaluation is desired. This can be evaluation of the complete schedule, or evaluation of city pairs, stations, aircraft fleet or an individual aircraft schedule. At this stage the direct access methods to the various files are used extensively, again to overcome the problem of limited main storage space.
5. **TYPOUT**

This block provides an interface between the internal files and the type of information the user would like to use as an output. The user can produce the schedule information by station, city pair, aircraft, or a complete periodical schedule (weekly or daily).

6. **SUPPORT DATA GENERATION**

This is a set of conversational programs for creating the Aircraft*, Station*, City Pair*, Market, and General Information* files. The user is prompted to enter his information and upon completion, the files are keyed and stored on a disk.

7. **CONTROL MODULE**

This module is comprised of a set of prompt alternative evaluation models for handling schedule disruptions. The user tells the system the type of irregularity he faces, and the system tests for a set of predefined options. The design of this module is not complete and has been left for future research.
3.6 Conclusion

The system presented here is designed with two major goals:

1. To provide the airline industry an easy-to-use, reliable, and adequate decision support tool for airline schedule planning and control.

2. To provide a low-cost, compatible and easy-to-upgrade microcomputer software package for airline schedule planning and control.

These goals are achieved by:

1. Using efficient hardware and an appropriate operating system.
2. Using a high-performance, high-level language, with transferable machine-independent source code.
3. Applying overlay techniques for efficient memory management and direct-access methods to increase performance and response time.
Chapter 4
THE PROCESS OF AIRLINE SCHEDULE EVALUATION

4.1 The Role of Schedule Evaluation

In Chapter 3 it was argued that the major goals of our system included an efficient and effective tool for evaluating information embedded within the newly-generated schedule, and also providing powerful tools for supporting a decision regarding the choice of a schedule among specified alternatives, or recommending changes in the proposed set of alternative schedules.

The process of schedule evaluation is the methodology used by the decision-maker to decide upon a final schedule. The major goals of this process is to provide valuable and coherent answers to questions such as anticipated level of service, resource utilization and usage, cost and revenue of operating the proposed system, and input-output ratios. It may also be used in evaluating policy decision-making and their impact on operations or economies of the aggregate airline system. Although the process and its objectives are clear, the implementation of a schedule evaluation system and its decision support tools is not a trivial issue and many complicated problems must be resolved before a system can be implemented.

This chapter is comprised of three parts. The first part describes the desired properties of evaluation criteria in the general sense. The second part is a brief discussion on the nature of air transport economics and the problems it introduces to the process of schedule evaluation. The third part is a description of the proposed indices, measures and methodologies for the schedule evaluation process.
4.2 Evaluation Criteria

The process of evaluating alternatives can be expressed as comparing the values of various indices and measures which the decision-maker is able to value and rank, either on an ordinal scale, or on an interval scale. In some cases neither are available and the decision-maker must attach some qualitative, judgmental value to each measure. In order to provide the decision-maker with the ability to do so, the measures must maintain several properties. In general, the process of selecting schedule evaluation indices and measures is guided by the following properties.

4.2.1 Appropriateness or Validity

The appropriateness of a measure is the degree to which it measures what was intended to be measured. In our case, we want to compare and evaluate alternative schedules. Any index which does not contribute directly to this goal is considered inappropriate. For example, the system promotional costs which are part of the system operating costs, while interesting, are inappropriate for the purpose of schedule evaluation, because it does not reveal any information regarding the attributes or the merits of a particular schedule.

4.2.2 Reliability of a Measure

The likelihood that several decision-makers starting with the same data, observing the same value for the measure, will come to the same conclusion, at least in an ordinary basis, is known as the reliability of a measure. If, for example, the index is vehicle utilization, there will be no ambiguity among decision-makers which value is higher and
thus better. Reliability is necessary to ensure that measures are transferable and replicable, regardless of local scenarios or circumstances.

4.2.3 Ease of Computation

The property of ease of computation is self-explanatory in general, and has special importance if the measures used are part of the D.S.S. This is due to the simple fact that measures which are easy to compute are usually easy to grasp and hence easy for decision-makers to deal with.

4.2.4 Relevancy

The relevancy of a measure is the degree to which the measure pertains to the issues addressed throughout the evaluation process. Many input/output ratios might be good indicators regarding some issues in the schedule evaluation process, though irrelevant to other issues. In the context of this work, relevant measures are those which are related to measuring elements of the quality of the schedule, such as supply, demand, load factor, and network design.

4.2.5 Sensitivity or Responsiveness

In order for a measure to reflect a change in the value of an important variable that affects the properties of the schedule, it has to be independent of compensating processes, which may take place simultaneously. Suppose, for example, that schedule A and schedule B are each producing 100,000 passenger miles. Schedule A carries 100 passengers while schedule B carries 500 passengers. One might argue
that the two schedules are equal in output. Suppose now that schedule A doubled its carried passengers to 200 passengers while reducing its average stage miles to 500 miles. The output apparently is still the same, even though a clear change took place which is not reflected by the single passenger-miles measure. In order to notice such differences, we need measures which are sensitive and responsive to the above changes.

4.3 The Economics of Air Transportation and Its Effects on Schedule Evaluation

The purpose of this section is to summarize the major properties of the economics of air transportation and the problem they present in choosing appropriate evaluation measures, which maintain the properties listed in the previous section.

4.3.1 Objective Function

Taneja, in his book *Airline Planning: Corporate, Financial and Marketing* [10, p. 13] states the following:

"The stated objectives inform various groups of what the airline wants to achieve;...Since the objectives of the airline provide the overall direction for the planning process, they should be stated explicitly so that there is a common understanding among the different levels of the team members who are expected to achieve them....In some cases, it may not be possible either to state some of the objectives in quantitative terms, or to be sufficiently explicit in their measurement....In each of these cases, an attempt shall be made to express the objectives in as concrete terms as possible to facilitate communication and measurement of actual performance.''

This statement expresses probably in the best way the internal paradigm between the actual set of objectives an airline sets, and the complex process of trying to evaluate a schedule against those
objectives. The reason for this phenomenon is that airline objectives are multidimensional, hard to define and sometimes contradict each other. Each individual objective function might be "uniquely defined", "well behaved", etc., but it becomes almost impossible to combine them together and get a single value on a common basis. Sometimes, the functions are defined only qualitatively, and an attempt to attach to them a quantitative value would probably not produce a measure that maintains an intrinsic meaning. The classic O.R./economics approaches have tried to classify three objective functions:

1. Traffic maximization at zero losses (maximum traffic case)
2. Maximum profit optima
3. Optimal service with subsidy

All three objectives functions are rational, but in most cases do not operate in an isolated environment. Thus a traffic maximization objective function might be combined together with maximum load factor objective function. In some cases (especially government-owned airlines) employee welfare is stated as a corporate objective.

When a scheduler is producing a schedule, he attaches to each objective function a subjective weight. The total sum of these weights is what the scheduler believes to be the best solution. When the process of evaluation takes place, it is important that the decision-maker have access to the mutually-exclusive values of each objective function. By adapting this concept, the decision-maker can attach to each individual objective function a value and evaluate the schedule according to his subjective judgment. The system has to report the values of each of the objective functions considered and what it intends to measure. This important concept has to be carefully explained to
the decision-maker. The DSS should present the value of each precon-
sidered objective function value, with an explicit explanation of the
role of the specific measure.

The following is a basic list of "objective function" type values.

1. Traffic carried (maximized, usually up to zero loss)
2. Profit (maximized usually)
3. Revenue (maximized usually)
4. Cost (minimized)
5. Average load factor (maximized) ¹

4.3.2 Service Between Two Cities

The service offered between two cities is another component in
the economics of air transportation. This service is largely defined by
the fare, frequency of departures, intermediate stops and load factor,
where load factor introduces an independent adjusted degree of
freedom. (This is due to the fact that capacity can vary by choosing
different aircraft sizes.)

Each of the items mentioned above influences the utility of the
schedule to the consumers, their benefits and hence the amount of demand.
These characteristics also determine the costs and revenues for the
operator and hence his profit or loss.

An appropriate set of evaluation criteria has to provide the
decision-maker with the information about:

a. how these four factors were combined together into a schedule

¹ Discussion of the effects of using aggregate data to evaluate the
above measures appears later in this section.
b. which combination of those factors makes one schedule superior to all other alternatives

We can summarize the economics of city pairs in air transportation as follows:

4.3.2.1 Supply Considerations

a. Total capacity and frequency are interchangeable and can be adjusted independently, although over a unit of time, their arithmetic product should be constant and lower-bounded by the perceived traffic level.

b. The cost of frequency is associated with vehicle trips, operated through the schedule, but not the cost of seat trips or passenger trips; hence frequency takes on the aspect of a fixed cost. This is a very important observation, especially in the case where total demand has been determined externally, usually by employing some simplistic assumptions about demand and market share in the city pair level (i.e. that market share has been derived a priori from a classical S curve). In this case each schedule has a different cost per seat, since average cost per seat falls with the number of seats, and as mentioned above, frequency takes the place of the fixed-cost element in the total service cost.²

² There is a set of airline operating costs which are independent of the
4.3.2.2 Demand Considerations

The demand scenario presented in this thesis is very simplistic; this is driven by three reasons:

a. Machine size -- the computational capacity of the hardware does not allow for very sophisticated, highly-detailed demand models. Provisions were made to add more sophisticated demand models in the future.

b. The use of complicated models as part of a Decision Support System might be counter-productive, at least in the first stages of the implementation process, due to the intrinsic resistance this type of models carry.

c. Sophistication policy and pace of upgrading the system should be determined by the user. This is an extension of reason (b). The motivation behind it is based on the idea that the user, through the use of the system, will develop a view of what further sophistication is needed.

This simplification suffers from some deficiencies in the way it describes the real world. One has to realize that schedulers are usually experienced and have a sense of real-world behavior, and hence the output (i.e. seat trips or passenger trips which vary with the physical movement of an aircraft). Maintenance burden or fixed station costs are examples of costs associated with aircraft operation (frequency) rather than passenger trips or seat trips.

![Diagram showing relationship between FOC and Pax trips.](image-url)
allocation of passengers to the individual flight is not completely indifferent to level-of-service considerations, at least with respect to departure time. While evaluating the schedule, a manual check regarding the reasonability of the passenger load has to take place.

4.3.3 Networks

City pair traffic is only a subset, or a link in a much more complicated structure that is established by the airline schedule, namely, the network of services between various city pairs. This network is defined over time and space and includes all the services offered between each city pair in the network over a given period of time. Airlines operate networks because there are technical cost savings gained in so doing. These savings come from combining passengers from several markets onto a single large aircraft. The observation that larger aircrafts have lower cost per seat, but cost/mile is reduced as stage length increases has been shown by Simpson [11, p. 35].

The issue of aircraft economies of scale as suggested by Swan [12, p. 218] is not totally clear, because the savings gained by combining passengers from several markets onto a single large aircraft are likely to be overshadowed by the higher cost per stage-mile resulting from many stops along the route, and possible reduction in market share due to reduced level of service.

This observation regarding the nature of flight operating cost creates a complex tradeoff in simultaneously selecting aircraft size and routing for a schedule of service over a network of markets. In focusing on network structure and its implication on the quality of the schedule, we have to consider at least the following fundamental
observations:

1. Transportation services are operated in networks because most markets are too small to be served alone, and networks are a powerful means of mitigating the problem of aircraft capacity. The fundamental gain in the process of network design is in the direction of increased aircraft loads, thus allowing increased aircraft size. Those scale economies are partially lost because load building means more expenses in stops, shorter stage length, and lower level of service.

2. Networks are sometimes measured in terms of seat-miles or ton-miles. These are aggregate measures of network extent and they do not provide any information about the cost of the service offered or about the characteristics of this service.

3. Available seats are jointly and simultaneously being offered to multiple markets. It is not possible, however, to determine the quantity of seats being offered to any individual market embedded in a network service (see Simpson [9, p. 15]).

4. Network design responds to three interrelated variables: number of terminals, number of markets and markets per terminal. The first is determined by the number of nodes in the network, the second relates to the number of city-pair markets or links, and

3 This simple example will clarify the point. Suppose an airline offers a flight A-B-C-D with connecting flights at each point. If the seat capacity of the aircraft assigned to this flight is 100 for a given class of service, the total of seat sales in all markets served by a given flight segment will be normally kept less than 100. If a seat is sold in the market AD, we must remove an available seat departure from space being offered in markets, AB, BC, AC, BD and CD, and all the connecting markets. It is clear that the available seats are jointly and simultaneously being offered to multiple markets.
the last one identifies the relationship between the individual nodes and links. These observations suggest that if a schedule is to be evaluated with relation to its network design, the above interrelated measures are to be captured.

5. For assessing costs, or general viability of networks, measures of the density of network services are useful indices because they identify the state of the network. Such measures include:
   -- aircraft capacity averaged over miles, departures or block hours
   -- stage length averaged over aircrafts or seats
   -- link frequencies or link departures averages over links or link miles, links per city and departures per city.

6. The distribution of stage length, aircraft capacities, frequencies and the correlation among them affect general cost and service levels offered over a network.

7. In many cases (excluding the U.S. domestic trunk network), a sparse network exists. Under these circumstances, the flexibility in routing and aircraft capacity control is minimal, and instead we are facing an assignment problem of aircrafts on timeslacks, rather than a network design process.

8. Recent economics studies [13] have identified three sources of economies which are embedded in the transportation network structure:
a). Economies of larger output

\[ \text{larger more efficient aircraft} \quad \text{has cost advantage over} \quad \text{smaller less efficient aircraft} \]

b). Economies of network configuration

\[ \text{joint production} \quad \text{has cost advantage over} \quad \text{non-joint production} \]

Hub networks with connecting services have cost advantages over linear networks with multistop service.

c). Economies of network operation

These economies result from combining the proper aircraft with the proper routes and making better utilization of the airline's terminal system, the airline equipment and the connecting system.

4.3.4 Aggregation Vs. Disaggregation

The above analysis so far suggests that while many factors affect the economics of a proposed schedule, aggregation of these factors will lead to loss of information at best, and biased information leading to wrong conclusions at worst. This conclusion is motivated by the classical property known in econometrics as "heteroscedasticity". An example of this phenomenon is the process of trying to estimate a cost function with pooled data from two different true cost structures. One
has low true cost per unit of production, while the other structure has high true cost per unit. Trying to estimate them together will lead to the following untrue estimated cost function

![Graph showing cost vs. units of production with low and high true costs.]  

As we see by this conceptual example, aggregation might be misleading.

Complete disaggregation, on the other hand, is also misleading, because the information does not consider any interacting effects embedded or created by the correlated effects (i.e., network structure).

Constructing a set of measures that will maintain the properties described in Section 4.1 on one hand and also give comprehensive, consistent, and unbiased information on the other hand, is the central problem in deciding upon the level of disaggregation that is appropriate. On one extreme, we have complete aggregation over the complete network, which is the current practice in producing evaluation measures. On the other extreme we can analyze each city-pair separately, which suffers of course from lack of information about intercorrelated effects.

Deciding about the "correct" level of disaggregation is deciding about the practical amount of information which can be compiled easily by a decision-maker. In this study the decision was to disaggregate the
information over short haul (less than 500 miles), medium haul (500 miles to 1500 miles), and long haul (1500 miles and more). The rationale behind this level of disaggregation is the following:

1. There is a set of economies, especially those which are related to vehicles, which are characterized by the length of haul. Each aircraft has an optimal range within which the cost per mile is the lowest. Widebody aircraft, for example, usually have lower cost per mile on long-haul flights. Issues such as breakeven load factors are also different for short-haul and long-haul flights. Thus, separately treating them would not suffer from loss of information which is typical for a complete aggregation.

2. Planners envision each of these groups as differently-characterized markets, especially in terms of the type of service, frequency offered, anticipated loads and, to some extent, the nature of travel. Short-haul services are more concerned with higher frequency, cheaper fares that are competitive with ground transportation, but less concerned with issues such as inflight services or passenger space. Long-haul services, on the other hand, are more concerned with good time slots than with frequency offered. Inflight services have major impact on the structure of service and the cost of providing long-haul services.

3. Long-haul services are less sensitive to multistop flights within a reasonable range (up to two stops), than short-haul flights, hence the nature of the network connectivity is crucial for short-haul services.
It should be mentioned that this level of disaggregation is incomplete, because it does not deal properly with the issue of hedonic market nature. One should realize that two hauls with the same length might be completely different in their market nature and with their relation to the complete service network. A simple example is the New York-Boston market, which is characterized by heavy business travel, and the Los Angeles-San Francisco market, which is characterized by more heterogenous traffic.

4.4 Schedule Evaluation Measures

4.4.1 System-Wide Performance Measures

1. **Available seat miles** -- the sum over all flight segments of the segment length times the aircraft capacity. This measure is reported both system-wide and by haul length groups, and will indicate to the decision-maker the aggregate input of the system in terms of capacity available, and the aggregate input for each group of hauls.

2. **Revenue passenger-miles** -- the sum over all flight segments of the segment load times the segment length. This measure is reported both system-wide and by haul length groups, and will indicate to the decision-maker the aggregate output of the system, and the aggregate output for each group of hauls.
3. **Total enplanement** -- the sum over all flights of the number of passengers allocated to each flight. This measure is reported both system-wide and by haul length groups and will indicate to the decision-maker how passengers are distributed over the different flight types.

4. **System load factor** -- RPM/ASM on a city-pair basis, averaged over the complete system, and over length of hauls. These different levels of reporting will enable the decision-maker to analyze the sensitivity of the load factor achieved for each group of flights against some predefined breakeven load.

5. **Average segment miles**

6. **Average segment seats** -- these two measures are reported both on the complete system level and on a haul length group level, and will indicate to the decision-maker the distribution of seats over the network.

### 4.4.2 Vehicle Utilization and Usage Measures

1. **Average utilization** -- average number of block hours for the entire fleet and for each aircraft type fleet. This measure provides the decision-maker with two important data items:
   
   (a) the number of hours an average aircraft in the fleet is occupied. This can be compared to a predetermined number
to get an idea about the degree of freedom that the vehicle system has.

(b) The distribution of aircraft hours among the various aircraft types, which provides information about the balance of operation and the aircraft load on a market basis, which provides information about the quality of the fleet mix.

2. Block hours/flight hours ratio -- computed for the entire fleet, and provides information about ground time delays for different markets.

3. Average stage length -- for the entire fleet and on an aircraft type fleet basis.

4. Out of optimal range ratio -- the ratio between the total number of miles flown outside the airplane optimal range to total miles flown, on an entire-fleet basis and on aircraft-type fleet basis. This ratio will provide the decision-maker with information regarding the efficient usage of the fleet.

4.4.3 Monetary Measures

1. Flight revenues -- reported for the complete system and for each haul length

2. Direct flight cost

3. Passenger service cost
4. Fixed cost
5. Total operating cost
6. Operating revenue

All of the above are reported for the complete system and for each haul length, in order to provide the decision-maker with the information regarding the variability of the monetary measures for each group of haul lengths.

4.4.4 Network Flow Measures

The set of network flow measures will provide the decision-maker with information about the inherent nature of the network of services in terms of flow distribution. It will enable him to distinguish between two schedules, when the nature of flow within the schedule is the basis of comparison. Most of the discussion in this section is described in detail in Gordon [14, pp. 88-98].

1. Network connectivity measure -- measure the ratio between the actual number of links in the network and the maximum links available:

\[ \gamma = \frac{\ell}{n(n - 1)/2} \]

where
\[ \ell = \text{number of connected links} \]
\[ n = \text{number of nodes in the network} \]
\[ n(n - 1)/2 = \text{maximum number of links possible in an } n \text{ node network.} \]
2. Network density measure -- measures the network in terms of passenger-miles flown, and the effect of the distribution of passengers in the network:

\[
x = \frac{2(\sum f_j)^2}{\sum f_j^2 n(n-1)}
\]

where

\(f_j = \) number of passenger miles in link \(j\)

\(x\) is maximized when \(f_j\) is equal for all \(j\). The measure is normalized by the maximum number of links possible in the network, allowing comparison of networks with different numbers of nodes.

3. Network coverage measure (indirect routing index) -- this is a circuitry factor scaled by passenger-hours instead of comparing number of links or distance.

\[
\phi = \frac{\sum \text{pax}_{ij} T_{ij}^1}{\sum \text{pax}_{ij} T_{ij}^0}
\]

where

\(T_{ij}^0 = \) direct flight time from \(i\) to \(j\)

\(T_{ij}^1 = \) routing time from \(i\) to \(j\)

4.5 Summary

In this chapter, we described the properties that are essential for a performance measure to be a decision support tool. We concluded that it is important to have disaggregate measures and we presented a set of measures which are useful under the assumptions made here concerning
the decision-making process. Although some first steps have been taken, the issue of quality measures for schedule evaluation is not completely resolved and a great deal of work still has to be done before a complete set of measures can be developed and used for schedule planning decision-making.
Chapter 5
SAMPLE USAGE

5.1 Introduction

This chapter illustrates the implementation of some of the concepts developed in the previous chapters. The following points are stressed:

1. System communicability
2. Ease of control

These points are illustrated by means of a typical user session, emphasizing some of the features that help to accomplish the design principles. All the exhibits shown in this chapter are actual printouts from a conversation with the implemented system. User input is shown in boxes.

5.2 Generation of the Supportive Data Base

Exhibit 2 shows a typical session, required to create an aircraft data base. Upon initialization, the user is prompted to enter his first aircraft, starting with the aircraft registration number. A standard 'EOF' convention is used to indicate the end of data for the current input data set. As each data item is entered the user is prompted to enter the next set of data items. Notice that the input is format-independent (list-oriented), thus relieving the user from the burden of fixed format input.

As can be seen in the first sample input line, the only requirement is that blanks (or commas) be maintained between the various data items. Beyond this limitation, any format, as long as the data items are legal,
Exhibit 2. Sample conversation for aircraft data entry

```
0 n12345
1 n12347
2 n25743
3 n84635
4 n592
5 eof
```

End of Execution

Exhibit 3. Sample aircraft key file
is acceptable. In the case of illegal data (i.e. alphanumeric characters instead of digits), the user will be prompted again to enter the correct format. Once the user has finished inserting data, a "key file" for that data will be produced. Currently, due to the experimental nature of the system, we perform the creation of a data set in two separate stages: data preparation and key generation. The current key attached to each record is the aircraft name. This provides a unique identification for each record and a direct access to each aircraft record through its key.

The process of direct access to a record is completed in the following way. At the beginning of the session, the key file is read into an array in the main memory. When a specific record is requested, a search over the keys is conducted until the aircraft name is found, then the record with an index equal to the key's array index is transferred to main memory. The key file is a sequential file allowing the user to search through it by using the editor.

Exhibit 3 shows the key file for the newly-created aircraft file. Exhibit 4 shows a typical session used to create a city-pair file. The characteristics of the city pair file are the same as the aircraft file. The list-oriented, free format data entry principles are maintained and the user is prompted by the system to enter each data item.

In order to maintain a uniquely-defined key, we chose to concatenate the code name of the origin and the destination code name. This method gives us several advantages for future use. Although the key used is directional (i.e., BOSNYC is usually interpreted as a link originating at Boston and terminating at New York City), the system can internally identify it as bidirectional. It allows us to maintain only half the records and the process of maintaining consistency of data
Exhibit 4. Sample conversation for city-pair data entry

Exhibit 5. Sample city-pair key file
becomes easier (only one record, instead of two, must be updated). In cases where the data is not completely symmetric (i.e. east bound vs. west bound flight times), a corrective computation takes place.

Exhibit 5 shows the key file created for the city-pair data set. This file maintains the same design principles as the aircraft key file (namely, it is a sequential file that is maintained as an array in main storage through execution and is searched sequentially every time a specific city-pair is requested. The index for the particular city-pair is the key for direct access to this city-pair record.)

An important objective for upgrading the system in the future is to maintain the efficiency of the data access methods. In order to accomplish this goal, the procedure which creates the key files for each data set can be easily extended to create a B tree-type key file, or to permit ISAM, HISAM-type access methods.¹

The issue of access method is of great importance to the future development and upgrading of the system. The following principles should be maintained in future development of the system.

1. Keys are loaded into memory and remain there throughout the

¹ B trees are multilevel or "tree" indices that have become extremely popular in recent years. The concept has been implemented in IBM's Virtual Storage Access Method, VSAM. The basic idea is to create a sequence set consisting of a single level dense index to actual data; the entries in the index are blocked and the blocks are chained together so that the data file ordering represented by the index is obtained by taking the entries (in physical order) in the first block on the chain, and so on. The index set, in turn, provides fast access to the separate set. For further discussion see Date,[18, p. 47-48]. HISAM is "Hierarchical Indexed Sequential Access Method" and ISAM is "Indexed Sequential Access Method". For a discussion of both systems, see Date [18, p. 313 -317].
complete session. A complicated hierarchy of keys might thus occupy a large portion of the main memory, and if the keying structure is not designed carefully, there may be no advantage over maintaining the actual data in main memory.

2. The hierarchy of the keys should be based on the logical structure of the data. Aircraft, for example, could be keyed at the high level by aircraft type and at the low level by aircraft tail number. The station file should be keyed first by geographical area and then by name.

3. The current structure of the system is oriented towards a single user. In a multiuser environment, we need "write" access locks to the data file. Using multiple keys, based on some logical hierarchy, will provide better system utilization, since the lock is applied only to a high level key, leaving the other parts of the data base accessible.

5.3 The Process of Schedule Generation

After the support data bases have been created or updated, the user can enter his alternative schedules into the system. Exhibit 6 shows the system's message after initialization. This is a basic memo comprised of eight optional actions. In this example, the user has chosen option 1 in order to create a new schedule. Next, the user is prompted by the system as to whether he/she is going to create a daily-based schedule or a weekly-based schedule.

Exhibit 7 shows how the user reacts in each case. After the user introduces the system with the basic information, he is prompted to enter
<table>
<thead>
<tr>
<th>Action</th>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter</td>
<td>1</td>
<td>Create new schedule file</td>
</tr>
<tr>
<td>Update</td>
<td>2</td>
<td>Update an existing schedule</td>
</tr>
<tr>
<td>Validate</td>
<td>3</td>
<td>Perform schedule validity check</td>
</tr>
<tr>
<td>Evaluate</td>
<td>4</td>
<td>Evaluate current schedule</td>
</tr>
<tr>
<td>Quit</td>
<td>5</td>
<td>Quit do not save schedule</td>
</tr>
<tr>
<td>File</td>
<td>6</td>
<td>Save current schedule file</td>
</tr>
<tr>
<td>Type</td>
<td>7</td>
<td>Type cure of current schedule</td>
</tr>
<tr>
<td>End</td>
<td>8</td>
<td>End current session</td>
</tr>
</tbody>
</table>

Enter action number you currently wish to perform.

Exhibit 6. The system's master menu

Enter w if you wish a weekly schedule
Enter d if you wish a daily schedule
d / w ? [5]

Enter month day year (type commas between items): [5, 7, 82]

Enter day of the week: 1 = Monday, 7 = Sunday

Exhibit 7a. Initialization of a daily schedule

Enter w if you wish a weekly schedule
Enter d if you wish a daily schedule
d / w ? [5]

Enter beginning of week date (Monday):
Month, day, year (type commas between items): [5, 15, 82]

Exhibit 7b. Initialization of a weekly schedule
Exhibit 8a. Entering data for one-segment flight -- daily schedule

Exhibit 8b. Entering data for one-segment flight -- weekly schedule.
enter schedule information in the following order:

- flight no. (enter none if no more flights)
- time:hour and minutes of departure
- aircraft registration (tail) no.; 0 if none
- origin and destination of current segment
- contains flight (enter - if same flight contin)
  enter - if no continuation flight
- o-d are illegal bus/rec?
  enter correct origin: bus
  enter correct destination: rec
  now enter passengers to your flight:
  fax from bus to rec

Exhibit 9. Error recovery -- illegal city code

enter schedule information in the following order:

- flight no. (enter none if no more flights)
- time:hour and minutes of departure
- aircraft registration (tail) no.; 0 if none
- origin and destination of current segment
- contains flight (enter - if same flight contin)
  enter - if no continuation flight
- registration no of a/c is unrecognized n12349?
  enter correct a/c tail number: n12346
- registration no of a/c is unrecognized n12346?
  enter correct a/c tail number: n12347
  now enter passengers to your flight:
  fax from rec to atl

Exhibit 10. Error recovery -- illegal aircraft tail number
the actual schedule information. The user is prompted line-by-line to enter his data items.

Exhibit 8a shows a simple standard single-segment flight data entry process. Exhibit 8b shows the entry process for a weekly schedule. The user is prompted to enter passenger information only after all the data has been checked and corrected.

Exhibit 9 shows the next flight, where the user has typed by mistake a non-existing station (NXC). The system will prompt the user for a complete origin-destination pair. Only after the data is recognized by the system does it ask for passenger loads.

Exhibit 10 shows the iterative process of error verification that the system performs until a recognized aircraft number is encountered. Only after this process is completed is the user invited to enter passenger data.

Exhibit 11 shows how the system prompts the user after illogical data is entered. The "-" character is used to notify the system that there are no more flights for this aircraft for this particular day.

Exhibit 12 shows the data entry process for a multiple-segment flight. The system is notified that this flight is a multiple-segment flight by entering the equal (=) character for the continuing segment. The user is prompted to add only the minimum information required, namely, time of departure, the new destination, and whether there is an additional segment to this flight. Once the system is notified about a new flight, it prompts the user to enter passenger loads for all passenger segments (three in a two-segment flight, six in a three-segment flight, \( n(n+1)/2 \) for an \( n \) segment flight).

Exhibit 13 shows the prompt if passengers loads in a multiple-
segment flight exceeds capacity. Notice that both the source of problem is identified (load to NYC) and a reminder of the aircraft capacity is provided.

Exhibit 14 shows what happens in the case of multiple errors, where the user has entered superfluous information (the number 30). The system will immediately ignore it and ask for the proper entry.

Once the user issues the dummy NOMORE flight number (Exhibit 15), the system prompts the user back to the basic menu, where he issues a "save" request (Exhibit 16).

The user is then transferred to the output module, where he is prompted by the output menu and again he must choose the desired current action (Exhibit 17) before the schedule is typed out (Exhibit 18). Upon completion of the task the user is asked again for his next step, and selection of option 8 in the master menu will signal the end of the current session.
enter schedule information in the following order:

flight no. (enter number if no more flights):

hour and minutes of departure:

aircraft registration (tail) no.: 0 if none:

origin and destination of current segment:

continuing flight (enter - if same flight contin)
enter - if no continuation flight:

minutes illegal 67?
enter correct minutes of departure:

now enter passengers to your flight:

Exhibit 11. Error recovery -- time illegal

enter schedule information in the following order:

flight no. (enter number if no more flights):

hour and minutes of departure:

aircraft registration (tail) no.: 0 if none:

origin and destination of current segment:

continuing flight (enter - if same flight contin)
enter - if no continuation flight:

hour and minutes of departure:

enter destination of current segment:

enter next flight (if same flight continue)
enter - if no more flights for this a/c today:

now enter passengers to your flight:

Exhibit 12. Entering data for two-segment flight -- daily schedule
Enter schedule information in the following order:

Flight no. (enter none or if no more flights): 456

Time: hour and minutes of departure: 13:10

Aircraft registration (tail) no.; 0 if none: 0552

Origin and destination of current segment: Luxembourg

Continuation flight (enter - if same flight continues); 0 - if no continuation flight

Time: hour and minutes of departure: 19:30

Enter destination of current segment: New

Enter next flight if same flight continues; enter - if no more flights for this a/c today:

New enter passengers to your flight:

Max from LAX to ATL: 150

Max from LAX to NCR: 150

Max from ATL to NCR: 100

Max load of aircraft to NCR exceeds capacity a/c capacity is 285

New enter passengers to your flight:

Max from LAX to ATL: 0

Max from LAX to NCR: 150

Max from ATL to NCR: 130

Exhibit 13. Error recovery for passenger load -- multisegment flight
enter schedule information in the following order:

flight no. (enter none more if no more flights): 0110

time: hour and minutes of departure: 20 30

aircraft registration (tail) no.: 0 if none: N25744

origin and destination of current segment: INVERNESS

continuing flight (enter Y if same flight continuing)

enter - if no continuation flight: 0

hour illegal 25?

registration no of a/c is unrecognized N25744?

enter correct departure hour: 13 30

enter correct a/c tail number:

registration no of a/c is unrecognized 30?

enter correct a/c tail number: N25743

now enter passengers to your flight:

 Pax from NUC to BOA: 100

Exhibit 14. Multiple error recovery

enter schedule information in the following order:

flight no. (enter none more if no more flights): N1110

Exhibit 15. End of schedule data entry convention

<table>
<thead>
<tr>
<th>*** action number</th>
<th>description</th>
<th>***</th>
</tr>
</thead>
<tbody>
<tr>
<td>enter</td>
<td>create new schedule file</td>
<td>1</td>
</tr>
<tr>
<td>update</td>
<td>update an existing schedule</td>
<td>2</td>
</tr>
<tr>
<td>validate</td>
<td>perform sched validity check</td>
<td>3</td>
</tr>
<tr>
<td>evaluate</td>
<td>evaluate current schedule</td>
<td>4</td>
</tr>
<tr>
<td>quit</td>
<td>quit do not save schedule</td>
<td>5</td>
</tr>
<tr>
<td>save</td>
<td>save current schedule</td>
<td>6</td>
</tr>
<tr>
<td>type</td>
<td>type copy of current schedule</td>
<td>7</td>
</tr>
<tr>
<td>end</td>
<td>end current session</td>
<td>8</td>
</tr>
</tbody>
</table>

enter action number you currently wish to perform: 6

Exhibit 16. The system's master menu
Exhibit 17. Output menu

### Schedule Information

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>7/8/82</td>
<td>10:00</td>
<td>N12347</td>
<td>B727-1</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>222</td>
<td>7/8/82</td>
<td>11:00</td>
<td>N12347</td>
<td>B727-1</td>
<td>110</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>333</td>
<td>7/8/82</td>
<td>08:00</td>
<td>N12347</td>
<td>B727-1</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>444</td>
<td>7/8/82</td>
<td>09:00</td>
<td>N12347</td>
<td>B727-1</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>555</td>
<td>8/1/82</td>
<td>10:00</td>
<td>N592</td>
<td>111-10</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>555</td>
<td>8/1/82</td>
<td>11:00</td>
<td>N592</td>
<td>111-10</td>
<td>120</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>555</td>
<td>8/1/82</td>
<td>08:00</td>
<td>N592</td>
<td>111-10</td>
<td>50</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>555</td>
<td>8/1/82</td>
<td>09:00</td>
<td>N592</td>
<td>111-10</td>
<td>0</td>
<td>130</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>666</td>
<td>8/1/82</td>
<td>10:00</td>
<td>N592</td>
<td>111-10</td>
<td>0</td>
<td>130</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>777</td>
<td>7/8/82</td>
<td>10:00</td>
<td>N12345</td>
<td>B727-2</td>
<td>60</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>777</td>
<td>7/8/82</td>
<td>11:00</td>
<td>N12345</td>
<td>B727-2</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>888</td>
<td>7/8/82</td>
<td>08:00</td>
<td>N12345</td>
<td>B727-2</td>
<td>50</td>
<td>70</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>888</td>
<td>7/8/82</td>
<td>09:00</td>
<td>N12345</td>
<td>B727-2</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**End of Schedule List**
CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The goal of this work was to explore the feasibility, and to produce a preliminary system design of a microcomputer-based airline planning system. The conclusions we present here include the following issues:

1. What is the preferred environment for schedule planning and control within the airline organization?
2. What is the planning methodology which best fits the airline schedule planning process?
3. What are the appropriate design techniques to be implemented in the airline planning environment in order to fulfill the user's needs and to cope with future technology?
4. What is the appropriate methodology to conduct the schedule evaluation process?

The recommendations we present here include suggestions for:

1. Future steps in the development of the database system
2. Future steps in the development of the planning decision support system, including some areas of future research
3. Future steps in the development of the schedule control system.

6.2 The Schedule Planning Process Within an Airline

The current practice of schedule planning in airlines is very diversified and can be categorized into four major approaches: planning as part of marketing, planning as part of finance, planning as an
independent entity, and noncentralized planning systems reporting directly to the chief executive officer. Since the schedule is both the airline product and its operating plan, a centralized planning unit is the preferred environment for schedule planning. The main rationale behind this conclusion is the desire to free the planning process from biases which are unavoidable when schedule planning in airlines takes place in one of the functional departments such as marketing or finance.

6.3 The Planning Methodology for Airline Scheduling

The schedule planning process is, in practice, the process of solving a semistructured decision problem, namely, a problem that has a normative internal structure but is not strictly and uniquely defined. The role of the decision-makers' judgment throughout the planning process is crucial in creating alternatives, in evaluating them, and in weighing the relative values of the various corporate objectives. The most appropriate methodology to deal with this type of problem is to adopt a Decision Support System, in the form of an interactive computer system consisting of an efficient data base, a friendly user interface and a set of decision support tools. Such a system can help the decision-makers to formulate alternative schedules, evaluate them and ultimately select one.

The system will free the planner from the burden of performing complicated computations. Since the system is centralized, a common base planning methodology can be applied, which will help to reduce conflicts within the airline organization. The fact that alternative evaluation will be an easier process will encourage the evaluation of a larger number of alternatives before any final operational decision is made. The
recommended planning methodology provides an environment for gradual sophistication, initiated and motivated by the user. It also provides a planning methodology which is clear to the user and not a "black-box" type of planning process. Concern over the latter was a major reason for non-acceptance of planning tools based on sophisticated O.R./M.S. formal techniques.

Currently, this type of system for schedule planning does not exist, neither at the philosophical/conceptual level, nor through a technical application.

6.4 System Design Concepts: Compatibility with the User Environment, and Compatibility with Current and Future Technologies

The system developed in this work is attractive to two groups of potential users: the operations planning and the operations control professionals. The system will support the users with both information handling and information analysis tools.

From our limited experience in applying the system, it is apparent that the friendly environment makes the system more readily accepted by the users, and communicability and ease of control proved themselves to be important issues throughout the application process.

Several of the concepts of data processing which were incorporated into this application have proven themselves to be efficient. The first concept is that in order to maintain consistency of the data, a data item should appear in the data base file system only once. Updating thus has to take place in a single record in order to maintain information consistency.

The second concept is that only relevant information at the time of
execution should reside in the main memory. This principle can be realized only by using relatively sophisticated access methods. Using direct accesses to files by using keys has proven to be an efficient method, and response time remains adequate (by adequate we mean that it is within the standard response time of a conversational system on a mainframe).

Some of the trends that are occurring in the area of microcomputing will make the system more powerful and more diversified in the type of tasks it is capable of carrying out. To mention a few:

-- standardization of microcomputer operating systems will increase the number of machines that the system can be executed on

-- virtual memory will eliminate some of current memory limitations and will permit an increase in the system's computational and data processing capacity to more complex network structures

-- advancement in communication and distributed processing capabilities will make it easy to maintain a remote copy of the schedule and manage it through communication lines

-- introduction of the Transaction Manager concept will make it possible to develop the system into a complete Management Information system, in a multiuser environment, with capabilities of performing multitasking and multithreading. A further discussion of this issue appears in the recommendations section.

6.5 Schedule Evaluation Methodology

For the system to efficiently support schedule decisions, the evaluation indices have to comply with the basic principles of air transport economic theory. In particular, the role of network structure
and network of services operating characteristics are important considerations.

The aggregate indices which are commonly used today in the industry to measure schedule performance are misleading in many cases. Some degree of disaggregation is needed for the measures to be of any value as a basis for decision making.

Evaluating the schedule against a single, uniquely-defined objective function might be improper. Instead, a set of "objective function" values should be produced in order to replicate the real-world multi-objective function environment.

A major drawback in this work is the way demand is treated. Although this approach is justified in the first stages of application, in the long run, a more realistic approach (one which is based on some service response principles) has to be adopted.

6.6 Recommendations on Future Steps in the Development of Decision Support Systems

The current system contains the following function:

-- a complete data entry generator
-- a complete output generator
-- several components of the evaluation procedure.

In order to make the system completely operational, we first have to implement the database updating function. This step is fairly easy and the following tasks are to be accomplished: expansion of the data entry generator, to make it capable of reading keyed records for updates; develop a function to merge existing data files with newly-created ones; and develop a function (which exists but has to be linked to the update
procedure) for keying the newly updated files. By completing the above tasks the system is made operational, though it has only limited capacity and manual checks are still required in the planning process. In order to further automate the routine procedure, the next step is to mechanize the validation function. The most important functions at this stage are legality of departure times and availability of aircraft. One has to remember that while linking the programs together into a module, the concept of individual overlay for each function has to be maintained.

6.7 Future Steps in the Development of the Decision Support System

Obviously more can be done in the development of tasks to support schedule planning decisions. There are three areas in which further study might provide the largest contribution, both to the quality of the model and its attractiveness for applications:

1. Improving the allocation of passengers to flights. It is recommended that first a simple S curve technique to determine market share from frequency share be adopted, and later on a simple demand model based on some regression techniques can be developed. An analysis of seat management policies and overbooking policies can also be included as topics for future research. The emphasis should not be on developing formal models, but rather on interactive heuristics for schedule planning decision support.

2. More research into the issues of proper performance measures and specifically the proper level of disaggregation is needed. Improving these types of measures will provide better insight into the alternatives' properties, thus making the decision process somewhat easier.
3. The use of graphics both for presentation of the schedule elements, such as aircraft route maps, subnetworks of services, etc., and for presentation of the evaluation results, such as distribution of variables, etc. Graphics techniques can provide a "visual" dimension to the user interface and help reduce the "abstraction" of some of the evaluation concepts, thus improving the friendliness of the system and its supportive quality.

6.8 Future Steps in Development of a Schedule Control System

Although the system is equipped with the technical features to provide an efficient control process, the specific methodology for such a process is not developed. The whole problem of schedule disruption has not been addressed and the only work dealing with this problem goes back to 1967 [15], in which the out-of-kilter algorithm is applied to deal with schedule disruption. No schedule control system, employing a decision support systems approach, has been addressed to date, and this is a very promising area for further research.

6.9 Conclusion

The interaction between the human schedule planner and the computerized decision support system is a critical factor in determining the efficiency of the schedule planning process. In recent years, several sophisticated tools have been developed for schedule planning. None of them, however, are motivated by the issue of interaction between the planner and the computer. This study represents one step in improving the schedule planning process, by introducing a planning system that is motivated by the organizational process of decision-making and by
focusing on the development of an easy-to-use, user-friendly airline schedule planning system.
REFERENCES


11. Simpson, Robert W., Airline Economics, class notes for course 16.74, Chapter 6, Massachusetts Institute of Technology, Flight Transportation Laboratory, 1981.


APPENDIX A
DATA BASE RECORD STRUCTURE AND FORMATS

All the data base files are direct access record files. The files cannot be printed or edited directly due to their internal structure, the WRITE option provides the user with the capability to display the files content.

The following are the files' record descriptions:

FILE NO. 1, SCHEDULE FILE

1. Flight number -- the official flight number, up to 6 alphanumeric characters
2. Date of flight -- monthly, day, and year, each item up to 2 digits.
3. Time -- hour and minutes, each item up to 2 digits.
4. Aircraft type -- only the index number of this aircraft type. This data item is automatically supplied by the system after the user issues the aircraft's tail number.
5. Aircraft registration (tail) number -- the official registration number of the aircraft, up to 6 alphanumeric characters.
6. Origin station of the segment -- the official airport code, up to 4 alphanumeric characters to comply with current and future airport code length (which is supposed to be increased from 3 to 4 letters).
7. Destination station -- for this flight segment, same properties as the origin station code.
8. Passenger data from the origin station of current segment to all the flight destinations (up to four altogether), this is integer data, and for each destination information is composed of the following items:
   a. First class passengers
   b. Coach passengers -- adults
   c. Tourist class (or economy) passengers -- adults
   d. Coach passengers -- children or reduced-fare passengers
   e. Tourist class (or economy) passengers -- children or reduced-fare passengers

9. Cargo -- from current segment origin to all destinations (up to four stations altogether).

10. Current segment number for a particular flight (generated by the system).

11. Next flight -- next flight that the aircraft is going to operate on.

FILE NO. 2, AIRCRAFT FILE

1. Aircraft registration number -- official tail number, up to 6 alphanumeric characters.

2. Aircraft type -- the index number of the aircraft in the global aircraft table.

3. Total seat capacity -- total number of seats.

4. First class seat capacity

5. Coach class seat capacity

6. Tourist (or economy) class seat capacity
7. Cargo capacity in metric tons
8. Cargo capacity in standard containers (for this type of aircraft)
9. Aircraft/operating unit cost (all data decimal with values up to 9999.99)
   a. Crew cost -- standard crew cost per hour for this type of aircraft
   b. Fuel burn for flying at standard conditions (gallons/hour)
   c. Operating cost
   d. Direct maintenance cost per hour of operation
   e. Cabin crew cost for standard size of cabin crew for this type of aircraft
10. Aircraft technical data
    a. Aircraft maximum range -- integer data (nautical miles)
    b. Aircraft cruise speed -- integer data (nautical miles)
    c. Type of engine -- up to 6 alphanumeric characters
    d. Maximum take-off weight (tons) -- decimal data
    e. Maximum zero fuel weight (tons) -- decimal data
    f. Airport -- runway class -- integer (ICAO classification)
11. Aircraft age (years)
12. Aircraft current estimated value -- millions of dollars, decimal value

FILE NO. 3, STATION FILE

1. Airport/city code name -- up to 4 alphanumeric characters
2. Market area -- if the city is within a designated market area, then up to 4 letter abbreviation of this market area can be used
3. Latitude and longitude coordinates of this station

4. Time zone -- three letter abbreviation (EST, MST, GMT, etc.) can be used

5. Station costs -- up to five groups of unit costs are available, with an option for a different computational method according to the user standards (applying default value of -1 sets any type of formula the user wishes to apply and overrides the standard computational method)
   a. Landing fee -- cost per metric ton
   b. Passenger handling -- cost per passenger
   c. Fuel -- cost per metric liter
   d. Aircraft cleaning -- cost
   e. Fixed catering cost -- catering setup costs
   f. Cost per meal
   g. Crew pick-up cost
   h. Aircraft parking cost (ton/hour)
   i. Passenger handling counter cost ($ counter/hour)
   j. Aircraft handling cost (towing, etc.)
   k. Peak factor -- additional cost due to peak operations

6. Minimum connection (in minutes) for this station -- integer

7. Runway restrictions (maximum runway length available) -- ICAO digit standard code

8. Regular peak hours (integer)
FILE NO. 4, CITY PAIR FILE

1. City pair name -- a concatenation of the two city code names (no matter which is first), the system will identify automatically the city pair (i.e. if the name is BOSORD then the system will count for ORDBOS) and proper data modification (such as east-bound, west-bound flight time) will be done automatically by the system

2. Origin city code -- up to 4 alphanumeric characters

3. Destination city code -- up to 4 alphanumeric characters. As mentioned above, the origin and destinations are arbitrarily set, and their order can be reversed

4. Flight time in hours for three types of aircraft: turbojets, small jets and large jets -- this is a decimal data item

5. Cost elements
   a. Navigation cost per ton/minutes
   b. International control cost (eurocontrol standard cost per ton)

6. Flight tariff
   a. First class tariff
   b. Coach tariff
   c. Tourist or economy class tariff

7. Standard tariff structure for the current link (fixed component and cost in cents/nautical mile)
FILE NO. 5, AGGREGATE SYSTEM DATA

1. Cost per available seat mile
2. Cost per revenue passenger mile
3. Cost per enplanement
4. Direct operating cost/hour
5. Operating cost
6. Daily cost
7. Maintenance cost/flight hour
8. Landing cost/ton
9. Handling cost/passenger
10. Cabin crew cost/hour
11. Cost per meal
12. Maintenance cost-burden/per aircraft type group (3 groups)
13. Average fuel cost
14. Maximum number of stops per flight
15. Minimum connection time (minutes)
16. Maximum load factor allowable
APPENDIX B. DESCRIPTION OF PROCEDURES AND CALLING SEQUENCE

<table>
<thead>
<tr>
<th>PROCEDURE NAME</th>
<th>FUNCTION</th>
<th>CALLED BY</th>
<th>TRANSFERS CONTROL</th>
<th>RETURN</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHED</td>
<td>main program, this procedure calls the proper action procedures according to user request</td>
<td>user: initiates B:TEMP B:SCHED</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>ENTER</td>
<td>procedure to create a new schedule</td>
<td>SCHED (option 1)</td>
<td>to DATES: current date</td>
<td>control to SCHED: no. of flight segment generated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>to BADQRY: the illegal query</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>to ERCHK: the current error status (0 = schedule check; 1 = pax check)</td>
<td></td>
</tr>
<tr>
<td>BADQRY</td>
<td>to notify the user about an illegal query</td>
<td>ENTER, TYPOUT</td>
<td>--</td>
<td>bad query message</td>
</tr>
<tr>
<td>DATES</td>
<td>to generate next day's date</td>
<td>ENTER</td>
<td>--</td>
<td>new date</td>
</tr>
<tr>
<td>ERCHK</td>
<td>to check legality of schedule data</td>
<td>ENTER</td>
<td>to ERMSG: error switches if the error check is done for pax data</td>
<td>control to ENTER after data is correct</td>
</tr>
</tbody>
</table>
### Appendix B (continued)

<table>
<thead>
<tr>
<th>PROCEDURE NAME</th>
<th>FUNCTION</th>
<th>CALLED BY</th>
<th>TRANSFERS CONTROL</th>
<th>RETURN</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILLUP</td>
<td>to fill schedule info automatically ENTER if the segment is not the first (flight number, aircraft name, origin)</td>
<td>ENTER</td>
<td>--</td>
<td>copy of relevant information for the non first flight segment</td>
</tr>
<tr>
<td>PAX-LF</td>
<td>to prompt the user to fill passengers into the appropriate passenger links</td>
<td>ENTER</td>
<td>to ERCHK: error status 1, to perform passenger loading validity check</td>
<td>passenger load to all destinations from current flight segment origin</td>
</tr>
<tr>
<td>CHAGN</td>
<td>to check if there are still errors that were not recorded after the previous passes</td>
<td>ERCHK</td>
<td>to ERCOR: error status bit vector</td>
<td>--</td>
</tr>
<tr>
<td>ERMSG</td>
<td>to notify the user in case an error has been detected</td>
<td>ERCHK</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ERCOR</td>
<td>to prompt the user and ask him to correct logical error</td>
<td>ERCHK</td>
<td>--</td>
<td>turned off error switch</td>
</tr>
<tr>
<td>ERPAX</td>
<td>to check validity of passenger loads</td>
<td>ERCHK</td>
<td>ERMSP - to notify if passenger loads are illegal</td>
<td>passenger error switch on</td>
</tr>
<tr>
<td>WRITE</td>
<td>to create a direct access schedule file</td>
<td>SCHED (option 7)</td>
<td>to KEYFLT - to create a multiple key to the schedule file</td>
<td>control to SCHED</td>
</tr>
<tr>
<td>PROCEDURE NAME</td>
<td>FUNCTION</td>
<td>CALLED BY</td>
<td>TRANSFERS CONTROL</td>
<td>RETURN</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------------------------------------</td>
<td>---------------</td>
<td>------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>KEYFLT</td>
<td>to create a multiple key file for the schedule file</td>
<td>WRITE</td>
<td>--</td>
<td>SCED file keys</td>
</tr>
<tr>
<td>TYPOut</td>
<td>to type out a copy of the schedule file</td>
<td>SCHED (option 7)</td>
<td>according to user request</td>
<td>control back to SCHED</td>
</tr>
<tr>
<td>COMPLT</td>
<td>to create a copy of the complete schedule for printout</td>
<td>TYPOUT (option 1)</td>
<td>PRTOUT - to type out the schedule</td>
<td>control back to TYPOUT</td>
</tr>
<tr>
<td>STASCD</td>
<td>to create a copy of a station schedule, upon user's request</td>
<td>TYPOUT (option 2)</td>
<td>PRTOUT - to type out the station schedule</td>
<td>control back to TYPOUT</td>
</tr>
<tr>
<td>ACROUT</td>
<td>to create a copy of an aircraft schedule (a fleet or an individual aircraft)</td>
<td>TYPOUT (option 3)</td>
<td>PRTOUT - to type out the aircraft schedule</td>
<td>control back to TYPOUT</td>
</tr>
<tr>
<td>SCDCPR</td>
<td>to create a copy of a city pair schedule, upon user's request</td>
<td>TYPOUT (option 4)</td>
<td>PRTOUT - to type out the city pair schedule</td>
<td>control back to TYPOUT</td>
</tr>
<tr>
<td>TYPo</td>
<td>to type out a copy of the schedule according to user's request</td>
<td>COMPLT, STASCD, ACROUT, SCDCPR</td>
<td>--</td>
<td>back to caller</td>
</tr>
<tr>
<td>EVALUA</td>
<td>to perform schedule evaluation</td>
<td>SCHED (option 4)</td>
<td>according to user request</td>
<td>control back to SCHED</td>
</tr>
</tbody>
</table>
### Appendix B (continued)

<table>
<thead>
<tr>
<th>PROCEDURE NAME</th>
<th>FUNCTION</th>
<th>CALLED BY</th>
<th>TRANSFERS CONTROL</th>
<th>RETURN</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENER</td>
<td>to prepare a copy of the complete schedule for evaluation purposes</td>
<td>EVALUA (option 1)</td>
<td>to EVAL: to perform the schedule evaluation</td>
<td>control back to EVALUA</td>
</tr>
<tr>
<td>CITEV</td>
<td>to create a copy of a city pair schedule for evaluation purposes (upon user's request)</td>
<td>EVALUA (option 2)</td>
<td>to EVAL: to perform the schedule evaluation</td>
<td>control back to EVALUA</td>
</tr>
<tr>
<td>STATEV</td>
<td>to create a copy of a station schedule for evaluation purposes (upon user's request)</td>
<td>EVALUA (option 3)</td>
<td>to EVAL: to perform the schedule evaluation</td>
<td>control back to EVALUA</td>
</tr>
<tr>
<td>FLT EV</td>
<td>to create a copy of a fleet type (up to three) schedule for evaluation purposes (upon user's request)</td>
<td>EVALUA (option 4)</td>
<td>to EVAL: to perform the schedule evaluation</td>
<td>control back to EVALUA</td>
</tr>
<tr>
<td>EVAL</td>
<td>schedule evaluation procedure</td>
<td>GENER, CITEV, STATEV, FLTEVL</td>
<td>to PRETEVL: to print evaluation results</td>
<td>control back to caller</td>
</tr>
<tr>
<td>PRTEVL</td>
<td>print out evaluation results</td>
<td>EVAL</td>
<td>--</td>
<td>control back to EVAL</td>
</tr>
<tr>
<td>CPAIR</td>
<td>to create the city pair database file</td>
<td>USER B:CPAIR, B:CITY</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Appendix B (continued)

<table>
<thead>
<tr>
<th>PROCEDURE NAME</th>
<th>FUNCTION</th>
<th>CALLED BY</th>
<th>TRANSFERS CONTROL</th>
<th>RETURN</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEYCP</td>
<td>to create a multiple key file for the city pair data base</td>
<td>USER</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B:KEYCP, B:CITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APLN</td>
<td>to create an aircraft data base file</td>
<td>USER</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B:APLN, B:ACFT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KEYPR</td>
<td>to create an aircraft multiple key file</td>
<td>USER</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B:KEYAC, B:ACFT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STA</td>
<td>to create a station data base file</td>
<td>USER</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B:STA, B:STA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KEYSTA</td>
<td>to create a station multiple key file</td>
<td>USER</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B:KEYSTA, B:STA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 These files are currently linked and loaded separately, outside the main stream of the system.