Report No. FAA-ASP-78-10,I

# THE AIRPORT PERFORMANCE MODEL
## Volume I: Extensions, Validation, and Applications

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OCTOBER 1978
FINAL REPORT



Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Office of Aviation System Plans
Washington DC 20590

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FAA-ASP-78-10,I | | |

| 4. Title and Subtitle | |
|---|---|
| THE AIRPORT PERFORMANCE MODEL, Volume I: Extensions, Validations, and Applications | 5. Report Date: October 1978 |
| | 6. Performing Organization Code |
| 7. Author(s) J. Bellantoni, H. Condell, I. Englander, L. Fuertes, J. Schwenk | 8. Performing Organization Report No.: DOT-TSC-FAA-78-21,I |
| 9. Performing Organization Name and Address: U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge MA 02142 | 10. Work Unit No. (TRAIS): FP705/R9119 |
| | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation System Plans, Washington DC 20590 | 13. Type of Report and Period Covered: FINAL REPORT January 1975 - June 1976 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract Vol I:


The Airport Performance Model is a computer simulation of airport delay and congestion prepared to help evaluate the benefit of capacity-related investments in the nation's airports. The model estimates dollar benefits to passengers and aircraft operators or delay reduction in landing, takeoff and gate docking, and reduction in fuel consumed and pollutants emitted as well as required groundside facilities. It does not include safety or noise reduction benefits, or increase in community values. The model has a data base comprising 31 high density airports.

The delay estimate from the model showed reasonably good agreement with data taken at JFK, LGA and EWR. It was used to evaluate proposed investments for Honolulu, Detroit and Charlotte, N.C.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| Airport, computer simulation, computer models, investment, benefit cost | DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 288 | |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# PREFACE

The Airport Performance Model described in this Volume is a computer simulation of the benefits that accrue to public investment in the airports of the National Airport system. It was developed under Project Plan Agreement FP706, sponsored by the Federal Aviation Administration, Office of Aviation System Plans, to explore the application of benefit-cost techniques to federally funded airport development projects.

Volume Two is a detailed User's Manual and program description of the Airport Performance Model.

In addition to the computer based models provided by the Airport Perfromance Model and the Airport Network Flow Simulator, a need was felt for a simple, manually-based technique to estimate the economic benefits of proposed investments in airport capacity. Accordingly, an Airport Capacity Investment Handbook[(4)] was developed, based on these two computer models.

The work described herein is an extension of the Airport Performance Model[(5)] first developed in FY 1975. Companion reports[(6), (7)] to the present one describe the development of a model of delay propagation in the network of airports. The benefits estimated by the network model are supplemental to those obtained form the Airport Performance Model.

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(1) See Volume II.

(2) See Volume II.

(3) See Volume II.

(4) Bellantoni, J. and L. Fuertes, "Airport Capacity Investment Handbook," Final Report No. FAA-ASP-78-8, October 1978. Prepared for the Federal Aviation Administration,

Office of Aviation System Plans, by the Transportation Systems Center, Cambridge, MA 02142.

(5) Hiatt, D., S. Gordon, and J. Oiesen, "The Airport Performance Model, Report No. FAA-ASP-5, April 1976. Prepared for the Federal Aviation Administration, Office of Systems Plans, by the Department of Transportation, Transportation Systems Center, Cambridge, MA 02142.

(6) Gordon, S., "The Airport Network Flow Simulator," Report No. FAA-ASP-75-6, May 1976. Prepared for the Federal Aviation Administration Office of System Plans, by the Department of Transportation, Transportation Systems Center, Cambridge, MA 02142.

(7) Bellantoni, J., "The Airport Network Flow Simulator," Report No. FAA-ASP-78-9, October 1978. Prepared for the Federal Aviation Administration, Office of Systems Plans, by the Department of Transportation, Transportation Systems Center, Cambridge, MA 02142.

The authors wish to acknowledge the contributions to this report of many at TSC: Dave Spiller and William Kutner provided valuable assistance in preparing the data for validation; Michael Grossman was the source of both theory and practical advise on data clustering techniques; Joseph McGann of the TSC Data Services Division, and John Dolan, Ellen Laviana, James Guarente, Robert Montanari, Scott Moffatt and Robert Wassmuth of Kentron International, Inc. were responsible for preparing the computer program and data base which are described elsewhere (4), (5), (6).

The assistance of Federal Aviation Administration personnel has also been indispensible in carrying out the work: Robert Woods, AAT-12, provided consultation and data on the Engineered Performance Standards; William Riggle, ASP-130, assisted in ADP matters; John Kal and Arnold Schwartz, ASP-130, assisted and guided the project throughout as Sponsors. Other individuals at the Federal Aviation Administration, particularly George Thompson and James Meadows of the Office of Management Systems, and Jane Miller of NASCOM, contributed data and time to this project. In addition, Joseph Windisch of the Aviation Economics Division of the Port Authority of New York and New Jersey, and James Fitzgibbon of the Bureau of Accounts and Statistics of the Civil Aeronautics Board were particularly helpful in providing data for this study. Numerous other individuals and groups also contributed data, documents and time to this project.

Finally, the guidance of Paul Larson, Dale McDaniel, Michael Zywokarte and Thomas Messier, FAA, Office of Aviation Systems Plans, and of William Duffy and Edwin Roberts, TSC Research Division, is acknowledged with appreciation by the authors.

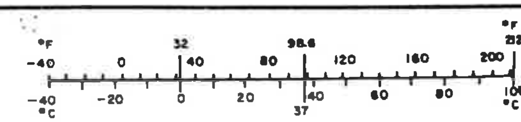
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# TECHNICAL SUMMARY

From 1970 through 1975 over $1.0 billion was invested by the Federal Government in development of the National Airport System. Current legislation increases this to over $2 billion in 1976-1980. These expenditures are intended to increase airport capacity, improve safety of operations, speed the flow of passengers through the airport, and reduce fuel consumption, pollution, and noise. A means of estimating these benefits for a specific airport improvement, however, has not been available to aid the Federal Aviation Administration in administering the funds. Accordingly, a computer based model of the benefits produced by airport investments was constructed by the Transportation Systems Center for the Office of Aviation System Plans of the Federal Aviation Administration from January 1975 to June 1976. This report describes the model, its data base, its validation, and its application as of the end of FY76. In summary,

- The Airport Performance Model (APM) estimates the dollar benefits to passengers and aircraft operators of delay reduction during takeoff, landing and gate docking; the reduction in pounds of pollutants emitted and fuel consumed by delayed aircraft; the groundside facilities required by the airport to avoid congestion, in terms of square feet of lobby and gate area, linear feet of baggage handling and curb space, number of short and long term parking spaces, number of access/egress lanes, etc.
- The APM does not estimate safety benefits, noise reduction value, or industrial and community enhancement or access/

egress vehicle pollutants.

- The landing, takeoff, and gate delays are obtained by a minute-by-minute simulation of aircraft operations (excluding taxi way and ramp/apron delays). The groundside facilities requirements are calculated from design rules and the flow of passengers produced by aircraft movements.
- The APM is airport-specific and presently has a data base for each of 31 high density NAS airports. The data were obtained from the Official Airline Guide, FAA Tower Traffic Reports, the National Climatic Center, FAA capacity studies, aircraft mix projections, and other sources.
- The APM runway delay estimates were compared to historical delay data for JFK, LGA and EWR obtained form the Port Authority of New York and New Jersey, the Civil Aeronautics Board Service Segment tapes, and the CATER (Collection and Analysis of Terminal Records) data gathered through the FAA and the airlines. The results show a reasonably good agreement between the APM output and these historical sources.
- The model was used to evaluate investments proposed for Honolulu, Detroit, and Charlotte N.C. airports, with results given in the report.
- The APM was written in FORTRAN IV, on the TSC PDP-10 at Cambridge, and is accessible from time-share terminals. Running cost on the PDP-10 is approximately $5 for an annual analysis. Program documentation and user's manual are contained in Volume Two.

# 1. INTRODUCTION

The Airport and Airway Development Act of 1970 authorized the expenditure of approximately $310 million for airport planning and development for fiscal years 1970 through 1975. These funds, provided by user charges paid into the Trust Fund, formed the basis of the Airport Development Aid Program (ADAP) and Planning Grant Program (PGP). At the time the funding authorization expired in 1975, a total of $1.302 billion had been obligated. Proposals subsequently enacted by Congress to extend the program call for approximately $2.4 billion more in funding from FY '76 through FY '80 for air carrier and commuter airports and about $375 million for general aviation airports over the same period.

From 1970 to 1975 the ADAP funds were disbursed on a project-by-project basis within the formula set by the Act of 1970. This formula provided that one third of the air carrier and reliever airport funds be disbursed to air carrier airports in proportion to passenger enplanements, one third to the states (half of which were assigned by population and half by area), and one third to the Secretary's discretionary fund. It also provided that 75% of the General Aviation airport funds be disbursed through the states (again, half by population and half by area), and the remaining 25% via the discretionary fund. Present legislation for FY '76 through FY '80 also incorporates disbursement formulas based on enplanements ar air carrier airports, and state population and area for General Aviation airports. The legislation (PL-94-343) provides a discretionary fund of about $900 millions for disposal by the Secretary of Transportation.

Considering the large amounts committed to ADAP and PGP in the 1970-1980 decade, it is incumbent on the Federal Aviation Administration to administer them in the most effective way. Toward this end, the FAA issues guidelines for airport planning, reviews airport master plans submitted with grant requests, and applies federal standards for construction, safety and project management. Considering these safeguards, and the fact that the amount allotted to each airport is largely predetermined by the legislation, one may view as superfluous any attempt to assess directly the economic benefits obtained from these funds. For the following reasons, however, a quantification of the benefits is a useful planning tool:

1. The Congress and taxpayer may legitimately inquire whether, and to what extent, these expenditures have been profitable to the nation's economy, and

2. The effectiveness of the Secretary's discretionary fund would be improved if dollar benefits could be estimated for each proposed airport plan.

The present project is a result of FAA's efforts to answer the need for quantification of the benefits of ADAP and PGP funds. A complete quantification was found to be beyond the resources of the present project and the state of the art; nevertheless, the important benefits of reduced delay, air pollution, and terminal congestion have been quantified and incorporated into a computer model. This program, The Airport Performance Model, is an expansion and a refinement of an initial version produced in FY'75 (Reference 1-1). It calculates annual values of these benefit measures as a function of airport capacity and demand, both present and projected. It accounts for weather, daily traffic fluctuations, aircraft mix changes, and other relevant factors for each of 31 airports in its data base.

The models and data employed in the APM are described in sections 2 through 6 of this report. Validation and application are described in sections 7 and 8. The remainder of this section will be devoted to the basic assumptions and rationale underlying the APM and the design criteria that guided its development.

## Airport Improvement Benefits

The physical benefits of the National Aviation System, and of the National Airport System in particular, have been discussed by Fromm (Reference 1-2), and in a recent FAA study (Reference 1-3), and elsewhere (Reference 1-4). The major general categories from these sources agree with the outline of the FAA's most recent planning document (Reference 1-5):

Safety - as measured by lives and property lost in aviation accidents

Capacity - as measured by the cost of air-traffic and airport delays

Productivity - as measured by the cost of operating the air-traffic and airport system

Environmental Compatibility - as measured by air and water pollution, noise, land use and petroleum consumption.

The Airport Performance Model has focused on the second and fourth of these categories. The reason for that selection is purely pragmatic; the present state of knowledge does not allow reasonably reliable estimates to be made of the safety and productivity benefits associated with airport improvement. Reliable measures do exist for capacity and for some of the environmental benefits. Therefore, the APM has been designed around those two types of benefits. It calculates delay reduction in landing, in take-off, and in gate docking. It also computes groundside facility levels required to avoid congestion. To help assess environmental impact, the present version of the APM determines the pollution emissions by aircraft due to both delayed and nondelayed operation. This particular measure (pounds of specific pollutants) provides a partial picture of the environmental impact of airport development. Other measures (e.g., noise, water pollution, land use) need to be added to complete the environmental assessment.

Guidelines Used to Develop the APM

Considering the intended application of the model, and the types of benefits chosen to be represented, several design objectives were adopted for the APM:

1. Annualized Benefits: In order to employ the APM for planning purposes it was deemed essential that an annual value of delay reduction and pollution reduction be calculated. A single-day or single-hour estimate, such as the peak day, or a "typical" day, while useful for design purposes, can give misleading values for the net economic benefit when extrapolated to a ten or twenty year planning period. Hence, it was considered essential that the APM produce a realistic annual value for benefits. This annual estimate is built up by several single day simulations based on the clustering technique described in Section 6.

2. Airport-Specific Data: In order to provide reasonably accurate delay calculations, it was found necessary to take into account the specific hourly pattern of demand experienced at the airport under study. This was obtained

for air carrier traffic from the Office Airline Guide (OAG) and for non-scheduled traffic from samples of FAA Tower records. In addition, weather patterns and capacity values were judged to be important influences in delay production. These were allowed for by incorporating into the APM specific weather history for each airport.

3. Thirty Airport Data Base: The purpose of the APM is to aid the deployment of funds among competing airports, as well as to assess the net benefit of the investment in any one of the NAS airports. While it is impractical to store data for all 3033 NAS airports existing in 1975, a design goal of 30 was set for the demand/capacity/weather data base. (The APM presently includes data for 31 airports.) Further, the cost and time required to expand the data base to over 200 airports should be reasonable (under $50K).

4. Ease of Use: It was taken as a major requirement that the APM should be readily usable by FAA personnel concerned with airport system planning rather than with computer technology. This implied 1) time-share, on-line use at the FAA/ASP location, 2) complete and unambiguous input and output, 3) user options for the major parameters, and 4) adequate documentation, including a User's Manual.

5. Groundside and Access-Egress Congestion: The recent extension of ADAP funds to terminal areas of airports PL-94-343) provides for 50% federal funding) makes it

desirable to determine whether present or projected terminal access and egress facilities are adequate and, if possible, the dollar benefit that would accrue to certain improvements. [This design objective was only partly met in the APM; the program calculates facility requirements consistent with airside demand, but does not calculate groundside or access/egress delays or delay costs.]

6. Validation of the Model: In order to base planning recommendations and decisions on the APM, the FAA required that a validation procedure be established. As a minimum, it was required that the APM prediction of delay or capacity for a limited set of days be checked against actual delay and capacity data gathered at specific airports. The data base for this validation should be as broad as possible.

7. Dollar Benefits: Where possible, benefits should be reduced to dollar values. This goal was expected to apply primarily to airside delays, where the greatest dollar benefits lie.

8. Use of Projected Traffic: Where traffic level and mix projections are available these should be incorporated into the APM data base. [This objective was achieved with regard to aircraft mix, but not volume levels. The present APM version allows the user to specify the annual volume, but does not include current FAA volume projections in its data base.]

In addition to meeting the above eight design guidelines, any planning tool must be inexpensive and accessible enough to allow repeated runs in a week. A nominal cost of $100 per run was set as a goal.

Limitations of the APM

Several limitations of the present APM should be noted.

First, the benefits calculated in the APM are not comprehensive, as discussed above. The most important omission, perhaps, is that of safety. A large part of ADAP funds are spent to improve airport safety (runway grooving, blast fences, runway lighting, etc.) as well as to reduce the cost of accidents (crash and rescue vehicles). For the reasons mentioned, such benefits could not be included in the APM.

Secondly, the detail with which particular investments are modelled is limited. Investments must first be interpreted in terms of capacity changes. This is usually possible, for example, for the addition of runways, ILS equipment, runway turnoffs, gates, and spacing rules.

Third, the approximate nature of the annualized delay must be allowed for in planning. The validation of annual delay, while not impossible, was beyond the resources of the project.

## REFERENCES

1-1. Hiatt, D., S. Gordon, J. Oiesen, "The Airport Performance Model," Report No. FAA-ASP-75-5, Interim Report prepared for Federal Aviation Administration, by Transportation Systems Center, Cambridge, MA 02142.

1-2. Fromm, G., "Economic Criteria for Federal Aviation Agency Expenditures," Final Report prepared for FAA by United Research Incorporated, Cambidge, MA, June 1962.

1-3. Jessiman, W. A., and D. J. Cartright, "Airport Development Priorities Mathematical Model and Review of Airport Development Aid Program," Final Report February 1972, under Contract DOT-FA71WA-2686, prepared by Peat, Marwick, Mitchell and Co., Boston, MA.

1-4. "Aviation Cost Allocation Study," Office of Policy Review, Department of Transportation, 1972.

1-5. Federal Aviation Administration "The National Aviation System Challenges of the Decade Ahead, 1977-1986," May 1976, Washington, D.C.

# 2. GENERAL DESCRIPTION

The APM is a FORTRAN IV interactive simulation of the flow of aircraft, people and vehicles through an airport. The user initiates the program from a time-share terminal connected to the TSC PDP-10 in Cambridge, MA. Data for 31 airports (see Table 2.0-1) are stored on disk at that facility. After he types in the airport of interest, the user receives a summary of the data stored for that airport. He may change these data from the terminal before execution. After execution he receives time histories and summaries of daily or annual delay, congestion, and pollution. The aircraft types used in APM are in Table 2.0-2.

The general interaction of user, model, and data base is shown in Figure 2.0-1. The major parts of the model and data base are described generally in what follows, and in more detail in Sections 3 through 6. For details of running and modifying the program, the reader should consult the APM User's Manual (Reference 2-1), the program documentation, (Reference 2-2) and the data base documentation (Reference 2-3). A sample Input/Output session is reproduced in Appendix 2.0-A.

## 2.1 USER INPUTS

The user inputs are listed in Table 2.1-1. With the exceptions of the airport identifier, and the type of analysis

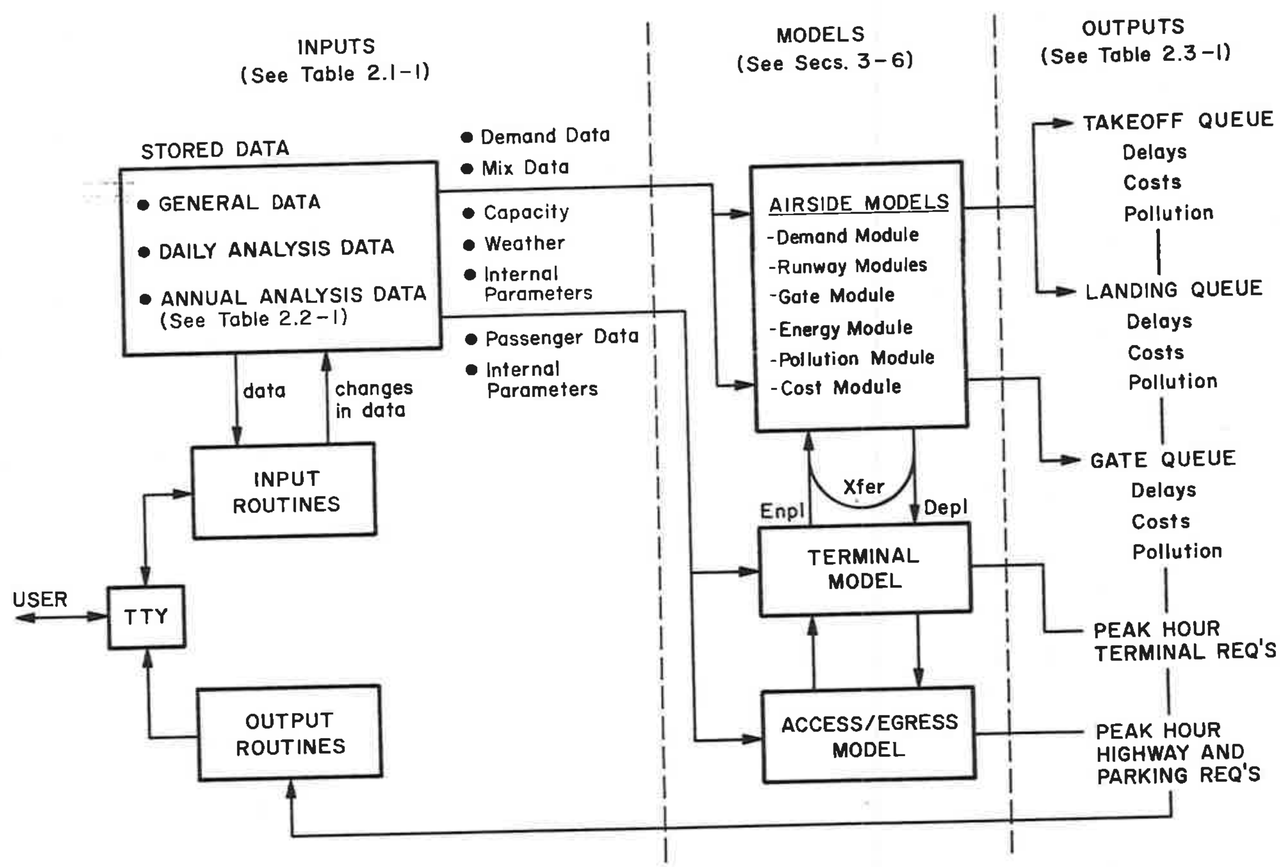


FIGURE 2.0-1. GENERAL INFORMATION FLOW IN APM

TABLE 2.0-1. LIST OF AIRPORTS IN APM

| 3-letter code | Name of city |
|---|---|
| ORD | Chicago (O'Hare) |
| ATL | Atlanta |
| JFK | New York (Kennedy) |
| LGA | New York (LaGuardia) |
| SFO | San Francisco |
| LAX | Los Angeles |
| DEN | Denver |
| PHL | Philadelphia |
| EWR | Newark |
| MIA | Miami (International) |
| DAL | Dallas (Love Field) |
| DCA | Washington (National) |
| PIT | Pittsburgh |
| BOS | Boston |
| CLE | Cleveland |
| DTW | Detroit (Metro Wayne) |
| MSY | New Orleans |
| LAS | Las Vegas (McCarren) |
| HNL | Honolulu (International) |
| STL | St. Louis (Lambert Field) |
| FLL | Fort Lauderdale (Hollywood) |
| TPA | Tampa (International) |
| MSP | Minneapolis - St. Paul |

TABLE 2.0-1. (Cont'd.)

| 3-letter code | Name of city |
|---|---|
| SEA | Seattle - Tacoma |
| BAL | Baltimore |
| CLT | Charlotte (North Carolina) |
| MKE | Milwaukee (Mitchell) |
| SLC | Salt Lake City |
| IAH | Houston (Intercontinental) |
| IAD | Washington (Dulles) |
| JAX | Jacksonville |

TABLE 2.0-2. AIRCRAFT TYPES USED IN APM[1]

| APM Designation | |
|---|---|
| H4W | Heavy 4-engine jets, wide body |
| H3 | Heavy 3-engine jets |
| H4S | Heavy 4-engine jets, standard and stretched body[2] |
| L3 | Large 3-engine jets |
| L2 | Large 2-engine jets |
| LP | Large propeller and Turboprop |
| S | Small aircraft |
| O | Other than the above |

[1] The designations Heavy, Large and Small correspond to FAA the weight categories: 300,000 lbs and over; 12,500 lbs to 300,000 lbs; under 12,500 lbs.

[2] Certain types of jet transports include aircraft over 300,000 lbs. GTOW as well as other aircraft under this weight limit. These aircraft are the Boeing 707 series and the McDonnell-Douglas DC-8. The Official Airline Guide (OAG) for 1972 and 1973 was used in developing airport fleet mix data, and did not distinguish between aircraft models within the series. As a result, it was impossible to identify, for example, operations by 707-120 aircraft from operations made by 707-320's. Since considerably more than half the 707's and DC-8's in service exceed 300,000 lbs., all aircraft for these model types were classified as heavy aircraft.

## TABLE 2.1-1. USER INPUTS TO APM

GENERAL

1. Airport 3-letter identifier (see Table 2.0-1)

2. Type of analysis desired (Daily or Annual)

DEMAND DATA

1. Average Traffic Volume

   1.1 Air Carrier-----operations/day, operations/yr
   1.2 Commuter/Air Taxi----------- " "
   1.3 General Aviation-------- " "
   1.4 Military-------- " "

*2. Assumed Hourly Demand Profile

   2.1 Air Carrier plus Commuter/Air Taxi, operations, by hour
   2.2 General Aviation plus Military, operations, by hour

MIX DATA

1. Mix of Aircraft Types (1)

   1.1 Mix forecasted by FAA for 1980, 85, 90, 95 2000, or
   1.2 User-supplied Mix, or
   1.3 Present Mix.

*2. Assumed Hourly Aircraft Type Mix

CAPACITY DATA

*1. Maximum Achievable Processing Rates

   1.1 VFR Cat A, ops/hr and equivalent PANCAP
   1.2 VFR Cat B, " " " "
   1.3 VFR Cat 0, " " " "
   1.4 VFR Cat 1, " " " "

TABLE 2.1-1. (Continued)

1.5 IFR Cat 2, ops/hr and equivalent PANCAP
1.6 IFR Cat 3, " " "

Note: These processing rates correspond to the foregoing MIX DATA, as modified by user. See footnote (2) for definition of weather categories. For Annual Analysis, only a single VFR processing rate and a single IFR processing rate are input.

WEATHER DATA

*1. Assumed Weather Category (Cat A, B, 0, 1, 2, 3 as above) by hour of the day

PASSENGER DATA

1. Percent of Passengers Continuing on Same Aircraft

2. Percent of Passengers Transferring To or From Other Aircraft

3. Access/Egress Mode Split

   3.1 Percent Enplaning Passengers by each mode
   3.2 Percent Deplaning Passengers by each mode
   3.3 Percent Airport Employees by each mode.

4. Air Carrier and Commuter/Air Taxi Load Factors

5. Seating for Passengers at the Gate (Yes or No)

6. Airport Employees

   6.1 Default Value Used
   6.2 Calculated by Annualization Subroutine
   6.3 User Input

7. Value of Passenger Time

INTERNAL PARAMETERS

1. Radar-Approach Spacing Standards

   1.1 Small Behind Heavy
   1.2 Other

TABLE 2.1-1. (Continued)

2. Aircraft Direct Operating Costs, by Type

   2.1 In the Air
   2.2 On the Ground

3. Aircraft Pollution Emission Levels, by Type

   3.1 In the Air
   3.2 On the Ground

4. Gate Parameters

   4.1 Number of gates, carrier and commuter/taxi
   4.2 Gate hold procedures (Yes or No)

5. Revenue Seats per Aircraft, by Type

6. Access/Egress Parameters, by Mode

   6.1 For Enplaning Passengers

      - Well-wishers per passenger
      - Mean Number of occupants per vehicle
      - Curb dwell time, hours

   6.2 For Deplaning Passengers

      - Well-wishers per passenger
      - Mean Number of occupants per vehicle
      - Curb dwell time, hours

   6.3 For Work Trips

      - Mean Number of occupants per vehicle

   6.4 Highway Peaking Factor (Average flow per minute during 20 minute peak, divided by average flow per minute for entire hour)

   6.5 Curb Design Peaking Factor

   6.6 Vehicle Curb Slot Length by Mode (ft)

TABLE 2.1-1. (Concluded)

6.7 Airport Work Force Arrival/Departure Distribution, by hour of day (percent)

(1) See Table 2.0-2 for a description of aircraft types used in the APM.

(2) VFR (Cat A) is defined in the APM as weather with ceiling and visibility above 2500 ft and 5 miles; VFR (Cat B) as below 2500 ft or 5 miles, but above 1500 ft and 3 miles; IFR (Cat 0) as below 1500 feet or 3 miles but above 400 ft and 1.0 miles; IFR (Cat 1) as below 400 ft or 1 mile but above 200 ft and 0.5 miles; IFR (Cat 2) as below 200 ft or 0.5 miles but above 100 ft and 0.25 miles; IFR (Cat 3) as below 100 ft or 0.25 miles.

*For Daily Analysis Only.

(Daily or Annual) all user inputs are in the form of modifications to the stored data base. Some user inputs pertain only to a Daily analysis and these are indicated by an asterisk (*) in Table 2.1-1.

## 2.2 STORED INPUTS

The data stored for each airport is listed in Table 2.2-1. Section 3.0, 4.0 and 5.0 describe the sources of these data and the method of extraction. In general, the daily analysis data are obtained from the annual analysis data. The latter are obtained from a year's sample (1972) traffic, clustered and averaged as described in Section 5.0 and 6.0 into 54 representative days. The annual analysis output is the sum of delay, etc., for these representative days, each weighted by the number of days in the sample year that it represents. Hence, the annual analysis data is similar in content to the daily analysis data, but many times more voluminous.

## 2.3 OUTPUTS

The model outputs shown in Figure 2.0-1 are listed in more detail in Table 2.3-1.

TABLE 2.2-1. STORED INPUTS TO APM

GENERAL DATA

1. Airport 3-letter code as in Table 2.0-1
2. Average daily operations, VFR weather days
   - air carrier,
   - commuter/air taxi
   - general aviation
   - military
3. Average daily operations, IFR weather days
   - air carrier
   - commuter/air taxi
   - general aviation
   - military
4. Number of VFR days in sample year
   Number of IFR days in sample year
5. t-Table for airport, (minimum interoperation time, in seconds, by aircraft type and operation types of leading and following aircraft)(1)
6. Forecasted aircraft type mix for 1980, 1985, 1990, 1995, 2000
7. Airport processing rate for weather types VFR Cat A, VFR Cat B, IFR Cat 0, IFR Cat 1, IFR Cat 2, IFR Cat 3
8. Airport demand peaking factor[2]
9. PASSENGER DATA, as given in Table 2.1-1
10. INTERNAL PARAMETERS, as given in Table 2.1-1

(1) See Section 3.3 and Appendix 3.3-A

(2) Employed only to calculate Practical Annual Capacity (PANCAP)

TABLE 2.2-1. (Continued)

DAILY ANALYSIS DATA

1. Average daily operations, scheduled[1]
   Average daily operation, non-scheduled
2. Arrival and Departure profiles of scheduled traffic as a fraction of the average daily schedule volume, for each minute in the day
3. Mix of scheduled traffic aircraft types[2] for each hour of the day
4. Ratio of Arrivals to Departures[3] for scheduled traffic, by hour of the day
5. Profile of non-scheduled traffic, as a fraction of average daily non-scheduled volume, for each minute in the day
6. Mix of non-scheduled traffic aircraft types,[2] for each hour of the day
7. Ratio of Arrivals to Departures[3] for non-scheduled traffic, by hour of the day
8. Profile of hourly weather types for daily analysis

ANNUAL ANALYSIS DATA

1. Number of single-day runs in the annualization calculation.

---

(1) Scheduled traffic has been taken from the OAG and has been assumed to be equal to the total of air carrier plus taxi/commuter reported by the FAA Tower at the airport involved. This approximation neglects the non-scheduled carrier and air taxi/commuter traffic reported in the tower data.

(2) See Table 2.0-2 for definition of aircraft types used in the APM.

(3) The quantity actually stored is the ratio of arrivals to total operations, since the Arrival/Departure ratio is undefined for hours with no departures.

TABLE 2.2-1 (Concluded)

For each run in the annualization calculation:

2. Scheduled Volume
3. Non-Scheduled Volume
4. Scheduled Aircraft Mix, by hour
5. Non-scheduled aircraft Mix
6. Scheduled Arrival/Departure Ratio, by hour
7. Scheduled Arrival Profile, by minutes
8. Scheduled Departure Profile, by minute
9. Weighting factor for the run.

TABLE 2.3-1. OUTPUTS OF APM

TAKEOFF QUEUE

LANDING QUEUE

GATE QUEUES

For each of the queues, there is given total daily or annual:

Delays

1. Aircraft Hours Lost in Queue
2. Passenger Hours Lost in Queue
3. Increase in Aircraft Operating Cost (dollars)
4. Cost of Passenger Time Lost (dollars)
5. Total Dollar Cost (3. & 4.)

Pollution

1. Excess Pounds of Hydrocarbons
2. Excess Pounds of Carbon Monoxide
3. Excess Pounds of Nitrogen Oxides

PEAK HOUR TERMINAL FACILITY REQUIREMENTS

1. Main Lobby Area (square feet)
2. Main Lobby Seating (seats)
3. Passenger Counter Area (square feet)
4. Passenger Counter Frontage (feet)
5. Baggage Claim Area (square feet)
6. Baggage Claim Frontage (feet)

PEAK HOUR HIGHWAY AND PARKING REQUIREMENTS

1. Short Term Parking (slots)
2. Employee Parking (slots)
3. Enplaning Curb Length Requirements (feet)
4. Depaning Curb Length Requirements (feet)
5. Outbound Access Road Requirements (lanes)
6. Peak Hour Long-Term Parking Space Requirements (over and above spaces taken at start of day): (spaces)
7. Net Increase in Long-Term Parking Spaces Occupied at the End of the Day (spaces)
8. Total Long-Term Parking Spaces Required
9. Total Airport Employees

TABLE 2.3-1. (Concluded

ENPLANEMENTS/DEPLANEMENTS

1. Total number of Enplanements
2. Total number of Deplanements
3. Total number of Transfers
4. Total number of Continuing Passengers
5. Total number of Originations
6. Total number of Passengers with destinations at the airport city

## REFERENCES


2-1. "The APM User's Manual," Transportation Systems Center, Cambridge MA, (to be published).

2-2. "APM Program Documentation," Transportation Systems Center, Cambridge MA, (to be published).

2-3. "APM Data Base Documentation," Transportation Systems Center, Cambridge MA (to be published).

2.-4 "Airline Delay Data, 1970-1974, DOT/FAA, material on file, February 1973.

# APPENDIX 2.0-A
## SAMPLE INPUT/OUTPUT SESSION

```
.RUN APM

%RUNNING KA-10 CODE ON A KI-10

                    AIRPORT PERFORMANCE MODEL
                   (FAA/ASP-130 VERSION 9/76)

PLEASE TYPE 3-LETTER IDENTIFIER FOR AIRPORT OF INTEREST
(FOLLOW ALL YOUR REPLIES BY CR,CARRIAGE RETURN)
HNL

TO COMPUTE GATE DELAYS:
     TYPE THE # OF SERVICE GATES:  29

     ARRIVAL SERVICE TIME IN MINUTES:  25

     DEPARTURE SERVICE TIME IN MINUTES:  25

     THRU-FLIGHT SERVICE TIME IN MINUTES:  40


          *** AVERAGE TRAFFIC VOLUME FOR HNL (1972-1973)***

                                      OPERATIONS/DAY    OPERATIONS/YR
AIR CARRIER + COMMUTER/AIR TAXI (AC+CAT)   376              137459
    GENERAL AVIATION + MILITARY (GA+MIL)   388              141814

                                    TOTAL  764              279273

DO YOU WISH AN ANNUAL OR MULTIPLE ANALYSIS ?
TYPE A OR M
A

DO YOU WISH TO MODIFY THE ABOVE TOTAL DEMANDS ?
TYPE YES OR NO
YES

TYPE TOTAL OPERATIONS FOR THE YEAR (AC+CAT): 178000

TYPE TOTAL OPERATIONS FOR THE YEAR (GA+MIL): 150000

AC+CAT =        178000
GA+MIL =        150000

 TOTAL =        328000
```

```
*** AVERAGE TRAFFIC VOLUME FOR HNL (1972-1973)***

                                              OPERATIONS/DAY     OPERATIONS/YR
AIR CARRIER + COMMUTER/AIR TAXI (AC+CAT)        487               178000
    GENERAL AVIATION + MILITARY (GA+MIL)        410               150000

                                        TOTAL   897               328000

DO YOU WISH TO MODIFY THE ABOVE TOTAL DEMANDS ?
TYPE YES OR NO
NO

THE # OF DAYS OR RUNS USED FOR ANNUALIZATION IS PRESENTLY 30.
DO YOU WISH TO CHANGE IT?  (YES OR NO)
NO

          *** MIX OF AIRCRAFT TYPES AT HNL 1975 ***

 TYPE                                              PERCENT
H4W HEAVY JETS - 4 ENGINE WIDE BODY                 10.3
H3  HEAVY JETS - 3 ENGINE                            0.6
H4S HEAVY JETS - 4 ENGINE STANDARD BODY             12.0
L3  LARGE JETS - 3 ENGINE                            0.1
L2  LARGE JETS - 2 ENGINE                           26.3
LP  LARGE PROP + TURBOPROP                           3.1
S   SMALL (12500 LBS. OR LESS)                      47.6
O   OTHER                                            0.0

                        *** DO YOU WISH TO ***
 1: USE FORECASTED MIX
 2: INSERT A NEW MIX
 3: NEITHER
TYPE 1, 2 OR 3
3

          *** MAX ACHIEVABLE PROCESSING RATE AT HNL ***

 WEATHER      LOWER LIMITS          OPERATIONS          EQUIVALENT
 CATEGORY     CLNG FT/VIS MI         PER HOUR             PANCAP

   VFR           1500/3                 55                186433.
   IFR             0/0                  55                186433.
DO YOU WISH TO MODIFY ABOVE
    1: OPS/HR
    2: PANCAP
    3: NEITHER ?
 TYPE  IN 1,2 OR 3
1
```

MAX ACHIEVABLE PROCESSING RATE AT HNL

| WEATHER CATEGORY | LOWER LIMITS CLNG FT/VIS MI | OPERATIONS PER HOUR | EQUIVALENT PANCAP |
|---|---|---|---|
| VFR | | 119 | 403373. |
| IFR | | 96 | 325410. |

*** MAX ACHIEVABLE PROCESSING RATE AT HNL ***

| WEATHER CATEGORY | LOWER LIMITS CLNG FT/VIS MI | OPERATIONS PER HOUR | EQUIVALENT PANCAP |
|---|---|---|---|
| VFR | 1500/3 | 119 | 403373. |
| IFR | 0/0 | 96 | 325410. |

DO YOU WISH TO MODIFY ABOVE
1: OPS/HR
2: PANCAP
3: NEITHER ?
TYPE IN 1,2 OR 3
3

| PARAMETER | VALUE | UNITS |
|---|---|---|
| RADAR APPROACH SPACING STDS. | | |
| 1 SMALL BEHIND HEAVY | 6 | MILES |
| 2 OTHER | 3 | MILES |
| 1975 AIRCRAFT DIRECT OPERATING COSTS, IN THE AIR | | |
| 3 HEAVY JET - 4 ENGINE | 24.53 | $/MIN |
| 4 HEAVY JET - 3 ENGINE | 17.92 | $/MIN |
| 5 LARGE JET - 4 ENGINE | 13.45 | $/MIN |
| 6 LARGE JET - 3 ENGINE | 10.42 | $/MIN |
| 7 LARGE JET - 2 ENGINE | 8.34 | $/MIN |
| 8 LARGE PROP + TURBOPROP | 14.96 | $/MIN |
| 9 SMALL(12500 LB OR LESS) | 0.38 | $/MIN |
| 10 OTHER | 0.00 | $/MIN |
| 1975 AIRCRAFT DIRECT OPERATING COSTS, ON GROUND | | |
| 11 HEAVY JET - 4 ENGINE | 17.56 | $/MIN |
| 12 HEAVY JET - 3 ENGINE | 13.32 | $/MIN |
| 13 LARGE JET - 4 ENGINE | 10.12 | $/MIN |
| 14 LARGE JET - 3 ENGINE | 8.27 | $/MIN |

15 LARGE JET - 2 ENGINE 6.87 $/MIN
16 LARGE PROP + TURBOPROP 14.13 $/MIN
17 SMALL 0.32 $/MIN
18 OTHER 0.00 $/MIN

1975 AIRCRAFT POLLUTION EMISSION LEVELS, IN THE AIR

19 HEAVY JET - 4 ENGINE 320.00 LBS/HR
20 HEAVY JET - 3 ENGINE 160.00 LBS/HR
21 LARGE JET - 4 ENGINE 80.00 LBS/HR
22 LARGE JET - 3 ENGINE 40.00 LBS/HR
23 LARGE JET - 2 ENGINE 20.00 LBS/HR
24 LARGE PROP + TURBOPROP 10.00 LBS/HR
25 SMALL 5.00 LBS/HR
26 OTHER 1.00 LBS/HR

VALUE OF PASSENGER TIME

27 AIR CARRIER AND COMMUTER/AIR TAXI 12.50 $/HR
28 GENERAL AVIATION 12.50 $/HR
29 MILITARY 12.50 $/HR

NUMBER OF GATES

30 AIR CARRIER AND COMMUTER/AIR TAXI 41 GATES
31 GENERAL AVIATION AND MILITARY 5 GATES

IS THERE A GATE WAITING AREA ? TYPE YES OR NO
YES

ARE GATE HOLD PROCEDURES IN EFFECT ?
TYPE YES OR NO
NO

SEATING CAPACITY,CARRIER+AIR TAXI/COMMUTER

| AIRCRAFT TYPE = | H4W | H3W | H4S | L3 | L2 | LP | S/O |
|---|---|---|---|---|---|---|---|
| 32 REV SEATS AVAIL. | 346.0 | 299.0 | 157.4 | 115.7 | 101.1 | 49.3 | 6.0 |

ACCESS/EGRESS MODE CHARACTERISTICS FOR ENPLANING PASSENGERS

| | MODE # | WELL WISHERS PER PASSENGER | VEHICLE OCCUPANCY | HOURS OF CURB DWELL TIME |
|---|---|---|---|---|
| 33 | 1 L.T. PARK | 0.960 | 1.790 | 0.000 |
| 34 | 2 CURB PU+D | 2.100 | 2.500 | 0.062 |
| 35 | 3 S.T.PK, CURB PU+D | 2.100 | 2.500 | 0.062 |
| 36 | 4 TAXI | 0.000 | 1.400 | 0.033 |
| 37 | 5 BUS | 0.290 | 20.000 | 0.066 |
| 38 | 6 LIMO | 0.290 | 7.000 | 0.083 |
| 39 | 7 RENT CAR | 0.000 | 1.790 | 0.000 |

| | | | | |
|---|---|---|---|---|
| 40 | 8 NON-HIGHWAY | 0.290 | 0.000 | 0.000 |

FOR DEPLANING PASSENGERS

| | MODE # | GREETERS PER PASSENGER | VEHICLE OCCUPANCY | HOURS OF CURB DWELL TIME |
|---|---|---|---|---|
| 41 | 1 PARK | 1.030 | 1.790 | 0.000 |
| 42 | 2 CURB PU+D | 2.060 | 2.300 | 0.062 |
| 43 | 3 S.T.PK, CURB PU+D | 2.060 | 2.300 | 0.062 |
| 44 | 4 TAXI | 0.000 | 1.500 | 0.033 |
| 45 | 5 BUS | 0.140 | 20.000 | 0.066 |
| 46 | 6 LIMO | 0.140 | 8.000 | 0.083 |
| 47 | 7 RENT CAR | 0.000 | 1.400 | 0.000 |
| 48 | 8 NON-HIGHWAY | 0.140 | 0.000 | 0.000 |

FOR WORK TRIPS

| | MODE # | VEHICLE OCCUPANCY |
|---|---|---|
| 49 | 1 DRIVE, PARK | 1.10 |
| 50 | 2 CURB PU+D | 1.10 |
| 90 | 3 S.T.PK, CURB PU+D | 1.10 |
| 51 | 4 TAXI | 1.10 |
| 52 | 5 BUS | 20.00 |
| 91 | 6 LIMO | 1.10 |
| 92 | 7 RENT CAR | 1.10 |
| 53 | 8 NON-HIGHWAY | 0.00 |
| 54 | HIGHWAY PEAKING FACTOR (AVERAGE FLOW PER MINUTE DURING 20 MIN PEAK DIVIDED BY AVERAGE FLOW PER MINUTE FOR THE ENTIRE HOUR ) | 1.50 |
| 55 | CURB DESIGN PEAKING FACTOR | 1.50 |

| | MODE # | VEHICLE CURB SLOT LENGHT(FT) |
|---|---|---|
| 56 | 1 DRIVE, PARK | 0.00 |
| 57 | 2 CURB, PU+D | 18.00 |
| 58 | 3 S.T.PK, CURB PU+D | 18.00 |
| 59 | 4 TAXI | 18.00 |
| 60 | 5 BUS | 45.00 |
| 61 | 6 LIMO | 25.00 |
| 62 | 7 RENT CAR | 0.00 |
| 63 | 8 NON-HIGHWAY | 0.00 |

WORK FORCE AIRPORT ARRIVAL/DEPARTURE DISTRIBUTION
% OF WORKFORCE

22-OCT-76

AIRPORT PERFORMANCE MODEL
(FAA/ASP-130, VERSION 9/76)

ANNUAL ANALYSIS
HNL

TAKEOFF QUEUE

| POLLUTANTS | | DELAYS | | | | |
|---|---|---|---|---|---|---|
| TOTAL TONS | EXCESS TONS | AC HRS | PAX HRS | AC $ | PAX $ | TOTAL $ |
| 30243. | 0. | 2025.1 | 95992.1 | 636247. | 1199901. | 1836148. |

LANDING QUEUE

| POLLUTANTS | | DELAYS | | | | |
|---|---|---|---|---|---|---|
| TOTAL TONS | EXCESS TONS | AC HRS | PAX HRS | AC $ | PAX $ | TOTAL $ |
| 18444. | 0. | 2994.2 | 141872.0 | 1370833. | 1773400. | 3144233. |

GATE DELAYS FOR LANDING AC (SCHEDS)
29 GATES

| POLLUTANTS | | DELAYS | | | | |
|---|---|---|---|---|---|---|
| TOTAL TONS | EXCESS TONS | AC HRS | PAX HRS | AC $ | PAX $ | TOTAL $ |
| 21. | 21. | 82.9 | 4270.7 | 27423. | 53384. | 80807. |

## ENERGY CONSUMPTION

| TOTAL | ARRIVAL | | DEPARTURE | | GATE DELAY |
|---|---|---|---|---|---|
| TONS | TOTAL TONS | EXCESS TONS TYPE 1 (DELAYS) | TOTAL TONS | EXCESS TONS TYPE 2 (DELAYS) | TOTAL TONS |
| 122467. | 51935. | 8823. | 61650. | 0. | 60. |

## TAKEOFF DELAYS

| LOCAL TIME | NO OF T-OS | MAX IN QUEUE | AV IN QUEUE | NO DELAYED | MAX DELAY MINS | AV DELAY MINS | TOTAL DELAY MINS |
|---|---|---|---|---|---|---|---|
| 00:00-01:00 | 4552. | 4 | | 1903 | 2.7 | 0.7 | 1344.2 |
| 01:00-02:00 | 635. | 1 | | 238 | 0.9 | 0.5 | 120.7 |
| 02:00-03:00 | 265. | 1 | | 50 | 0.4 | 0.4 | 21.2 |
| 03:00-04:00 | 1098. | 2 | | 270 | 1.4 | 0.8 | 203.7 |
| 04:00-05:00 | 307. | 1 | | 45 | 0.7 | 0.7 | 30.8 |
| 05:00-06:00 | 442. | 0 | | 0 | 0.0 | 0.0 | 0.0 |
| 06:00-07:00 | 1077. | 3 | | 697 | 1.8 | 0.8 | 547.5 |
| 07:00-08:00 | 8535. | 5 | | 5193 | 2.8 | 0.9 | 4692.1 |
| 08:00-09:00 | 7531. | 7 | | 5642 | 5.0 | 0.9 | 5185.3 |
| 09:00-10:00 | 10841. | 7 | | 7723 | 4.6 | 1.3 | 9884.3 |
| 10:00-11:00 | 10194. | 5 | | 6189 | 3.6 | 0.8 | 4906.0 |
| 11:00-12:00 | 11895. | 11 | | 8912 | 7.0 | 1.6 | 13885.7 |
| 12:00-13:00 | 12014. | 9 | | 8595 | 8.9 | 1.6 | 13941.6 |
| 13:00-14:00 | 8644. | 5 | | 6107 | 3.6 | 1.0 | 5915.4 |
| 14:00-15:00 | 11398. | 7 | | 8387 | 4.8 | 1.3 | 10906.2 |
| 15:00-16:00 | 13276. | 7 | | 10366 | 5.6 | 1.2 | 12186.0 |
| 16:00-17:00 | 11349. | 7 | | 8232 | 5.0 | 1.0 | 8593.9 |
| 17:00-18:00 | 13723. | 7 | | 8854 | 5.3 | 1.1 | 9509.9 |
| 18:00-19:00 | 12328. | 5 | | 8295 | 5.0 | 0.9 | 7321.1 |
| 19:00-20:00 | 8948. | 3 | | 3130 | 2.1 | 0.7 | 2236.6 |
| 20:00-21:00 | 3744. | 3 | | 1719 | 2.1 | 0.7 | 1224.6 |
| 21:00-22:00 | 8684. | 7 | | 4213 | 5.2 | 1.6 | 6638.8 |
| 22:00-23:00 | 3909. | 3 | | 2173 | 2.3 | 0.8 | 1715.9 |
| 23:00-24:00 | 2081. | 2 | | 866 | 1.7 | 0.6 | 492.3 |
| | 167470. | | | | | | 121503.9 |

LANDING DELAYS

| LOCAL TIME | NO OF LAND | MAX. IN QUEUE | AVR. IN QUEUE | NO. DELAYED | MAX. DELAY MINS | AVR. DELAY MINS | TOTAL DELAY MINS |
|---|---|---|---|---|---|---|---|
| 00:00-01:00 | 4594. | 4 | | 1506 | 3.3 | 1.2 | 1743.3 |
| 01:00-02:00 | 5580. | 4 | | 2583 | 3.2 | 1.1 | 2923.0 |
| 02:00-03:00 | 1484. | 3 | | 238 | 2.3 | 1.4 | 343.5 |
| 03:00-04:00 | 193. | 1 | | 4 | 0.8 | 0.8 | 4.0 |
| 04:00-05:00 | 782. | 1 | | 60 | 0.8 | 0.8 | 48.9 |
| 05:00-06:00 | 210. | 0 | | 0 | 0.0 | 0.0 | 0.0 |
| 06:00-07:00 | 7059. | 5 | | 3826 | 5.5 | 1.8 | 6767.0 |
| 07:00-08:00 | 3318. | 2 | | 1233 | 1.7 | 0.9 | 1124.0 |
| 08:00-09:00 | 13188. | 10 | | 8504 | 8.3 | 1.8 | 15367.9 |
| 09:00-10:00 | 10585. | 8 | | 6957 | 7.0 | 2.1 | 14556.0 |
| 10:00-11:00 | 8099. | 11 | | 4685 | 9.0 | 2.6 | 11988.9 |
| 11:00-12:00 | 10436. | 5 | | 6334 | 4.5 | 1.2 | 7865.1 |
| 12:00-13:00 | 10077. | 9 | | 7126 | 8.4 | 2.0 | 14377.1 |
| 13:00-14:00 | 11791. | 6 | | 7573 | 5.5 | 1.6 | 12202.0 |
| 14:00-15:00 | 13432. | 10 | | 9783 | 8.5 | 2.1 | 20467.4 |
| 15:00-16:00 | 10251. | 5 | | 5644 | 3.7 | 1.1 | 6158.8 |
| 16:00-17:00 | 13766. | 10 | | 9957 | 8.2 | 2.3 | 22912.0 |
| 17:00-18:00 | 8805. | 11 | | 5527 | 10.3 | 3.0 | 16568.4 |
| 18:00-19:00 | 8946. | 5 | | 4698 | 4.1 | 1.2 | 5594.5 |
| 19:00-20:00 | 1823. | 2 | | 368 | 1.7 | 0.7 | 245.3 |
| 20:00-21:00 | 6599. | 9 | | 3706 | 7.3 | 3.0 | 10987.9 |
| 21:00-22:00 | 140. | 1 | | 64 | 0.3 | 0.3 | 17.1 |
| 22:00-23:00 | 4723. | 7 | | 2343 | 6.4 | 1.9 | 4454.6 |
| 23:00-24:00 | 6318. | 3 | | 2734 | 3.3 | 1.1 | 2935.1 |
| | 162200. | | | | | | 179651.8 |

## ARRIVAL GATE DELAYS

| LOCAL TIME | NO OF OPS | MAX IN QUEUE* | AV IN QUEUE | NO DELAYED | MAX DELAY MINS | AV DELAY MINS | TOTAL DELAY MINS |
|---|---|---|---|---|---|---|---|
| 00:00-01:00 | 2101. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 01:00-02:00 | 3961. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 02:00-03:00 | 522. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 03:00-04:00 | 172. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 04:00-05:00 | 504. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 05:00-06:00 | 20. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 06:00-07:00 | 5926. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 07:00-08:00 | 2213. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 08:00-09:00 | 7728. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 09:00-10:00 | 6092. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 10:00-11:00 | 3715. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 11:00-12:00 | 6495. | 6 | | 561 | 18.0 | 8.9 | 4973.6 |
| 12:00-13:00 | 6704. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 13:00-14:00 | 7768. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 14:00-15:00 | 8975. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 15:00-16:00 | 5082. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 16:00-17:00 | 6285. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 17:00-18:00 | 3726. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 18:00-19:00 | 4011. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 19:00-20:00 | 469. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 20:00-21:00 | 3204. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 21:00-22:00 | 140. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 22:00-23:00 | 3147. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 23:00-24:00 | 3827. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| | 92784. | | | | | | 4973.6 |

## DEPARTURE GATE DELAYS

| LOCAL TIME | NO OF OPS | MAX IN QUEUE* | AV IN QUEUE | NO DELAYED | MAX DELAY MINS | AV DELAY MINS | TOTAL DELAY MINS |
|---|---|---|---|---|---|---|---|
| 00:00-01:00 | 1623. | 2 | | 0 | 0.0 | 0.0 | 0.0 |
| 01:00-02:00 | 179. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 02:00-03:00 | 656. | 3 | | 0 | 0.0 | 0.0 | 0.0 |
| 03:00-04:00 | 21. | 1 | | 0 | 0.0 | 0.0 | 0.0 |
| 04:00-05:00 | 420. | 2 | | 0 | 0.0 | 0.0 | 0.0 |
| 05:00-06:00 | 0. | 0 | | 0 | 0.0 | 0.0 | 0.0 |



* See Note 1.

| | | | | | | |
|---|---|---|---|---|---|---|
| 06:00-07:00 | 1995. | 4 | 0 | 0.0 | 0.0 | 0.0 |
| 07:00-08:00 | 6026. | 4 | 0 | 0.0 | 0.0 | 0.0 |
| 08:00-09:00 | 3709. | 6 | 0 | 0.0 | 0.0 | 0.0 |
| 09:00-10:00 | 5317. | 6 | 0 | 0.0 | 0.0 | 0.0 |
| 10:00-11:00 | 6060. | 6 | 0 | 0.0 | 0.0 | 0.0 |
| 11:00-12:00 | 6879. | 9 | 537 | 17.0 | 10.2 | 5466.1 |
| 12:00-13:00 | 7843. | 4 | 0 | 0.0 | 0.0 | 0.0 |
| 13:00-14:00 | 4706. | 3 | 0 | 0.0 | 0.0 | 0.0 |
| 14:00-15:00 | 5379. | 5 | 118 | 4.5 | 4.2 | 496.0 |
| 15:00-16:00 | 6839. | 5 | 0 | 0.0 | 0.0 | 0.0 |
| 16:00-17:00 | 4581. | 6 | 0 | 0.0 | 0.0 | 0.0 |
| 17:00-18:00 | 5349. | 4 | 0 | 0.0 | 0.0 | 0.0 |
| 18:00-19:00 | 3911. | 3 | 0 | 0.0 | 0.0 | 0.0 |
| 19:00-20:00 | 2150. | 3 | 0 | 0.0 | 0.0 | 0.0 |
| 20:00-21:00 | 3998. | 8 | 0 | 0.0 | 0.0 | 0.0 |
| 21:00-22:00 | 1812. | 3 | 0 | 0.0 | 0.0 | 0.0 |
| 22:00-23:00 | 2571. | 3 | 0 | 0.0 | 0.0 | 0.0 |
| 23:00-24:00 | 413. | 1 | 0 | 0.0 | 0.0 | 0.0 |
| | 82439. | | | | | 5962.2 |

ENERGY CONSUMPTION

| LOCAL TIME | ARRIVAL TOTAL TONS | DEPARTURE TOTAL TONS | GATE DELAY TOTAL TONS | TOTAL TONS |
|---|---|---|---|---|
| 00:00-01:00 | 1374. | 1719. | 0. | 3093. |
| 01:00-02:00 | 1584. | 241. | 0. | 1826. |
| 02:00-03:00 | 398. | 179. | 0. | 577. |
| 03:00-04:00 | 55. | 387. | 0. | 441. |
| 04:00-05:00 | 205. | 134. | 0. | 339. |
| 05:00-06:00 | 87. | 118. | 0. | 205. |
| 06:00-07:00 | 2141. | 502. | 0. | 2643. |
| 07:00-08:00 | 888. | 3182. | 0. | 4070. |
| 08:00-09:00 | 4229. | 2766. | 0. | 6996. |
| 09:00-10:00 | 3568. | 3942. | 0. | 7510. |
| 10:00-11:00 | 2719. | 3777. | 0. | 6496. |
| 11:00-12:00 | 3154. | 4573. | 60. | 7786. |
| 12:00-13:00 | 3456. | 4237. | 0. | 7693. |
| 13:00-14:00 | 3739. | 3116. | 0. | 6855. |
| 14:00-15:00 | 4556. | 4204. | 0. | 8760. |
| 15:00-16:00 | 2989. | 4907. | 0. | 7896. |
| 16:00-17:00 | 4808. | 4139. | 0. | 8948. |
| 17:00-18:00 | 3159. | 5041. | 0. | 8200. |
| 18:00-19:00 | 2658. | 4480. | 0. | 7137. |

| | | | | |
|---|---|---|---|---|
| 19:00-20:00 | 509. | 3299. | 0. | 3808. |
| 20:00-21:00 | 2281. | 1348. | 0. | 3629. |
| 21:00-22:00 | 67. | 3161. | 0. | 3229. |
| 22:00-23:00 | 1489. | 1439. | 0. | 2928. |
| 23:00-24:00 | 1822. | 758. | 0. | 2580. |

PEAK TERMINAL FACILITY REQUIREMENTS

| MAIN LOBBY AREA (SQ FT) | MAIN LOBBY SEATS | PAX COUNTER AREA (SQ FT) | PAX COUNTER FRONTAGE (FT) | BAG CLAIM AREA (SQ FT) | BAG CLAIM FRONTAGE (FT) |
|---|---|---|---|---|---|
| 25202 | 1339 | 8574.1 | 214.4 | 36050 | 1030 |

PEAK HIGHWAY AND PARKING REQUIREMENTS

| SHORT TERM PARKING (SLOTS) | EMPLOYEE PARKING (SLOTS) | ENPLANING CURB LENGTH REQUIREMENTS (FT) | DEPLANING CURB LENGTH REQUIREMENTS (FT) | INBOUND ACCESS ROAD REQUIREMENTS (LANES) | OUTBOUND ACCESS ROAD REQUIREMENTS (LANES) |
|---|---|---|---|---|---|
| 232.4 | 8829.2 | 1197 | 1196 | 5 | 6 |

PEAK HOUR LONG-TERM PARKING SPACE REQUIREMENTS OVER AND ABOVE SPACES TAKEN AT START OF DAY : 1244.9 SPACES

NET INCREASE IN LONG-TERM PARKING SPACES OCCUPIED AT THE END OF THE DAY : 626.8 SPACES

TOTAL AIRPORT EMPLOYEES : 22023.0

PEAK HOUR ENPLANEMENTS : 4314.7 PAX

PEAK HOUR DEPLANEMENTS : 3967.1 PAX

## PEAK TERMINAL FACILITY REQUIREMENTS

| LOCAL TIME (HOUR) | LOBBY AREA (SQ FT) | PAX COUNTER (SQ FT) | BAGG CLAIM (SQ FT) | TIX COUNTER (LN FT) |
|---|---|---|---|---|
| 00:00-01:00 | 9308 | 2921.4 | 16870 | 73.0 |
| 01:00-02:00 | 2576 | 528.0 | 15470 | 13.2 |
| 02:00-03:00 | 2342 | 445.7 | 9520 | 11.1 |
| 03:00-04:00 | 2540 | 517.9 | 5915 | 12.9 |
| 04:00-05:00 | 2432 | 476.2 | 7420 | 11.9 |
| 05:00-06:00 | 2342 | 445.7 | 6825 | 11.1 |
| 06:00-07:00 | 2630 | 549.9 | 14175 | 13.7 |
| 07:00-08:00 | 10568 | 3369.7 | 9660 | 84.2 |
| 08:00-09:00 | 8696 | 2704.5 | 22750 | 67.6 |
| 09:00-10:00 | 21044 | 7090.0 | 36050 | 177.2 |
| 10:00-11:00 | 18236 | 6096.3 | 26040 | 152.4 |
| 11:00-12:00 | 23186 | 7856.0 | 23065 | 196.4 |
| 12:00-13:00 | 19604 | 6583.3 | 33460 | 164.6 |
| 13:00-14:00 | 18794 | 6292.8 | 34160 | 157.3 |
| 14:00-15:00 | 17786 | 5934.2 | 32445 | 148.4 |
| 15:00-16:00 | 25202 | 8574.1 | 28245 | 214.4 |
| 16:00-17:00 | 15824 | 5235.0 | 25375 | 130.9 |
| 17:00-18:00 | 22502 | 7609.3 | 22925 | 190.2 |
| 18:00-19:00 | 19316 | 6477.0 | 20860 | 161.9 |
| 19:00-20:00 | 17012 | 5660.6 | 13965 | 141.5 |
| 20:00-21:00 | 6086 | 1778.4 | 15120 | 44.5 |
| 21:00-22:00 | 16850 | 5603.9 | 5810 | 140.1 |
| 22:00-23:00 | 14906 | 4913.7 | 22225 | 122.8 |
| 223800-24:00.8 | 7940 | 2433.8 | | |

## PEAK ACCESS FACILITY REQUIREMENTS

| LOCAL TIME (HOUR) | SHORT TERM PARKING (SLOTS) | EMPLOYEE PARKING (SLOTS) | ENPLANING CURB LENGTH REQUIREMENTS (FT) | DEPLANING CURB LENGTH REQUIREMENTS (FT) | INBOUND ACCESS ROAD REQUIREMENTS (LANES) | OUTBOUND ACCESS ROAD REQUIREMENTS (LANES) |
|---|---|---|---|---|---|---|
| 01:00 | 83.7 | -269.3 | 241 | 600 | 1 | 2 |
| 02:00 | 37.5 | -359.0 | 48 | 426 | 1 | 1 |
| 03:00 | 18.9 | -448.8 | 61 | 206 | 1 | 1 |
| 04:00 | 10.4 | -448.8 | 63 | 45 | 1 | 1 |
| 05:00 | 10.1 | -359.0 | 50 | 76 | 1 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 06:00 | 10.5 | 180.2 | 72 | 59 | 2 | 1 |
| 07:00 | 49.5 | 5045.3 | 330 | 281 | 5 | 1 |
| 08:00 | 87.0 | 6667.0 | 495 | 235 | 3 | 2 |
| 09:00 | 127.3 | 7027.3 | 778 | 592 | 3 | 2 |
| 10:00 | 230.1 | 7027.3 | 1042 | 1138 | 3 | 3 |
| 11:00 | 198.6 | 7027.3 | 1149 | 840 | 3 | 3 |
| 12:00 | 217.3 | 6486.8 | 1108 | 716 | 3 | 3 |
| 13:00 | 200.0 | 6847.2 | 1019 | 1067 | 3 | 3 |
| 14:00 | 182.3 | 7748.1 | 871 | 1196 | 3 | 3 |
| 15:00 | 219.2 | 8829.2 | 1197 | 1029 | 4 | 3 |
| 16:00 | 232.4 | 8108.5 | 983 | 959 | 3 | 3 |
| 17:00 | 186.3 | 3784.0 | 1060 | 869 | 3 | 6 |
| 18:00 | 189.5 | 2702.8 | 1009 | 763 | 2 | 3 |
| 19:00 | 173.1 | 2162.3 | 861 | 640 | 2 | 3 |
| 20:00 | 133.9 | 1801.9 | 549 | 434 | 2 | 2 |
| 21:00 | 84.2 | 1441.5 | 617 | 403 | 2 | 2 |
| 22:00 | 110.0 | 1261.3 | 661 | 116 | 2 | 2 |
| 23:00 | 100.2 | 1261.3 | 481 | 539 | 2 | 2 |
| 24:00 | 101.5 | 0.0 | 440 | 802 | 2 | 3 |

PASSENGER MOVEMENTS

| LOCAL TIME (HOUR) | THROUGH (PAX) | TRANS FERS (PAX) | ORIGIN ATING (PAX) | TERMIN ATING (PAX) | EN-PLANED (PAX) | DE-PLANED (PAX) |
|---|---|---|---|---|---|---|
| 00:00-01:00 | 79.6 | 468.7 | 1014.4 | 1043.2 | 1470.1 | 1511.9 |
| 01:00-02:00 | 70.0 | 412.1 | 193.3 | 917.2 | 265.7 | 1329.3 |
| 02:00-03:00 | 29.8 | 175.4 | 154.8 | 390.5 | 224.3 | 565.9 |
| 03:00-04:00 | 5.5 | 32.3 | 179.8 | 71.9 | 260.6 | 104.2 |
| 04:00-05:00 | 15.7 | 92.7 | 165.3 | 206.4 | 239.6 | 299.1 |
| 05:00-06:00 | 11.8 | 69.5 | 154.8 | 154.8 | 224.3 | 224.3 |
| 06:00-07:00 | 61.2 | 360.3 | 190.9 | 802.0 | 276.7 | 1162.3 |
| 07:00-08:00 | 30.8 | 181.3 | 1170.0 | 403.5 | 1695.7 | 584.7 |
| 08:00-09:00 | 119.2 | 702.3 | 939.1 | 1563.2 | 1360.9 | 2265.6 |
| 09:00-10:00 | 208.8 | 1229.8 | 2461.8 | 2737.3 | 3567.8 | 3967.1 |
| 10:00-11:00 | 141.5 | 833.2 | 2116.8 | 1854.5 | 3067.8 | 2687.7 |
| 11:00-12:00 | 121.4 | 714.9 | 2727.8 | 1591.2 | 3953.3 | 2306.1 |
| 12:00-13:00 | 191.4 | 1127.4 | 2285.9 | 2509.5 | 3312.9 | 3636.9 |
| 13:00-14:00 | 196.2 | 1155.8 | 2185.0 | 2572.7 | 3166.7 | 3728.5 |
| 14:00-15:00 | 184.7 | 1087.6 | 2060.5 | 2420.9 | 2986.2 | 3508.5 |
| 15:00-16:00 | 156.1 | 919.6 | 2977.1 | 2046.8 | 4314.7 | 2966.3 |
| 16:00-17:00 | 136.9 | 806.3 | 1817.7 | 1794.6 | 2634.4 | 2600.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 17:00-18:00 | 120.3 | 708.5 | 2642.1 | 1577.0 | 3829.2 | 2285.5 |
| 18:00-19:00 | 106.4 | 626.5 | 2248.9 | 1394.4 | 3259.3 | 2020.9 |
| 19:00-20:00 | 60.0 | 353.2 | 1965.5 | 786.2 | 2848.5 | 1139.4 |
| 20:00-21:00 | 67.7 | 398.7 | 617.5 | 887.4 | 894.9 | 1286.0 |
| 21:00-22:00 | 4.8 | 28.2 | 1945.8 | 62.8 | 2820.0 | 91.6 |
| 22:00-23:00 | 115.7 | 681.5 | 1706.1 | 1516.9 | 2472.7 | 2198.5 |
| 23:00-24:00 | 153.3 | 902.9 | 645.1 | 2009.7 | 1224.7 | 2912.6 |
| TOTAL | 2388.6 | 14068.8 | 34756.0 | 31314.4 | 50371.0 | 45383.2 |

```
..
.DEL Q1MS0.LPT
FILES DELETED:
Q1MS0.LPT
32 BLOCKS FREED

.K/F
JOB 20, USER [4072,546]  LOGGED OFF TTY5     1007  22-OCT-76
SAVED ALL FILES (16602 BLOCKS)
Runtime 32.89 Sec.
```

Note 1. Aircraft requiring gate service are placed in gate queues. Gate delays consist of the time between the presence of an aircraft in the gate queue and the time the aircraft is served at the gate. When an aircraft is added to the gate queue and served instantaneously by an empty gate, no gate delay is incurred. It is possible for a number of aircraft to enter the queue simultaneously and receive immediate service if an adequate number of gates are free. A maximum gate queue length greater than zero is consistent with zero gate delays within the framework of these definitions.

# 3. AIRSIDE MODELS

## 3.1 OVERVIEW OF AIRSIDE MODELS

A number of transport activities take place at an airport, including the movement of aircraft, passengers and ground airport access vehicles. Movement of passengers in the terminal building and the movement of airport access vehicles on the approaches and circulation system of the airport are dealt with in the groundside models of the Airport Performance Model. The arrival and departure of aircraft at the airport runways and the loading and unloading of aircraft at the airport gates are transportation activities which are examined by the airside models of the Airport Performance Model. The airside modules are of central importance to the overall model. Many of the performance measures for the airport analysis are based on airside model outputs. Most of the investments to be analyzed will be examined by altering components of the Airside Model and estimating the resulting benefits. The airside models therefore are important to the understanding of the operation of the Airport Performance Model.

The airside models include modules which interact with the Airport Performance Model data bases, modules which estimate performance for the airport runways and gates, and modules which evaluate aircraft and passenger delay costs, aircraft energy consumption, and pollution, emissions, etc. This chapter discusses the logic used in each of these individual modules, and the flow of information between the different modules. Subsequent chapters contain additional information on the data base and demand inputs which are the basis for inputs to the Airport Performance Model. Accordingly, these topics will receive only a limited discussion here. This chapter is organized following the information flow of the Airport Performance Model airside modules shown in Figure 3.1-1. The initial element of the airside model contains the demand profiles for airport activity. This feature of the program is discussed briefly in Section 3.2, and in additional detail in Chapters 5 and 6. Section 3.3 deals with the aircraft processing logic of the model which develops arrival and departure delays for the runway operations at the airport. Section 3.4 treats the operation of the gate model, and discusses the interaction between the runway operation and the activities at the airport gates. Section 3.5 discusses the estimates of energy consumption and air pollution emissions from airside operations. Finally, Section 3.6 discusses the models which produce estimates of airside operating costs.

## 3.2 AIRCRAFT DEMAND MODULE

The Airport Performance Model is driven by aircraft demand characteristics. The movement of passengers in the terminal building is logically tied to aircraft movements in the model, and delay and cost calculations are made in response to the aircraft demand characteristics input to the model.

The demand information fed into the Airport Performance Model contains information on the level of aircraft traffic operations, the mix of aircraft in use at the airport, and weather conditions. For each airport present in the Airport Performance Model, a daily

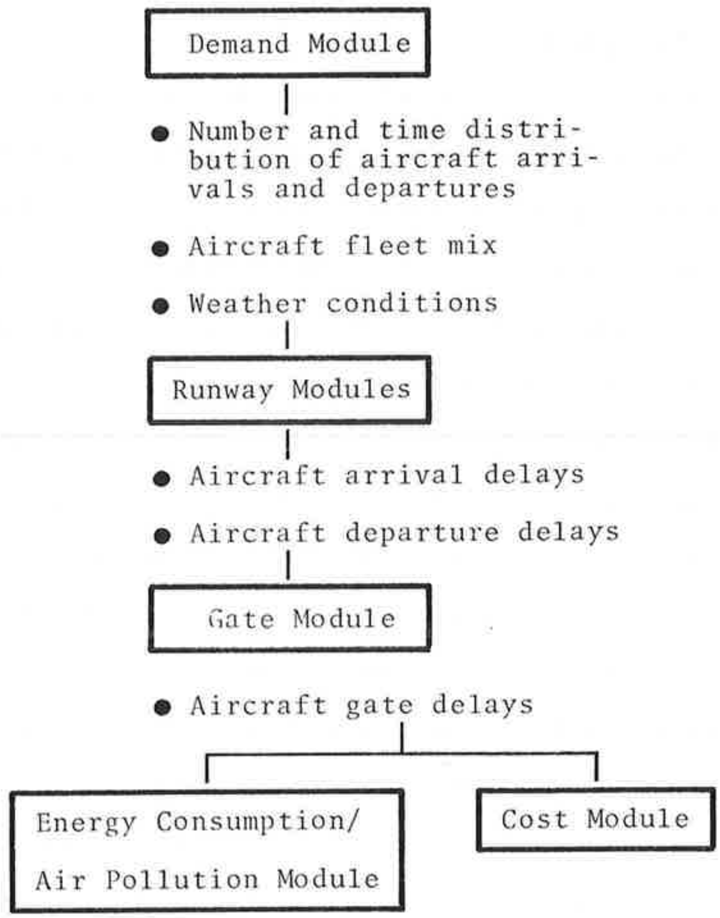


FIGURE 3.1-1. INFORMATION FLOW IN AIRPORT PERFORMANCE MODEL AIRSIDE MODULES

and an annual demand record has been developed. Equivalent classes of information are present in both demand files.

Traffic Distribution

Aircraft activity records include the distribution of operations by scheduled aircarriers and by general aviation and military aircraft.[1] For scheduled airport traffic, the demand distribution functions record activity separately for arrivals and departures on a minute-by-minute basis. A single function representative of the time distribution of activity for an average day is present in the daily demand file. These separate distribution functions are present in the annual demand file, representing variation in demand patterns which occur during the course of the year. Separate distribution functions for scheduled traffic were developed for each airport present in the model.

Separate processes are used to develop arrivals and departures for scheduled and non-scheduled (i.e., general aviation and military) traffic.[2] The process can be illustrated for the generation of scheduled arrivals during a daily run. The total daily demand volume is multiplied by the arrival profile. The product is a floating point number, typically containing a

[1] The distribution of scheduled air carrier operations is taken from the Official Airline Guide for each airport using 1973 data. A single generalized distribution function for non-commercial traffic is used for all airports. This distribution function was developed from operations records from EWR, JFK and LGH from 1972. For a more detailed discussion of the airport activity distribution functions, see Chapter 6 of this report.

[2] Note that the term "non-scheduled traffic" as used here refers to general aviation and military traffic. Commercial traffic not appearing in the Official Airline Guide is not included in this category of airport activity.

fractional part. Starting with the first minute of the day, the fractional part of the arrival schedule is subtracted and added to the arrival schedule for the next minute. In this fashion an integer number of operations is developed for each minute of the day, which is the arrival profile actually used in the model. The profile for departure demands are developed from a separate departure distribution function, but the procedure used is directly analogous to that used for generating the arrival profile. The same basic approach is used for non-scheduled traffic, although slight modifications are used because of the nature of the input data.[3] Total airport arrival and departure demand is generated by adding arrival and departure demands generated from scheduled and non-scheduled traffic.

This procedure used in daily analysis is the basis for the annual analysis as well. The annual program develops up to 54 daily analyses to represent activity over the course of the year.[4] The volume of scheduled and non-commercial activity is established for each of the 54 days, and the distribution of traffic for each of the days is present on the annualization file together with the appropriate volume figures for the two classes of airport traffic.

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[3]General aviation activity distribution uses the percentage of operations to take place during a 30 minute period. Individual operations are distributed to specific minutes through a random distribution procedure within the 30 minute period. In addition, operations are separated into arrivals and departures using the ratio of arrivals to total operations for commercial traffic developed in the demand file from the Official Airline Guide.

[4]The techniques for establishing the characteristis of the 54 days are discussed in Chapter 6.

The same procedure for developing aircraft arrival and departure demand described above for daily analysis is repeated for each of the 54 days (weighting factors representative of the frequency of occurrence of each of the 54 days are used to transform the costs, pollution etc. estimated for each of 54 days into estimates of arrival levels of costs, pollution and so on).

Aircraft Mix

The mix of aircraft in operation is recorded on the Airport Performance Model demand data base for each airport in an hourly fashion for scheduled air traffic. The mix of aircraft in use for general aviation and military operations is constant over the day for each airport.[5] The process for deriving the noncommercial, non-scheduled fleet mix is discussed in Appendix 3.2-1. The total airport fleet mix for each hour analyzed is generated by combining the aircraft mix for scheduled operations with the mix for non-scheduled airport operations. The two different fleet mixes are combined based on the volume operations for each of the two classes of traffic for the hour being analyzed.

Weather conditions are not treated directly by the data base for daily analysis. As a default, all VFR conditions are present in the daily file, but the user has the option of altering this input to investigate the impact of IFR conditions on daily airport operations. Weather is treated more explicitly in the 54 daily runs making up the annualization process. One-half of the

[5] The fleet mix for general aviation and military operations does change for IFR and VFR conditions in the annualization procedure, however.

54 days on the annualization file represent IFR days in which more than 2 of the 6 weather observations made during the "busy" period of the day (6 AM to 9 PM local time) indicated IFR weather was in effect. The division of the 54 representative days into IFR and VFR days enables the model to capture the characteristic changes in airport traffic (particularly general aviation traffic levels) which occur during IFR weather. In addition, later elements of the Airside Model change the airport aircraft processing rate to reflect the impact of IFR weather on airport capacity.

To change the level of operations for a model run, the user must specify the level of scheduled traffic for the analysis (including both air taxi and commercial air carrier) as well as the level of non-scheduled or noncommercial traffic (which is made up of general aviation and military traffic). Within the logic of the model, this alternation proportionately scales up or down all the volume levels for these two classes of airport traffic in the airport demand profiles. Other elements of the demand characteristics of the airport are also altered as a result of modifications in airport traffic volumes.[6]

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[6]For example, changes in the level of scheduled and non-scheduled (i.e., noncommercial traffic) at an airport will also change the fleet mix for the airport. The mix of aircraft in scheduled service at the airport is set on the demand file as in the mix for non-scheduled, noncommercial traffic. The total mix for all operations at an airport is essentially an average for the mixes from the two classes of traffic weighted by the daily volumes for the two classes of traffic. Changing the volumes for the two classes of traffic changes the weights used in deriving total airport mix and thereby changes the total airport mix.

When the user alters the mix of aircraft at the airport, the user's substitute airport fleet mix is assumed to be in effect for all airport operating hours for both IFR and VFR days.

## 3.3 AIRCRAFT PROCESSING MODELS

The products of the demand model will be a minute-by-minute demand for aircraft arrivals and departures from the airport runway system. The mix of aircraft to be served is known by the hour, and the weather conditions (IFR or VFR) will also be established by the demand model. The next component of the Airport Performance Model, the aircraft processing model, simulates the manner in which the aircraft demands at the airport will be served, and estimates the delays associated with this service. The key measure of aircraft processing capability used in the Airport Performance Model is the average time between operation when the airport is operating at capacity. This service rate, together with the aircraft arrival patterns, will determine the pattern of aircraft service and the levels of airport delay.

The aircraft service time is influenced by a number of factors, and as these factors change, substantial variation can occur in aircraft service times. Because of this variation in service times, the Airport Performance Model has a series of features which are used to develop accurate estimates of aircraft service times. These features are supported by theoretical modelling assumptions as well as empirical evidence on actual airport operations.

## Types of Aircraft Operations

The first factor which directly influences the aircraft service time is the type of aircraft operation observed. Aircraft arrivals have different service time requirements than do aircraft departures. In this study, the variation in aircraft service times due to type of operation was captured by specifying four different types of aircraft/airport interactions. These interactions correspond to an aircraft arrival on the airport runway surface which was preceded by another arrival, an arrival which was preceded by a departure, a departure following an arrival and finally, a departure following another departure. These four different interactions take different amounts of time because of the intrinsic differences between an aircraft arrival and a departure, and also because of FAA airport operating procedures. It is worthwhile to discuss these procedures briefly for the simple case of a single runway airport.

An aircraft arrival which is following another arrival must trail the leading aircraft by a specifically stated minimum distance. In addition, the following arrival cannot touch down on the runway surface until the preceding aircraft has exited from the runway. Similarly, a departure following an arrival must wait until the arriving aircraft has cleared the runway prior to taking off. A departure following another departure must allow the leading aircraft to establish a minimum distance separation prior to departing. Similar restrictions on simultaneous runway occupancy apply to arriving aircraft which land following an aircraft departure. These basic operating restrictions are compounded by additional restrictions due to other operating considerations (inclduing problems caused by aircraft wake turbulence, for example). Additional restrictions on aircraft operations arise from the complications associated with intersecting or parallel, dependent runway configurations, but these considerations will be discussed later.

Aircraft Types

These operating restrictions affect different types of aircraft to differing extents. The speed of approach for an arriving aircraft will influence the time required to travel the required separation distance behind a lead arrival aircraft, and approach speed also influences the manner in which an arriving aircraft exits the runway. In addition to the differences in aircraft performance characteristics, FAA airport operating procedures establish different inter-aircraft spacing requirements in terminal area operations.[7] For these reasons, the Airport Performance Model differentiates between both type of aircraft and type of aircraft operation in estimating aircraft service times.

The Federal Aviation Administration has developed terminal area operating procedures which differentiate between the following categories of aircraft:

1. Heavy - aircraft capable of takeoff weights in excess of 300,000 pounds;
2. Large - aircraft of more than 12,500 pounds, maximum certified takeoff weight, up to 300,000 pounds.

[7] See "FAA Notice N7110.431, Subject: Air Traffic Separation Standards," dated October 9, 1975.

3. Small - aircraft of 12,500 pounds or less, maximum certified takeoff weight.

Analysis of the landing speeds of aircraft[8] in commercial and private service led to a further refinement in these three aircraft categories. The category of Large aircraft as defined by the FAA was further divided into the two categories of Large Jet and Large Prop for use in aircraft service time estimates for the Airport Performance Model. This refinement was motivated by the distinct difference in published landing speed estimates as shown in Table 3.3-1. As the table indicates, the range of landing speeds for the resulting aircraft categories are distributed over a reasonably compact range of values and further refinement of aircraft categories was not considered necessary.

TABLE 3.3-1. LANDING SPEEDS FOR AIRCRAFT CATEGORIES USED IN THE AIRPORT PERFORMANCE MODEL

| AIRCRAFT TYPE | LANDING SPEED (M.P.H.) | |
|---|---|---|
| | RANGE OF VALUES | WEIGHTED AVERAGE FOR CLASS* |
| Heavy | 143-162 | 157 |
| Large Jet | 125-155 | 142 |
| Large Prop | 77-130 | 101 |
| Small | 59-92 | 80 |

*Based on number of aircraft in U.S. commercial service as reported in Flight Magazine December 5, 1974 (World Airlines Census, reported by airline) and in Commuter Air Carrier Traffic Statistics for the year ended December 31, 1972 Bureau of Operating Rights, Standards Division, U.S. Civil Aeronautics Board, September 1973.

[8] As published in performance specifications in Aviation Week and Space Technology, March 17, 1975 and Jane's All the World's Aircraft, various editions.

Even if all factors above were known for a particular airport and hour, the service time is not completely determined. There remain several unpredictable factors such as aircraft speed variations, communications time, pilot performance, controller performance, wind fluctuations about mean, etc. The service time, therefore, is properly treated as a random variable. Although estimates of the mean values of the service times could be generated for sequential arrivals, for example, by using the landing speeds and the separation spacing requirements established by the FAA, there are a number of indications that this method of estimating aircraft service times would not yield good estimates of actual airport performance characteristics.

Table 3.3-2 demonstrates the problems associated with estimating aircraft service times analytically. The Table represents estimates of the time between consecutive aircraft arrivals for airport operations on a single runway, which were calculated based on uniform 3-mile approach spacing standards and the approach speeds presented in Table 3.3-1, and contrasts these analytical estimates with estimates of aircraft service times based on historical observations during a peroid in which arrival separations were 3 miles. The analytic estimate indicates that the small aircraft, with relatively slow approach speeds, should take longer between operations than would the heavier, faster aircraft types also shown in the Table. By contrast, both the estimates of interarrival times derived from actual observations of airport performance indicate that small aircraft in practice have shorter inter-arrival times than do the heavier, faster aircraft types. The figures indicate that in practice the small

TABLE 3.3-2. COMPARISON OF ESTIMATES OF TIME BETWEEN AIRCRAFT ARRIVALS DEVELOPED BY DIFFERENT TECHNIQUES
(in seconds between arrivals)

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT | ANALYTIC ESTIMATE* | HISTORICAL SOURCE[1] | OBSERVATIONS SOURCE[2] | |
|---|---|---|---|---|---|
| | | | | IFR | VFR |
| Heavy Jet | Heavy Jet | 68.8 | 129.64 | 105.2 | 105.3 |
| Large Jet | Large Jet | 76.1 | 101.5-109.8 | 91.4 | 70.2 |
| Large Prop | Large Prop | 106.9 | 100.9-102.9 | 90 | 60.5 |
| Small | Small | 135.0 | 53.8 | 90 | 28.8 |

*Based on aircraft speeds shown in Table 3.3-1 and uniform 3 mile arrival separations.

Source 1: Technical supplement to Procedures for Determination of Airport Capacity, preapred for the Federal Aviation Administration, May 1975.

Source 2: Based on analysis of airport capacity curves for single runway presented in technical appendix to Airport Capacity Criteria Used in Preparing the National Airport Plan, Federal Aviation Administration, Washington, D.C., July, 1968. The assumption that interarrival times are determined only by the following aircraft was made in developing estimates.

aircraft are capable of achieving smaller separation standards in final approach. Direct comparison of the statistics from the three different sources may be somewhat misleading due to significant differences in aircraft category definitions used by the different sources, but the primary implication of the table is that inter-arrival times based solely on analtyic estimates of aircraft service times can yield results which are contrary to actual information.

Unfortunately, there are certain difficulties involved with using historical airport service times in the Airport Performance Model. There is considerable variance in observed values of inter-arrival times observed at an airport.[9] It is unclear how well the mean value of these observations reflects the aircraft processing capability of the airport. In addition, neither source of historical aircraft processing rates is completely satisfactory for developing inter-operation times (because of differences in fleet mix definitions, lack of data, or the significance of assumptions necessary to extract the required data).

The difficulties in estimating interoperation service times for use in the Airport Performance Model led to the use of several different data sources in deriving aircraft service time inputs to the model. Every attempt was made to develop accurate estimates of aircraft service times, and particular care was taken that the service times for different aircraft types were internally consistent and had reasonable relative magnitudes.

[9] The standard deviation for estimates from source 1 in Table 3.3-2 range from 28 to 39 seconds, which is large compared to the mean values listed in the table.

In a qualitative sense, data based on historical observation of airport operations has revealed that time between operations is small for light aircraft relative to heavy aircraft, and aircraft interactions in which the following aircraft is an arrival tend to require less time than interactions in which a departure is the following aircraft. The analysis performed for this study on airport operations data resulted in a table for inter-operation times on a single runway which appears in the appendix to this section. The values in the table represent a best estimate of aircraft servicing times given existing data on airport operations, and the relative magnitude of inter-operation times appears reasonable when contrasting different types of aircraft and different types of airport operations.[10] The entries themselves represent the time required for a specific airport/aircraft interaction (an arrival followed by a second arrival, for example) to take place for a single runway airport.

Runway Configuration

Analysis of airport capacity estimation procedures[11] revealed a relationship between airport capacity for different runway configurations. This relationship was such that the capacity of a given runway layout and airport fleet mix will be a multiple of the capacity of a single runway airport serving the same fleet

[10] One finding of this analysis was the determination of the need for an expanded data base on airport operating times. Limited data exists for operations with certain fleet mix combinations and improved data of this nature would greatly improve airport capacity and delay models.

[11] Based on data in [1], using analytic approaches shown in Appendix 3.3-A.

mix, and the ratio of the capacity of the two runway configurations will remain essentially constant when the fleet mix to be served is changed. This relation was found true for several different types of runway configurations when contrasted with the capacity for a single runway. The implications of this are that a good estimate of aircraft service times for an airport configuration of interest can be derived by multiplying the table of aircraft inter-operation times developed for a single runway configuration by the appropriate scaler. As a result of this finding, the inter-operation time developed for the single runway case can be utilized to develop inter-operation times for other runway configurations.

Hourly Variation in Processing Rates

The Airport Performance Model develops aircraft processing rate estimates for daily estimation procedures for each hour being simulated.[12] The airport fleet mix is present in the demand data base for each hour, and this fleet mix information is used to develop hourly aircraft processing rate estimates. For each of the four aircraft/airport interactions possible (arrival following arrival, departure following departure, arrival following departure and departure following arrival), the average service time for the interaction is estimated by combining the inter-operation times for specific aircraft types. The different inter-operation times are combined by taking a weighted average of the different times using

[12] For the cases analyzed by this study, the error introduced by this procedure is less than 10% of the estimated value of capacity.

the percentage of hourly operations by each aircraft type as the weighting factor. This procedure can be represented mathematically as seen below:

$$1) \quad t_h^n = \sum_i \sum_j \left(P_{ih}\right)\left(P_{jh}\right) \hat{t}_{ij}^n$$

where $t_h^n$ is the average airport service time for interaction type n for hour h;

$P_{ih}$ and $P_{jh}$ are the percentage of all operations in hours h scheduled to be made by aircraft types i and j respectively, and;

$\hat{t}_{ij}^n$ is the time for interaction n to take place when the lead aircraft type i and the following aircraft is type j.

The $\hat{t}_{ij}^n$ term is based on the time required for interaction n to take place for aircraft if followed by aircraft j on a single runway; however, the single runway service time may be multiplied by a scaler to coincide with the airport capacity and service time advantages of the particular airport being considered (the methodology for calibrating the aircraft service times $\hat{t}_{ij}^n$ to reflect the aircraft processing capabilities of individual airports is discussed in the appendix to this section).

When the weighted average described in 1) is completed, four average aircraft service times (one each for each combination of arrival and departure interactions) are defined for analysis. These service times are fundamental in determining aircraft delay statistics.

Aircraft Service Rules

The demand file for the airport analysis generates aircraft arrival and departure demands for each minute of the day. All aircraft service demands are assumed to be generated on the first second of the appropriate minute. If no activity is underway in the airport performance simulation at the time a single aircraft service demand is generated, the model serves the aircraft instantaneously and no aircraft delay is recorded by the model. If two demands are generated simultaneously at the beginning of a minute when no activity was taking place at the airport, the model will serve one of the two (selecting which of the demands to serve based on decision rules internal to the model) while the second demand incurs a delay. The duration of the delay is $t_h^n$, when n is the type of aircraft service defined by the two demands (if the two aircraft service demands were both arrivals, the delay for the second arrival would be the average time for an arrival followed by arrival for the hour being considered determined using equation 1) and the fleet mix for the appropriate hour, for example). The delay $t_h^n$ corresponds to the additional time required to serve the second aircraft service demand over the time which would be required if no other airport activity were taking place when the aircraft service demand was generated by the demand profile.

The decision rules for processing aircraft demands from the arrival and departure queues present in the model are rather straightforward. If the demand model indicates that aircraft arrival and departure demands are entered simultaneously, and if the runway system is not in use at the time of the demands, the model will service the arrival first and then the departure. After each simulated aircraft operation, the model checks both queues to determine if aircraft are still waiting to arrive or depart the airport. The model will continue to interweave arrivals and departures alternatively in the simulation of airport operations as long as aircraft are present in both queues. Aircraft service times are the departure followed by arrival time and the arrival followed by departure time developed for the hour being simulated. When one queue becomes depleted of aircraft waiting to be processed, the model will serve operations from the active queue repeatedly. At this point, the service time will either be the departure followed by departure" or the "arrival followed by arrival" time for the hour, depending on which of the two queues is being served.

The process continues as new arrivals or departures are generated from the demand module, continuing throughout the hour. In the simulation, the aircraft inter-operation service times are changed each hour as fleet mix changes. The queues developed during the previous hour of the simulation which are still full at the conclusion of that hour are carried into the next hour, with the processing rate reflecting the scheduled mix for the current hour rather than the fleet mix of aircraft still awaiting service.

Generation of Airport Performance Statistics

The model maintains statistics on the status of both the arrival and departure queues as the simulation progresses. The delays associated with each simulated operation are determined, and the cumulative totals for both arrival and departure delays are continually updated.[13] Delay statistics are also maintained for

[13] The mathematical relationship used to generate delay schedules appears in the appendix to this section.

individual hours in the delay simulation. By the definition used in the model, hourly delays represent the total delays for all aircraft operations which take place in the hour. Additional statistics for the operation of the arrival and departure queues are also maintained, including average delay and maximum delay, maximum length of the queue and average queue length. Like the statistics for total arrival and departure delay, all these queuing statistics are calculated for the entire simulation and for each hour simulated. These statistics are output when the model user performs a simulation of airport activity for a single day. When the user is analyzing airport performance for a year using the annualization feature of the program, a slightly more complicated procedure is used to develop program outputs.

The annualization procedure estimates delays (and other statistics) for a year by simulating activity at the airport for a maximum of 54 specially structured daily runs.[14] Based on statistical analysis of historical airport activity volume, aircraft activity distribution over the day, and weather patterns at the airport, the Airport Performance Model has a record of how many of the actual days of the airport's operations in a year have been represented by each of 54 or less days which are simulated in the annualization procedure. Each of the 365 actual days in the year have been assigned to one of 54 simulation days in the annualization program, and the number of actual days assigned to a single simulation day is the weighting for that simulation day. In

[14] The reader is referred to Chapter 6 for a detailed description of the annualization procedure.

the annualization program, airport activity is simulated for each of the 54 days in the annualization profile sequentially, and delay estimates for each of the days are generated. The delays associated with each of the days simulated are multiplied by the weighting for that day and total weighted delays for all simulated days are combined to produce the estimated annual delay for the year being analyzed. The weighting factors are also used in combining other queuing and airport performance statistics for individual days simulated by the annualization routine of the Airport Performance Model into estimates of annual delays and other measures of airport performance.

Summary

The basis for the determination of aircraft service times within the Airport Performance Model is a matrix of inter-operation times for single runway operations. The elements of this matrix are the time required for a specific type of airport operation to take place for a specific combination of aircraft types. Four basic airport operations are treated by the matrix (arrival followed by arrival, departure followed by departure, arrival followed by departure and departure followed by arrival). The matrix yields the time required for these four operations for the sixteen possible "lead-follow" combinations of the four aircraft mixes used in the model. The first step in developing the aircraft processing characteristics of the airport is the multiplication of each of the 64 (=16 X 4) elements of this table by the appropriate scaler. This scaler calibrates the inter-operation times to reflect aircraft processing rate for the airport runway configuration and weather conditions being simulated, given the reference fleet mix for the airport which is consistent for the airport processing rate used.

Second, a single, constant interoperational time is calculated for each of the four operation types for each hour for which airport performance is being simulated based on the fleet mix for aircraft operations during that hour (hourly airport fleet mix data are present in the airport demand profile discussed in Section 3.2).

Third, the operations for the airport for each hour are simulated. The minute-by-minute demands for aircraft arrivals and departures from the airport demand profile are used as the inputs to a deterministic queuing process. Separate queues are established for arrivals and departures and the airport runway system is modelled as a single facility which services demands in both queues. The aircraft in the queues are processed, using the processing times for the appropriate operation type (which were developed in the previous step). The process continues for each hour of the day until the operations for the entire day are processed.

Fourth, the delays associated with the simulation are calculated. The delay for an individual aircraft operation is the time elapsed between the time of the initial generation of the aircraft service demand and the time the aircraft is actually processed in the simulation. The program generates separate statistics for delays occurring on takeoff and on arrival. When the model is used to analyze the performance of an airport for a single day, the simulation delay estimates are output directly at the end of the simulation. For annual runs (in which the airport performance for a year is simulated by the analysis of a maximum of 54 individual days), the delay data for each of the individual runs is given the appropriate weighting and combined with the appropriately weighted delays from other runs in the annualization procedure to yield estimates of total annual delay.

The user of the Airport Performance Model has the option to alter the level of airport operations, to change the mix of aircraft to be used in the simulation, or to input different airport processing rates for IFR and VFR weather. These options affect the internal program parameters but do not affect the steps involved in developing estimates of airport delay. Thus, the aircraft processing methodology described above applies to all types of runs made using the Airport Performance Model, ranging from daily to annual analysis, and including runs in which the user uses default demand values as well as runs in which the user inputs desired demand characteristics.

## 3.4 GATE MODEL

Gate operations at major airports are relatively complex airport-dependent phenomena. The intent of the APM gate model is to obtain an approximate value for the carrier and commuter/air-taxi delays incurred for the entire airport in docking for the purposes of loading or discharging passengers. These delays result in losses both to the aircraft operator and the travelling public, including pollution and energy consumption, and serve as a measure of airport performance.

The delays in gate docking can result in gate departure delays on the next leg of a multi-stop flight. Network models (including references 3.4-1, 3.4-2 and 3.4-3) are best suited to examine the impacts of delay propagation from one flight to another. Accordingly, the Airport Performance Model focuses only on the gate delays which occur when aircraft are unable to dock at the airport gate areas due to lack of unoccupied gate space. Models referenced above are capable of evaluating propagated delays and their network effects, and supplement the outputs of the APM.

### Airport Gate Operations

Some of the salient features of gate operations at major airports are first discussed in order to provide a background for the gate model assumptions to be made in the next section.

Gate docking delays are to be distinguished from taxi-way and ramp congestion delays. In poor visibility weather, in particular, the flow of aircraft on the surface of the airport may be inhibited at intersections and along taxi-ways for reasons other than gate capacity. This includes cases in which aircraft parked on an apron or taxi-way while waiting for a free gate, inhibit the flow of surface traffic. Such delays are not considered here to be gate delays and are not simulated in the APM.

Gate delays commonly accrue to air carriers rather than general aviation or military aircraft, since the latter have much greater freedom in selecting a loading or unloading point. Air taxi and commuter/taxi aircraft, however, are restricted to a few loading and unloading points much as the carriers are.

In determining gate docking delays, a simple count of gate numbers may not be indicative of capacity for several reasons. First, loading and unloading may occur from areas temporarily designated as gate areas; two aircraft may simultaneously deboard in the same general gate area; and loading may occur at "split" gates both feeding from the same gate waiting area. For these reasons, capacity is more accurately described by a count of the maximum number of active loading or unloading points available at the airport.

Gate swapping among airlines is the exception rather than the rule at larger airports. Normally, gate docking queues, if any exist, pertain to individual airlines.

The gate service time is dependent on several factors, some of which are highly variable. The major ones are: aircraft type, whether or not the aircraft is a through-flight (partial deboarding or boarding), or a terminating flight (deboarding only), or an originating flight (boarding only), or a changeover flight (continuing with a new flight number); the number of passengers boarding and/or deboarding, the length of the previous leg, the length of the following leg (the latter affects refueling and restocking times), and the need for crew change. In general, the latter factors, and hence gate service time, increase with aircraft size. Load factors and the proportion of continuing flights to terminating or originating flights vary with time of day, and this causes gate service time to vary with time of day.

Finally, it should be noted that delays in landing will postpone the demand for deboarding gates. The demand for boarding gates, in turn, will be influenced by delays in deboarding as well as by delays in landing. The net effect of landing and gate delays, then, is to shift the demand for take-off services to later times. This catenation of services through the gate facilities is one of the most difficult aspects of all to model accurately.

Gate Model Assumptions

The complexity of gate operations, described above, and the aim of the APM to provide an investment analysis tool rather than an airport design tool, have led to the following simplifying assumptions for the gate model:

1. Taxi-way and apron delays not directly due to boarding or deboarding are not considered in the gate model.
2. Gate delays may accrue to air carriers and scheduled commuter/air taxi operations, but not to general aviation or military operations.
3. Gate capacity is proportional to the maximum number of available loading/unloading points, rather than to number of gates. (Henceforth, the term gate should be understood to mean a loading/unloading point).
4. The total number of loading/unloading points at an airport are available to all carriers, including international and scheduled commuter/air taxi operators.
5. Gate service times are assumed to be the same for all airlines. The gate service time is assumed to be constant with time of day and aircraft type, but to be different for a) through or changeover flights, b) originating flights, c) terminating flights.
6. Landing delays affect the demand for gates, but gate delays do not affect the demand for take-off service at the runway complex.

The most important of these assumptions are 4, 5, and 6. They will be discussed in what follows.

Assumptions 4 and 5 allow simulation of a single gate queue for all carriers at the airport in place of one simulation for each carrier. In other words, the APM estimates gate queue delays for a single composite carrier, for which the demand is the total of the individual airline demands at the airport, and which has a number of gates (loading/unloading points) equal to the total number available to all the airlines at the airport. The delays thus simulated are not equal to the sum of the delays of the individual airlines, and must be adjusted to give correct answers. The reason for the adjustment is that a single, composite airline would experience demand with percentage fluctuations that were, on the average, smaller than those experienced by the individual airlines and hence its delays would be less than the sum of the individual airlines' delays. Viewed another way, the composite airline would be able to pool unused gates to accommodate demand fluctuations. This is counteracted in the APM single-airline model by using fewer gates than are available at the airport, as described by Appendix 3.4-A.

Assumption 6 simplified the calculation of take-off delays. These are computed from the undelayed scheduled and non-scheduled profiles, since assumption 6 avoids any delay in the departure profile due to gate delays. The effect of this assumption on accuracy should be discussed.

Gate delays on arrival and departure will be relfected in runway take-off demand if the aircraft is not a terminating flight and if it has inadequate slack in its schedule to absorb delays. This effect on runway take-off demand is not modelled in the APM. Rather, the take-off demand is extracted directly from the unmodified OAG schedule, without reference to preceding delays in landing, gate arrival and gate departure. The reason for the assumption is that it greatly simplifies the modelling problem: the take-off demand profile is affected by enroute delays and delays at up-line stations which are outside the scope of the AMP, as well as by landing the date delays, which are within the scope of the APM. A complete model, therefore, is not practical within the APM. To the extent that these delays are network dependent, however, they are handled by a companion model, the Airport Network Flow Simulator (Reference 3.4-1).

The inaccuracy introduced by assumption 6 is difficult to assess. If the departure and arrival schedules are peaked, and strongly connected by the same aircraft, then the landing and gate delays tend to smooth out the peak demand for take-off services. Ignoring the effect, as is done in the assumption ignores the cost to passengers of gate departure latenesses. The interaction of these two opposing phenomena makes it difficult to determine the effect on accuracy of the assumption without further simulation.

Operation of the Gate Delay Model

The gate delay model is a minute-by-minute simulation of gate activity. It keeps track of a gate arrival queue and a gate departure queue by the following steps:

1. Aircraft coming off the runway after landing are segregated into scheduled and non-scheduled streams. The non-scheduled aircraft are assumed to be general aviation and military flights, which incur no gate delays, and are not processed further.

2. Scheduled aircraft from step 1. are put into the gate arrival queue, if there is no available gate. (By the single-airline model of the APM, as described in Appendix A, any aircraft may be serviced at any of the G gates of the airport).

3. Each of the aircraft entering the gate arrival queue in Step 2. is assigned to be either a through or change-over flight (unloads and loads without leaving the gate), or to be a termination flight (unloads, leaves its gate empty). The fraction of flights assigned to be through flights is a stored datum for the airport which may be modified by the user before a computer run is made (See Data for the Gate Model below). For every arrival flight designated as a through flight, a flight is deleted from the gate departure schedule.[1]

4. Aircraft are taken from the gate departure schedule, (allowing for the deletions of step 3.) at their scheduled departure time less the gate service time for departure flights, and are placed in the gate departure queue if no gate is available.

[1]This affects only the gate delay model, not the runway take-off delay part of the APM, where such a deletion is not made. See Assumption 6 of the Gate Model Assumptions of Appendix A.

5. Aircraft are serviced from the gate arrival queue and gate departure queue as gates become available. The aircraft with the longest time in either queue is selected for service at the available gate.

6. When an aircraft is assigned for service at a gate, that gate becomes unavailable to other aircraft for an interval equal to the appropriate gate service time. If the aircraft came from the gate arrival queue, the appropriate service time is either that for through flights for for terminating flights, depending on the assignment received in step 3. If the aircraft comes from the gate departure queue, the appropriate service time is that for originating flights. At the end of the service time the gate once again becomes available.

The above six steps determine the contents of the gate arrival and gate departure queues throughout the day. They also determine the number of gates occupied throughout the day. Queue length and delay time statistics are extracted from the two queues in the same manner as from the landing queue or take-off queue. It should be noted that the gate arrival and gate departure queues are, in effect, a single queue because of the servicing rule stated in step 5, and in this respect they differ from the landing and take-off queues of the APM.

The definitions of gate arrival and gate departure delays, used in determining benefits, are as follows: Gate arrival delay is the time from entering the departure gate queue to the time at which a gate becomes available for the aircraft. Since taxi times are considered constant, the time of entering the queue is taken to be the time of completion of landing service at the runway, with no loss in accuracy of delay calculation. Similarly, departure gate delay is taken to be the time from entering the departure gate queue (step 4. above) to the time at which a gate becomes available. It should be noted that no departure gate delay accrues to through flights, which load for departure without leaving their arrival gate, and which are deleted from the gate schedule in step 3. above.

the calculation of gate delays for an annual run is treated similarly to the annual calculation of take-off and landing delays: the annual delay is taken as the weighted average of a selected sample of daily delays (See Reference (1), Section 6). The use of gate delays to calculate pollution and energy consumption is discussed in Section 3.5 of Reference (1).

Data for the Gate Delay Model

The data required for the gate model are

1. The total number of gates at the airport.
2. The mean gate service time for through flights and for departure and arrival flights.
3. The fraction of all operations at the airport made by through, departure, and arrival flights.

The user is given the option of inputting these data for the airport of interest. If he chooses not to do so, the program employs the default values shown in Table 2.-1 for the total number of gates, the values of Table2.-3 for the gate service times, and the values of Table 2.-3 for the fractions of item 3. The method of deriving these data will now be discussed.

1. Number of Gates (Table 3.4-1)

The major source of Table 3.4-1 was the Apron and Terminal Building Manual, Reference (5), published for the FAA by Ralph M. Parsons Company. Figure A-3 in that reference shows gate data in graph form, but becuase of lack of detail in the graph it was necessary to employ the original material obtained from the FAA. The numbers refer to "active loading positions in domestic scheduled operations." In total, data for 25 airports were obtained from this source.

The next source of data was the report "Airport Surface Traffic Control Systems Deployment Analysis" by the MITRE Corporation for the FAA, (Reference (6)). This source provided data for 39 airports. Five of them (IAH, STL, DFW, JFK, MIA) were necessary

TABLE 3.4-1. GATES IN DOMESTIC AND INTERNATIONAL OPERATIONS

| Airport ID | Estimated Active Loading/Unloading Points<br>Domestic | International | Total |
|---|---|---|---|
| ORD | 80 | 1.10 | 81 |
| ATL | 78 | 0.63 | 79 |
| JFK | 72 | 24.33 | 96 |
| LGA | 43 | 0.00 | 43 |
| SFO | 54 | 1.34 | 55 |
| LAX | 64 | 2.44 | 66 |
| DEN | 60 | 0.00 | 60 |
| PHL | 39 | 1.39 | 40 |
| EWR | 38 | 1.20 | 39 |
| MIA | 41 | 8.94 | 50 |
| DAL | 20 | 0.20 | 20 |
| DCA | 37 | 0.00 | 37 |
| PIT | 36 | 0.08 | 36 |
| BOS | 55 | 3.56 | 59 |
| CLE | 40 | 0.14 | 40 |
| DTW | 48 | 1.14 | 49 |
| MSY | 24 | 0.67 | 25 |
| LAS | 32 | 0.00 | 32 |
| HNL | 35 | 3.73 | 39 |
| STL | 35 | 0.00 | 35 |
| FLL | 18 | 0.29 | 18 |
| TPA | 38 | 0.67 | 39 |
| MSP | 37 | 0.00 | 37 |

Table 3.4-1. (Continued)

| Airport ID | Domestic | International | Total |
|---|---|---|---|
| SEA | 34 | 0.97 | 35 |
| BAL | 18 | 1.04 | 19 |
| CLT | 16 | 0.00 | 16 |
| MKE | 20 | 0.00 | 20 |
| SLC | 21 | 0.00 | 21 |
| IAH | 40 | 0.62 | 41 |
| IAD | 24 | 4.30 | 28 |
| JAX | 15 | 0.00 | 15 |
| DFW | 68 | 1.01 | 69 |
| Average | 38.9 | 1.87 | 41. |

to supplement the data of Reference (5). Because there was good correlation between the two sources, for airports with primarily demestic service, the MITRE report numbers were used for Huston, St. Louis and Dallas-Ft. Worth without modification. For JFK and MIA, however, the numbers were reduced by a fraction based on the percent domestic and international operations to give an estimated number of gates in domestic service. A similar calculation was made for Honolulu from data obtained by telephone.

Having obtained estimates of gates in domestic operations on a uniform basis, the next step was to allow for gates in international service, and then, finally, to add them to obtain total gates (loading/unloading points) available at the airports of interest. The number of international gates was estimated by multiplying the number in domestic service by the ratio of international to domestic operations for the airport, as obtained form "Airport Activity Statistics of the Certificated Route Carriers" for the twelve months ending December 31, 1974. The results are shown in Table 3.4-1 along with the totals.

2. Gate Service Times (Table 3.4-2.

The three types of gate service times employed in the APM are modelled as constants. The three types are (1) through or changeover flights, which unload and load, as required, without leaving the gate; (2) arrival-only flights, which unload and leave the gate empty for parking or storage; and (3) departure only flights, which dock empty, laod, and then leave the gate for take-off.

The three service times were extracted from the Official Airline Guide for February 16, 1976, North American Edition. Only flights to or from U.S. and Canadian airports were included, for the most part.[2] The method of extraction was as follows:

(1) Flights that arrive and depart at the airport under the same flight number were classed as through-flights.

[2]Airports included were those in the contiguous 48 states, plus YUL, YYZ, ADQ, ENA, AKN, JNU, FAI, ANC, HNL, SJU.

(2) Arriving flights and departing flights of the same airline and aircraft type with different flight numbers were compared, and in many cases, linked together using modifications of existing algorithms (Reference (8)). They were classed as "connecting" flights.[3] The remaining flights at the airport were classed as either arriving-only or departing-only flights.

(3) The times from gate arrival to gate departure for the through and connecting flights of (1) and (2) were tabulated and sorted by airport and aircraft type.

(4) The minimum of the times tabulated for each aircraft type was selected for each of the 31 airports in the APM. A weighted average of these times was taken as the through/connecting gate service time for the airport.

(5) Arriving gate service time was taken as a fraction (one third) of the through/connecting gate service time.

(6) Departing gate service time was taken as a fraction (two thirds) of the through/connection gate service time.

The results are tabulated in Table 3.4-2.

3. Through, Arrival and Departure Flight Fractions (Table 3.4-3.).

As a by-product of the process described in 2. above, it was possible to estimate what fraction of all flights at an airport were of the through/connecting type, as defined above, as well as the fractions of arriving-only and departing-only flights. The arriving flights in the APM are assigned to be througn/connecting or arriving only, in the proportions indicated by the two fractions, as described in 2.1 above.

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[3]This use of the term "connecting" differs from airline usage, where two different air frames are considered "connecting flights" if a passenger may connect from one to another.

TABLE 3.4-2. GATE SERVICE TIMES DERIVED FROM THE OAG (SECONDS)

| | THROUGH | ARRIVAL | DEPARTURE |
|---|---|---|---|
| ORD | 2023. seconds | 668. seconds | 1355. seconds |
| ATL | 1857. | 613. | 1244. |
| JFK | 2338. | 783 | 1565. |
| LGA | 1599. | 528. | 1072. |
| SFO | 1990. | 657. | 1334. |
| LAX | 2257. | 745. | 1512. |
| DEN | 1840. | 607. | 1232. |
| PHL | 1436. | 474. | 962. |
| EWR | 1859. | 620. | 1239. |
| MIA | 2106. | 695. | 1411. |
| DAL | 2340. | 772. | 1568. |
| DCA | 1376. | 454. | 922. |
| PIT | 1344. | 444. | 900. |
| BOS | 2122 | 700. | 1422. |
| CLE | 1661. | 548. | 1113. |
| DTW | 1983. | 654. | 1329. |
| MSY | 1583. | 522. | 1060. |
| LAS | 1666. | 550. | 1116. |
| HNL | 2281. | 753. | 1528. |
| STL | 1470. | 485. | 985. |
| FLL | 1452. | 479. | 973. |
| TPA | 1308. | 432. | 877. |
| MSP | 1874. | 618. | 1256. |
| SEA | 1927. | 636. | 1291. |

TABLE 3.4-2. (Cont.)

| | THROUGH | ARRIVAL | DEPARTURE |
|---|---|---|---|
| BAL | 1170. | 386. | 784. |
| CLT | 1246. | 411. | 835. |
| MKE | 1368. | 451. | 917. |
| SLC | 1836. | 606. | 1230. |
| IAH | 1600. | 528. | 1072. |
| IAD | 986. | 325. | 661. |
| JAX | 1555. | 513. | 1042. |

TABLE 3.4-3. FRACTION OF THROUGH, ARRIVAL, AND DEPARTURE FLIGHTS

| APT | $f_T$ | $f_D$ | $f_A$ |
|---|---|---|---|
| ORD | | .10 | .13 |
| ATL | .81 | .08 | .11 |
| JFK | .55 | .20 | .24 |
| LGA | .60 | .22 | .18 |
| SFO | .64 | .20 | .17 |
| LAX | .66 | .18 | .17 |
| DEN | .77 | .11 | .12 |
| PHL | .62 | .20 | .18 |
| EWR | .46 | .27 | .28 |
| MIA | .60 | .20 | .20 |
| DAL | .73 | .14 | .14 |
| DCA | .60 | .20 | .20 |
| PIT | .62 | .19 | .19 |
| BOS | .51 | .22 | .21 |
| CLE | .66 | .16 | .17 |
| DTW | .67 | .16 | .17 |
| MSY | .75 | .12 | .12 |
| LAS | .68 | .16 | .16 |
| HNL | .54 | .25 | .21 |
| STL | .76 | .11 | .13 |
| FLL | .62 | .17 | .20 |
| TPA | .78 | .10 | .12 |
| MSP | .59 | .21 | .20 |

TABLE 3.4-3. (Cont.)

| APT | $f_T$ | $f_D$ | $f_A$ |
|---|---|---|---|
| SEA | .63 | .20 | .17 |
| BAL | .65 | .18 | .17 |
| CLT | .79 | .12 | .10 |
| MKE | .73 | .13 | .13 |
| SLC | .63 | .19 | .82 |
| IAH | .73 | .14 | .13 |
| IAD | .46 | .26 | .27 |
| JAX | .84 | .09 | .07 |

NOTE: Fractions may not be added to 1.00 because of rounding.

## 3.5 AIR POLLUTION/ENERGY CONSUMPTION MODEL

A model for estimating the energy consumption and air pollution emissions associated with airprot terminal operations was developed within the context of the Airport Performance Model. The goal of this model was to simulate as closely as possible the air pollution and energy consumption performance of aircraft operating at the airport in question. No attempt was made to model the pollution and energy consumption characteristics of the groundside airport access modes. This decision was made not because these access movements are insignificant in these two phenomena but because the principal goal of the model was to reflect how changes in airport airside configuration and capacity would affect airport-related air pollution emissions and energy consumption.

The air pollution and fuel consumption models attempt to simulate the impact of both normal aircraft operation and aircraft operational delays on emissions and fuel consumption. The models are based upon earlier work on aircraft engine technology assessment[1] which estimate engine fuel consumption and pollution per unit time for idle, approach, climbout and takeoff engine throttle settings. The approach taken in these models required that representative aircraft categories be established that air pollution and energy consumption characteristics for these aircraft be estimated, and that the time duration of operation be modelled for nominal, no-delay operation and for delays on arrival

[1] Manit, R., E. Danielson and J. Daimen, Aircraft Technology Assessment: Interim Report on the Status of the Gas Turbine Program, U.S. Environmental Protection Agency (Washington, D.C.) 1975. See Appendix A for engine performance specifications.

and departure. The air pollution and energy consumption models can easily be embedded within the context of the entire Airport Performance Model given this modelling approach.

## Aircraft Categories

Data concerning aircraft engine performance was evaluated together with equipment specifications (number and type of engines) for prominent aircraft types. From this analysis, it was clear that considerable error in estimates of energy consumption and air pollution could result if aircraft types were placed in a very small number of categories. The categories which were finally decided upon appear in Table 3.5-1 below. Whenever possible, the most numerous aircraft type within the class was used as representative of the group. In certain instances the operating characteristics of the engine type associated with the most common aircraft type in the group were not available and a less frequently occurring aircraft type was selected as representative of the group. Five categories of large (greater than 12,500 pounds gross takeoff weight) turbofan/turbojet aircraft were specified for separate classification. One large turboprop/piston aircraft group was specified. All small aircraft (weighing less than 12,500 pounds) were classified together. Rotary wing aircraft were included in this category as well.

## Model Sensitivity to Airport Operation

Air pollution emissions and energy consumption levels were tied to airport activity and delay conditions through aircraft operating characteristics for idle, approach climbout, and takeoff.

TABLE 3.5-1. AIRCRAFT CATEGORIES FOR AIR POLLUTION/ENERGY CONSUMPTION MODELS

| Aircraft Category | Representative Aircraft | Engine Type | Percent of Category Made up by Representative Aircraft |
|---|---|---|---|
| 1. Small (E.T.O.W. less than 12,500 lb.) | Beech 99 | PT6A | 13% (86 of 684) |
| 2. Large Prop (Turboprop or piston greater than 12,500 lb G.T.O.W.) | Lockheed Electra | 4 Allison 501-D13 | 17% (38 of 222) |
| 3. Large Jet (Turbofan/turbojet greater than 12,500 lb G.T.O.W. but less than 300,000 lb) | | | |
| a. 2 Engine | DC-9,737 | 2 JT8D | 94% (576 of 615) |
| b. 3 Engine Standard and Stretched | 727 | 3 JT8D | 100% (793 of 793) |
| 4. Heavy Jet (Turbofan/turbojet greater than 300,000 lb G.T.O.W.) | | | |
| a. 4 Engine Standard and Stretched | DC-8,707 | 4 JT3D | 90% (423 of 471) |
| b. 3 Engine Wide Body | DC-10 | 3 JT9D | 11% (22 of 195) |
| c. 4 Engine Wide Body | 747 | 4 JT9D | 100% (88 of 88) |

Air pollution emissions are considerd only for operations below 3,000' above-ground level. This includes all on-airport operations and certain landing and climb out operations. The amount of emissions associated with aircraft landings is derived by assuming aircraft use a 3° glide slope, deriving the straight-line flight distance associated with descent operations below 3,000 feet and determining operating time for this landing given aircraft landing speeds. The straight-line flight distance associated with a 3° glide slope under 3,000 feet altitude is slightly over 11 miles. A representative three engine narrow bodied jet aircraft has a normal landing speed of 145 miles per hour, and would therefore make this approach in 4.7 minutes, or 282 seconds. The normal air pollution emissions for this jet aircraft during landing would be the emissions per second characteristics associated with this aircraft type during approach times 282 seconds. When this emission level has been developed for all aircraft types, total emissions associated with all landing operations can be estimated by multiplying the landing emissions factor for each aircraft type times the number of operations by that aircraft in the reference time period, and running across all aircraft types. Note that emissions associated with aircraft holding operations prior to landing are assumed to take place above the 3,000 foot altitude level, and are ignored ty this model. Takeoff emissions are estimated by assuming that 40 seconds elapse between the start of the brake roll until lift off. Climb-out pollution emissions to the 3,000 foot altitude ceiling are calculated assuming aircraft takeoff speeds and climb out angles as shown in Table 3.5-2.

TABLE 3.5-2. AIRCRAFT PERFORMANCE CHARACTERISTICS USED IN CALCULATING ENERGY CONSUMPTION AND AIR POLLUTION EMISSIONS

| Aircraft Category | Approach Angle (Degrees) | Approach Speed (M.P.H.) | Time under 3000 feet (Minutes) | Climb Out Angle (Degrees) | Climb Out Speed (M.P.H.) | Time Under 3000 feet (Minutes) |
|---|---|---|---|---|---|---|
| Small | 3 | 80.5 | 8.14 | 4.6 | 154 | 2.76 |
| Large Turboprop/ Piston | 3 | 101 | 6.49 | 4.6 | 154 | 2.76 |
| Large Two Engine Jet | 3 | 141 | 4.64 | 10 | 192 | 1.02 |
| Large Three Engine Jet | 3 | 143 | 4.58 | 9 | 192 | 1.13 |
| Large Four Engine Jet | 3 | 157 | 4.17 | 7.5 | 192 | 1.36 |
| Three Engine Wide Body Jet | 3 | 152 | 4.30 | 9 | 192 | 1.13 |
| Four Engine Wide Body Jet | 3 | 160 | 4.09 | 9 | 192 | 1.13 |

Straight-line flight paths are assumed during climbout to 3,000 feet.

Pollution emissions while aircraft taxi on the airport surface are somewhat more difficult to model. A nominal taxi time between airport gates and runways will result in a certain level of pollution emission. Emissions resulting from idling caused by gate and runway delays will also add to pollution caused by aircraft movement on the airport surface. The relationship between taxi/idle time and runway and gate delay is complicated by a number of aircraft operating procedures employed at certain airports or by certain airlines. Many aircraft idle with less than full power as a result of airline fuel conservation policies. This policy is not uniformly practiced by all airlines, however, and may not be followed at all times even when it is airline policy to do so. Thus, it is difficult to take the procedure of "half power idle" policies into consideration with any degree of confidence.

In addition to the use of less than full power idle strategies to save fuel during gate and taxi delays, gate hold procedures are in use at many commercial airports to reduce delay-related fuel consumption and air pollution or to minimize community annoyance caused by aircraft idling on taxiways prior to departure. When these procedures are in use, aircraft are held at the departure gate whenever the departure queue at the runway exceeds a certain level (either in number of aircraft or length of average departure delay). The effect of these policies is to set an upper bound on the aircraft idle time independent of departure delays. These policies are used at many airports, and are in general managed by the ATC tower supervisor. A great deal of experience goes into the operating rules for the gate hold procedures, and many aspects of the program are airport specific. At a number of airports, gate hold programs can take place at only a limited level because of the shortage of aircraft gates or lack of apron or taxiway space for manuevering.

The discussion above referred to gate hold procedures motivated by runway delays on departure. A second program of gate holds is also currently in use which is motivated by arrival delays taking place at the upper line airports. Thus, an aircraft scheduled to depart from airport A to airport B may be held at the gate at airport A when arrival delays at airport B exceed a certain threshold level. This system is currently in use for only a limited number of heavily used up line airports but it may be expanded to other airports.

Because of the absence of system-wide uniformity of operating standards for gate hold procedures and less than full power idling, it was necessary to make a series of simplifying assumptions for modelling certain air pollution and energy consumption activities. Specifically, it was assumed that

- all delays upon arrival would result in energy consumption at a rate equivalent to approach for landing. This effectively ignores the effect of gate-hold procedures at down-line stations, which are in effect for only a few airports. Delays taking place prior to aircraft arrival are assumed to take place while aircraft are in holding patterns in excess of 3,000 feet above the airport surface. These delays are therefore considered to result in additional energy consumption, but are not considered as a source of ground level air pollution;

- when gate hold procedures are in effect because of departure runway delays, it is assumed that aircraft will sustain a maximum of 10 minutes of idling at full power prior to departure;
- when gate hold procedures are <u>not</u> in effect it is assumed that aircraft idle with full power for the first 10 minutes of runway delay and at half power thereafter;
- Normal taxiing between the airport gates and runways is assumed to take place at full power idle.

Within the context of the larger model, aircraft type is considered through the hourly fleet mix. Although the movements of individual aircraft result in delay calculations for an hour, the Airport Performance Model is structured in such a way that aircraft classification identity is not retained for individual aircraft within each hour. In keeping with this structure, the air pollution and energy consumption characteristics of aircraft operating within an hour are combined using a weighted average system based on the hourly fleet mix into a composite characteristic for that hour. Total air pollution emissions and energy consumption statistics are estimated by multiplying the nominal and delay time associated with simulated aircraft activity during the hour in terms of idle, approach, takeoff and climb out operations times the composite energy consumption and air pollution emission characteristics for the hour.

Appendix 3.5-A describes the methodology used to calculate energy consumption and air pollution estimates within the Airport Performance Model. Appendix 3.5-B presents the coefficients of aircraft energy consumption and energy consumption that are used in the Airport Performance Model.

## REFERENCES


3.3-1 Airport Capacity Criteria Used in Preparing the National Airport Plan, Federal Aviation Administration, July 8, 1968.

3.3-2 Procedures for Determination of Airport Capacity, prepared for the Federal Aviation Administration by Douglas Aircraft Company in accordance with Peat, Marwick, Mitchell & Co., McDonnel-Douglass Automation Company and American Airlines, Inc., May 1975.

3.3-3 Performance Measurement System for Major Airports, Federal Aviation Administration, November 1975.

3.4-1 Gordon, Steven, "The Airport Network Flow Simulator," Report No. FAA-ASP-75-6, U.S. Department of Transportation, Transportation Systems Center, Cambridge MA, May 1976.

3.4-2 Cheng, Joseph C., "FORTRAN Conversion of the Airport Network Flow Simulator," U.S. DOT/TSC, material on file, May 1976.

3.4-3 Bellantoni, J.F., "User's Manual for the FORTRAN ANFS," DOT/TSC, material on file, May 1976.

3.5-1 Munt, R., E. Danielson and I. Deimen, Aircraft Technology Assessment Interim Report on the Status of the Gas Turbine Program, U.S. Environmental Protection Agency, December 16, 1975.

## 3.6 COST MODELS

The purpose of the cost models within the APM is to convert to dollars the cost of air and ground delays experienced by aircraft. No attempt is made to attach dollar costs to air pollution, terminal congestion, or access lane congestion. In the case of air pollution, even an approximate cost estimate is beyond the scope of the APM study, because it involves numerous medical, economic and social considerations that have not yet been fully investigated (Reference 3.6-1 is an initial attempt at quantifying these costs). In the case of terminal and access lane congestion dollar costs were not calculated because of the nature of the groundside models (See 4.0 GROUNDSIDE MODELS). These models estimate the facilities required to maintain groundside congestion at nominal levels, and hence do not yield estimates of the actual passenger and ground vehicle delay times.

Three types of aircraft delays were costed out in the APM: air delay upon arrival, ground delay on takeoff, and ground delay in gate docking.

### Air Delay Operating Costs

The operating cost of air delay was based on the five cost elements shown in Table 3.6-1: crew, fuel and oil, airframe maintenance, engine maintenance, and maintenance burden. These costs were broken down for the eight categories of aircraft employed in the APM, as shown in the same Table. They are the same categories employed in the delay model and in the pollution and energy consumption models.

The data in the Table (except for S-type) were taken from Reference 3.6-2, prepared by the CAB, covering U.S. Certificated and Supplemental Carriers for 1974. The data for the Certificated carriers was used, rather than that for the Supplementals, because the latter included insurance and other costs, which do not accrue to airborne delay. It should be noted that the data shown in Table 3.6-1 for the Certificated Carriers include ground as well as airborne cost divided by total block hours. This is a reasonable approximation to the desired values of airborne costs divided by airborne hours, since most of total operating time and cost is airborne.

Crew costs increase with airborne delay because crews are commonly paid by block time, which is affected by airborne delay. The fuel and oil cost shown in the Table is an average over total block hours, as described above. It includes the higher fuel consumption of takeoff and climb, as well as the lower fuel consumption of taxi, which bracket the desired fuel consumption rate for holding. Maintenance costs are included because maintenance is usually based on engine hours and/or flying hours.

The total operating cost for small aircraft shown in Table 3.6-1 was calculated from data contained in Reference 3.6-3. The calculation, shown in Table 3.6-2, yields a weighted hourly operating cost of \$22.79 for small aircraft ($\leq$ 12,500 lbs TOGW). This average was obtained by considering the total hourly operating cost for each of four subtypes of the S category and weighting each by the average hours flown per year by that subtype. This yields an average cost over all Small aircraft subtypes.

TABLE 3.6-1: OPERATING COSTS[1] AFFECTED BY AIR DELAY

| | AIRCRAFT TYPE[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | H4W | H3 | H4S | L3 | L2 | LP | S | O[3] |
| CREW | 335.81 | 291.32 | 250.36 | 219.18 | 192.47 | 345.51 | | 111.41 |
| FUEL AND OIL | 586.60 | 388.39 | 298.58 | 218.34 | 152.24 | 107.42 | | 42.19 |
| AIRFRAME MAINTENANCE | 139.05 | 101.86 | 70.31 | 55.39 | 52.77 | 141.02 | | 160.16 |
| ENGINE MAINTENANCE | 233.50 | 152.07 | 60.75 | 46.10 | 31.70 | 113.36 | | (4) |
| MAINTENANCE BURDEN | 177.07 | 141.36 | 127.04 | 86.45 | 71.44 | 190.19 | | 83.60 |
| | 1472.03 | 1075.00 | 807.04 | 625.00 | 500.62 | 897.50 | 22.79[5] | (6) |

(1) Data from Reference 3.6-2

(2) See Table 3.5-1 for description of aircraft categories.

(3) "Other" category assumed to be helicopter

(4) Contained in cost for Airframe Maintenance above.

(5) See Table 3.6-2 and text for S-type cost.

(6) See text

TABLE 3.6-2: AVERAGE OPERATING COSTS FOR U.S. SMALL AIRCRAFT

| i | SMALL AIRCRAFT TYPE | $C_i$ (2) | $h_i$ (3) | $n_i$ (4) | $H_i$ (5) | $\overline{C}$ (6) |
|---|---|---|---|---|---|---|
| 1. | SINGLE-ENGINE PISTON (1 TO 3 SEATS) | $ 11.28 | 158 | .323N | 51.03N | $3.07 |
| 2. | SINGLE-ENGINE PISTON (4 OR MORE SEATS) | 15.81 | 186 | .530N | 98.6N | 8.31 |
| 3. | TWIN-ENGINE PISTON (12,500 LBS OR LESS TOGW) | 47.60 | 289 | .111N | 32.08N | 8.41 |
| 4. | TWIN-ENGINE TURBO PROP (12,500 LBS OR LESS TOGW) | 96.76 | 727 | .008N | 5.82N | 3.00 |
| | | | | | $\overline{C}$ = $22.79 | |

(1) Data from Reference 3.6-3

(2) $C_i$ = cost per aircraft hour of operation (1974), type i

(3) $h_i$ = average operating hours per year per aircraft (1971), type i

(4) $n_i$ = number of aircraft of given type i (1971); N = total number of small aircraft

(5) $H_i$ = nh = average aircraft hours of operation by given type i

(6) $\overline{C} = \sum_{i=1}^{4} H_i C_i / \sum_{i=1}^{4} H_i$

TABLE 3.6-3: AIRCRAFT OPERATING COSTS[1] AFFECTED BY GATE ARRIVAL DELAY

AIRCRAFT TYPE[2]

| | H4W | H3 | H4S | L3 | L2 | LP | S | O[3] |
|---|---|---|---|---|---|---|---|---|
| CREW | 335.81 | 291.32 | 250.36 | 219.18 | 192.47 | 345.51 | | |
| FUEL AND OIL[4] | 168.22 | 112.63 | 98.53 | 89.52 | 63.94 | 58.01 | | |
| AIRFRAME MAINTENANCE | 139.05 | 101.86 | 70.31 | 55.39 | 52.77 | 141.02 | | |
| ENGINE MAINTENANCE[4] | 67.72 | 44.10 | 20.05 | 18.90 | 13.31 | 61.21 | | |
| MAINTENANCE BURDEN | 177.07 | 141.36 | 127.04 | 86.45 | 71.44 | 190.19 | | |
| TOTAL | 887.87 | 691.27 | 566.29 | 469.44 | 393.93 | 795.94 | 00.00[5] | 00.00[6] |

(1) Based on data in Reference 3.6-2
(2) See Table 3.5-1 for description of aircraft categories
(3) "Other" category assumed to be helicopters
(4) Prorated on the basis of idle fuel/approach fuel, Reference 3.6-4, Appendix
(5) See text
(6) See text

TABLE 3.6-4: TOTAL AIRCRAFT OPERATING COSTS[1] AFFECTED BY TAKE-OFF DELAYS

| | AIRCRAFT TYPE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | H4W | H3 | H4S | L3 | L2 | LP | S | O |
| <u>WITH GATE HOLDS</u> | | | | | | | | |
| FIRST 10 MINUTES | 887.87 | 691.27 | 566.29 | 469.44 | 393.93 | 795.94 | 19.00 | (2) |
| THEREAFTER | 651.93 | 534.54 | 447.71 | 361.02 | 316.68 | 676.72 | 15.20 | (2) |
| <u>WITHOUT GATE HOLDS</u> | | | | | | | | |
| FIRST 10 MINUTES | 887.87 | 691.27 | 566.29 | 469.44 | 393.93 | 795.94 | 19.00 | (2) |
| THEREAFTER | 679.90 | 612.91 | 507.00 | 415.23 | 355.41 | 736.33 | 17.10 | (2) |

(1) See text for method of obtaining these costs.

(2) See text

The actual cost is probably higher at the major N.A.S. airports and lower at the smaller airports because the smaller and less costly subtypes are less common at the larger airports. In the absence of accurate data on the operations rate by different small aircraft at specific airports, however, it is difficult to make an accurate adjustment for the specific airports presently covered by the APM.

The airborne delay costs in the APM are calculated directly from the arrival queue statistics and mix. Implicit in the use of the arrival queue, as described previously, are the assumptions of no diversions, overflights or cancellations, and no ground holds at upline stations. Ground holds can occur during the application of flow control procedures such as FAD or AFCP. The use of the current hourly mix is also an approximation, since the arrival queue may contain some aircraft types from the previous hour. The effect of this displacement of types in time has been ignored in the APM cost model.

Gate Arrival Delay Operating Costs

Aircraft that have landed and are delayed in docking incur the same operating costs as those waiting to land, except that engine speed is reduced to idle. As a result, fuel and oil costs and engine maintenance costs are lower. It has been assumed that for other than S-type aircraft both are reduced by the ratio of idle fuel consumption to approach fuel consumption, as shown in Table 3.6-3. This Table was obtained from Table 3.6-1 by applying to "Fuel and Oil" and "Engine Maintenance" the idle/approach fuel consumption ratios taken from Reference 3.6-4, Appendix A. This implicitly ignores the possibility of half-power idle while waiting to dock.

Gate arrival delay costs are not calculated for small type aircraft because these vehicles generally unload on aprons and ramps where congestion is not ordinarily a factor. Similarly, "other" type aircraft are primarily helicopter and amphibian, which do not experience the usual gate delays.

Takeoff Delay Operating Costs

The calculation of takeoff delay costs is complicated by the practices of half-power idle and gate hold procedures, just as in the case of the pollution and energy consumption models (see 3.5). Similar assumptions are made here for takeoff delay costs:

- When gate hold procedures are in effect because of departure runway delays, it is assumed that aircraft will sustain a maximum of 10 minutes of delay at full idle power prior to departure.
- When gate hold procedures are not in effect it is assumed that aircraft operate at full-idle power for the first 10 minutes, and at half-idle power thereafter.

The above assumptions make it necessary for the user to specify whether or not gate hold procedures are in effect at the airport. The total aircraft operating costs for departure delays are shown in Table 3.6-4. The difference in total costs are due to differences in fuel and oil and engine maintenance costs with and without gate holds, according to the assumptions above and the user's specification of whether or not gate holds are in effect.

In the case of small aircraft types, the idle operating cost was taken to be the same as airborne cost, except for fuel.

It was assumed that fuel costs were 1/3 of total airborne costs, and that full idle fuel consumption is one-half of airborne fuel consumption. This gives a differential of $3.80 per hour between air and full idle ground costs, or a ground full idle cost of about $19.00 per hour for S-type aircraft. The half-idle cost is thereby $17.10 and the engine off cost is $15.20. Half-idle costs were used in evaluating delay costs for delays longer than 10 minutes for airports without gate holds on departure, while engine-off costs were used in evaluating delay costs when gate hold procedures are in effect for delays longer than 10 minutes. For the reasons given in the previous section, takeoff delay costs for "other" type aircraft are not computed in the APM.

Passenger Delay Costs

The cost of lost passenger time due to air, gate and takeoff delays depends on the number of passengers aboard the aircraft and the value of passenger time.

The average value of passenger time varies widely with trip purpose, aircraft type, origin, destination, and time of day. Within the General Aviation category, in particular, generalizations are difficult to make. Accordingly, a nominal value of $12.50 per passenger hour has been employed universally in the APM for the value of passenger delay time. This value corresponds to the current (1976) nominal value employed in FAA and DOT air transport benefit studies.

The number of passengers aboard aircraft other than small (S-type, 12,500 lbs or less) was estimated as the product of seating capacity and load factor. The values employed are given in

Tables 3.6-5 and 3.6-6. The number of seats for each major subtype was weighted by the number of aircraft of that subtype that were in service in 1975 to obtain an average seating capacity for the type. The calculation is shown in Table 3.6-5. The load factors were not available by aircraft type but were available for about half the airports in the APM data base. A 50% load factor was assumed for the remainder.

The number of passengers aboard the aircraft for all S-type aircraft has been taken to be 3.0. This figure was arrived at by considering the average number of fatalies per fatal accident for General Aviation aircraft. This has remained fairly constant over the last 20 years at $1.9 \pm 0.2$ fatalities/fatal accident (see, for example, Reference 3.6-5). On the assumptions that (a) all occupants are killed in a fatal G.A. accident* and (b) G.A. aircraft are representative of S-type aircraft, and (c) G.A. aircraft involved in fatal accidents are representative of all G.A. aircraft, it follows that the average occupancy of S-type aircraft is about 1.9. The number of occupants affected by delays, however, would be larger than this for the following reasons:

1. Most large airports have heavy business and air taxi traffic. The Beech 99, a popular air taxi aircraft type, carries 15 people maximum, but still falls within the small category, as do many business jets of 8 to 10 seats.

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*A fatal accident is defined as one in which one or more fatalities occur to occupants or other persons.

TABLE 3.6-5 SEATING CAPACITIES[1] OF MAJOR COMMERCIAL TRANSPORTS[2]

BY TYPE

| CLASS | TYPE | SEATS[3] | NUMBER IN SERVICE[4] | WEIGHTED SEATS |
|---|---|---|---|---|
| H4W | B747 | 374 | 88 | 346 |
| | B747-CARGO | 0 | 7 | 0 |
| | | | 95 | 346 |
| H3 | DC-10 | 315 | 120 | 180 |
| | L-1011 | 325 | 77 | 119 |
| | DC-10 CARGO | 0 | 13 | 0 |
| | | | 210 | 299 |
| H4S | B707-300/400 | 181 | 202 | 68.5 |
| | B707-100 | 140 | 92 | 24.0 |
| | DC8-30/40/50 | 146 | 77 | 20.9 |
| | DC8-STRETCHED | 236 | 67 | 29.1 |
| | DC8-10/20 | 146 | 28 | 7.7 |
| | DC8-CARGO | 0 | 39 | 0.0 |
| | B720 | 127 | 30 | 7.2 |
| | | | 535 | 157.4 |

(1) Source: Reference 3.6-7, pp 98-99, 129

(2) Many less common types have been omitted. The more numerous cargo configurations have been included.

(3) The figure shown is the average of the upper and lower ends of the range given in Reference 3.5-7.

(4) As of 1975, as reported in Flight International, December 4, 1975 (U.S. carriers only).

TABLE 3.6-5 CONT'D

| | | | | |
|---|---|---|---|---|
| L2 | BAC111 | 82 | 31 | 4.2 |
| | B737-100 | 112 | – | 0.0 |
| | B737-200 | 123 | 239 | 48.0 |
| | DASAULT FALCON | 11 | 5 | .1 |
| | DC9-20 | 90 | 316 | 46.5 |
| | DC9-30/50 | 125 | 11 | 2.3 |
| | DC9-CARGO | 0 | 10 | 0.0 |
| | | | 612 | 101.1 |
| L3 | B727-100 | 100 | 314 | 39.6 |
| | B727-200 | 154 | 392 | 76.1 |
| | B727-CARGO | – | 87 | 0.0 |
| | | | 793 | 115.7 |
| LP | DC-3 | 18 | 47 | 4.6 |
| | DC-4 | 24 | 4 | .5 |
| | DC-6 | 38 | 18 | 3.7 |
| | F27 | 44 | 13 | 3.1 |
| | F227 | 48 | 31 | 8.0 |
| | ELECTRA | 82 | 61 | 26.9 |
| | M404 | 38 | 12 | 2.5 |
| | | | 186. | 49.3 |

*The APM mix data are based on the OAG which does not allow distinguishing class L4 from class H4S. Accordingly, the OAG L4 traffic has been assigned entirely to class H4S in the APM.

TABLE 3.6-6 AVERAGE LOAD FACTORS[1] BY AIRPORT

| | | | |
|---|---|---|---|
| ORD | 60% | DTW | 62 |
| ATL | 57 | MSY | 50 (2) |
| JFK | 44 | LAS | 50 (2) |
| LGA | 61 | HNL | 50 (2) |
| SFO | 48 | STL | 53 |
| LAX | 44 | FLL | 50 (2) |
| DEN | 55 | TPA | 50 (2) |
| PHL | 50 (2) | MSP | 50 (2) |
| EWR | 48 | SEA | 50 (2) |
| MIA | 32 | BAL | 50 (2) |
| DFW | 51 (3) | CLT | 50 (2) |
| DCA | 60 | MKE | 50 (2) |
| PIT | 54 | SLC | 50 (2) |
| BOS | 49 | IAH | 50 (2) |
| CLE | 50 (2) | IAD | 50 (2) |
| | | JAX | 50 (2) |

(1) Source: Reference 3.6-8

(2) A 50% value has been assumed in absence of data.

(3) Data actually gathered for DAL, Dallas Love.

2. G.A. accident data include agricultural, exhibition and industrial flights which have a lower occupancy and higher accident rate than most S-type aircraft operating at large and medium airports.

On the other hand the occupants affected by delay would be smaller than 1.9 because pilots hired with corporate and business aircraft are included in the 1.9 accident figure, but should be excluded in the count of passengers affected by delay. (They are accounted for as part of the operating cost of the aircraft, as described previously). In 1962, Fromm (Reference 3.6-6, page VI-8 and Table VI-6) estimated an average of three passengers in each business aircraft in 1965, four in 1970 and five in 1975. These estimates are unsupported by data, however, and apparently include the pilot. If so, they correspond to four passengers per business aircraft in 1975. If the four in business aircraft is taken as an upper estimate, and the accident-derived value of 2.0 is taken as a low estimate, one is led to the assumed value of 3.0 passengers affected by delays per small aircraft. This estimate can be considered only a very approximate one that can be considerably in error at any one airport.

## REFERENCES


3.6-1 Ingram, G.K., and G.R. Fauth," TASSIM A Transportation and Air Shed Simulation Model" 2 Vols, Report No DOT-OS-30099-4, Prepared for U.S. Department of Transportation, Office of the Secretary, Washington, D.C. March 1974.

3.6-2 Civil Aeronautics Board, Economics and Evaluation Division, Bureau of Accounts and Statistics, "Aircraft Operating Cost and Performance Report, Fiscal 1974," February 1975.

3.6-3 Federal Aviation Administration. "General Aviation Cost Impact Study," Final Report, prepared by Battelle-Columbus Laboratory, Columbus, Ohio, June 1973.

3.6-4 Munt, R., E. Danielson and J. Daimen, Aircraft Technology Assessment: Interim Report on the Status of the Gas Turbine Program, U.S. Environmental Protection Agency (Washington, D.C.) 1975.

3.6-5 Federal Aviation Administration, "FAA Statistical Handbook of Aviation," published annually by U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C.

3.6-6 Fromm, G., "Economic Criteria for Federal Aviation Agency Expenditures," Final Report prepared for FAA by United Research Incorporated, Cambridge, MA, June 1962.

3.6-7 Aviation Week and Space Technology, "Aerospace Forecast Inventory," March 17, 1975, Vol. 102, No. 11, McGraw Hill Co., New York.

# APPENDIX 3.1-A
## ESTIMATION OF NON-SCHEDULED AIRCRAFT MIX

In order to estimate the mix of aircraft types among the non-scheduled flights at an airport, several assumptions were made:

First, it was assumed that non-scheduled carrier and taxi/commuter operations were negligible compared to general aviation (GA) and military (ML) operations. Next, it was assumed that GA and ML operations are proportional to hours flown by GA and ML.

With the above assumptions it is possible to obtain a GA mix, by employing Tables D-55, D-56 and D-57 of Reference [1]. These tables give aircraft hours flown by type for GA aircraft based on FAA towered airports for 1970. They were derived from the FAA Master Civil Aircraft Statistical File. Because these tables are aggregated over all tower airports, it was necessary to make an additional assumption: GA aircraft mix for any hour of the day at the 31 airports of interest in the APM is representable by the average mix over FAA towered airports. With this assumption, the data in Reference [1] give: GA Small 93%; GA Large Turboprop 4%; GA Large Jet 3%.

In order to break down the above percentages into IFR and VFR, it was assumed that IFR flights constituted 83% of GA Large Jet flights, 56% of GA Large Turboprop/Propeller flights and 16% of GA Small aircraft flights. The results are:

| | VFR | IFR |
|---|---|---|
| GA Large Jet | 1% | 5% |
| GA Large TP | 3 | 15 |
| GA Small | 96 | 80 |

and all other categories 0%. These data were employed in the APM to calculate the total mix, along with the scheduled mix, the number of VFR and IFR days per year at the airport, and the GA and ML volume at the airport.

The ML mix could not be derived from available data. The following judgmental values were assumed:

| | VFR | IFR |
|---|---|---|
| ML Large Jet | 20% | 20% |
| ML Large TP | 10 | 10 |
| ML Small | 30 | 30 |
| ML Other | 40 | 40 |

and all other categories 0%.

## REFERENCES

1. "Aviation Cost Allocation Study," Office of Policy Review, U.S. Department of Transportation, Working Paper No. 5., Appendix, Tables D-55, D-56, D-57, July 1972.

## APPENDIX 3.2-A

## DEVELOPMENT OF AIRSIDE PARAMETERS AND MODEL PROCEDURES

The airside module of the Airport Performance Model contains a number of features which were developed based on analysis and assumptions which were referred to briefly in the preceding section of this report. These topics are treated in somewhat greater detail in this Appendix.

### Estimating Time Between Aircraft Operations

The basic element of the aircraft service module is the time between aircraft runway operations. Four possible combinations of operations are considered in the model: arrival followed by arrival, departure followed by departure, arrival following departure and departure following arrival. Because of differences in aircraft performance and air traffic control spacing requirements between different aircraft mixes, separate data are present in the model for each of the four aircraft operation types by aircraft fleet mix type as defined in this study. The time between aircraft runway operations was estimated for single runway operations, taking data from a number of different sources. The data sources which were examined[1] varied somewhat in aircraft fleet

[1]These include Performance Measurement System for Major Airports (Washington, D.C., 1975) prepared by the Federal Aviation Administration; a technical supplement to Procedures for Determination of Airport Capacity (Washington, D.C., 1975) prepared for the Federal Aviation Administration by Doublas Aircraft Company in association with Peat Marwick Mitchell & Co., McDonnell-Douglass Automotion Company and American Airlines; and Airport Capacity Criteria Used in Preparing the National Airport Plan (Washington, D.C., 1968) prepared by the Federal Aviation Administration.

mix definition and separation standards. In addition, certain assumptions were used in developing interoperation time.

Special analysis was performed to transform airport capacity statistics presented in [1] to interoperation times. As shown in Table 3.2-A(1), the reference specifies airport capacity statistics for a single runway configuration for 100% arrivals for given fleet mix combinations. It was assumed that the inter-operation time is dependent solely on the characteristics of the trailing aircraft, and the interoperation times taken from this source were estimated from the solution of a series of equations, based on this assumption. The form of the equations derived from the airport capacity data is shown below:

1) $$\sum_i f_i \cdot t_i = 3600/C_n$$

where $f_i$ is the fleet mix percentage for aircraft type i in the capacity observation n

$C_n$ was the capacity observation (in operations/hour) for the observation n

$t_i$ is the interarrival time for aircraft type i, in seconds.

The assumption that interarrival times are dependent only on the aircraft class of the following aircraft is appropriate for these calculations because the capacity estimates were derived during the period when interarrival spacing requirements were uniformly 3 miles for all aircraft types. As a result of this, there is no need to consider differences in spacing because of the interactions between leading and following aircraft. The inter-arrival times

TABLE 3.2-A(1). AIRPORT CAPACITY AND FLEET MIX RELATIONSHIPS 100% ARRIVALS ON SINGLE RUNWAY, VFR CONDITIONS

| FLEET MIX FOR CAPACITY ESTIMATE | AIRCRAFT CAPACITY OPERATIONS/HOUR | | |
|---|---|---|---|
| | EXIT RATING 1 | EXIT RATING 3 | EXIT RATING 5 |
| 1. 100% D+E | 124 | 96 | 67 |
| 2. 15% C, 85% D+E | 106 | 88 | 61 |
| 3. 30% C, 70% D+E | 94 | 81 | 57 |
| 4. 30% B, 30% C, 40% D+E | 70 | 66 | 46 |
| 5. 60% B, 20% C, 20% D+E | 56 | 53 | 39 |
| 6. 20% A, 40% B, 20% C, 20% D+E | 45 | 43 | 33 |
| 7. 40% A, 30% B, 20% C, 10% D+E | 40 | 37 | 29 |
| 8. 60% A, 20% B, 20% C | 38 | 35 | 28 |

| NOTE - CLASS | TYPICAL AIRCRAFT MEMBER OF CLASS |
|---|---|
| A | Boeing 707, 720, 747; Douglas DC-8 |
| B | Boeing 727, 737; Douglas DC-9, DC-6, DC-7; Lockheed Electrics |
| C | Beech 18; Douglas DC-3; Fairchild F-27 |
| D | Beech Bonanza, Queen Air; Piper Aztec |
| E | Cessna 140, 150, 170, 180, 210; de Haviland Beaver |

Source: Airport Capacity Criteria Used in Preparing the National Airport Plan (AC 150/5060-1A) Federal Aviation Administration, July 8, 1968.

derived from [1] are shown in Table 3.2-A(2). There are eight capacity observations from which interarrival times for four trailing aircraft types were calculated. The solution of all the equations revealed a certain amount of variation in the estimated interarrival times. This variation was most noticeable for the estimate of interarrival times for instances in which aircraft category A is the trailing aircraft.

Capacity estimates were presented in [1] for different runway exit ratings. The exit ratings of the runway reflect the number and location of runway turnoffs, which influence the amount of time an arriving aircraft will remain on the runway before another operation can occur. As shown in the figures in Table 3.2-A(2), the improved exit rating of runways has the largest percentage impact on the inter-arrival times for aircraft types D and E.

A similar procedure was used to develop interoperation times from hourly capacity data presented in [1]. Table 3.2-A(3) shows the departure followed by departure time. These estimates of minimum time between departures were developed using the assumption that the lead aircraft determines the time between two consecutive departures.

Table 3.2-A(4) presents estimates of arrival followed by departure plus departure followed by arrival times developed from airport capacity data in [1]. It was not possible to separate the minimum service time for these two operations due to the format of airport capacity used in the source. It is assumed for both types of operations that only one of the two aircraft involved determines minimum service time. It is assumed that the minimum time for a

TABLE 3.2-A(2). ESTIMATED INTERARRIVAL TIMES 100% ARRIVALS ON SINGLE RUNWAY, VFR CONDITIONS

| OBSERVATION NUMBER | FOLLOWING AIRCRAFT TYPE | MINIMUM TIME BETWEEN OPERATIONS (SECONDS) EXIT RATING 1 | EXIT RATING 3 | EXIT RATING 5 |
|---|---|---|---|---|
| 1 | D+E | 29.0 | 37.5 | 53.7 |
| 2 + 3 | D+E | 29.5 | 37.4 | 54.9 |
| 2 + 3 | C | 60.0 | 60.9 | 82.5 |
| 4 | B | 72.1 | 71.1 | 105.2 |
| 5 | B | 77.3 | 80.5 | 108.0 |
| 6 | A | 162.5 | 178.1 | 197.7 |
| 7 | A | 129.7 | 150.1 | 176.5 |
| 8 | A | 112.1 | 127.4 | 151.7 |

NOTE: Interarrival time estimated based on capacity figures in Table 1, and assumption that following aircraft determines time duration. See note on Table 1 for explanation of aircraft types.

Source: <u>Airport Capacity Criteria Used in Preparing the National Airport Plan</u> (AC 150/5060-1A) Federal Aviation Administration, July 8, 1968.

TABLE 3.2-A(3). ESTIMATED TIME BETWEEN DEPARTURES 100% DEPARTURES ON SINGLE RUNWAY, VFR CONDITIONS

| FLEET MIX FOR CAPACITY ESTIMATE | AIRPORT CAPACITY (OPERATIONS/HOUR) | LEAD AIRCRAFT TYPE | | MINIMUM TIME BETWEEN DEPARTURES (SECONDS) |
|---|---|---|---|---|
| 1. 100% D+E | 142 | 1 | D+E | 25.2 |
| 2. 15% C, 85% D+E | 126 | 2 + 3 | D+E | 25.9 |
| 3. 30% C, 70% D+E | 115 | 2 + 3 | C | 44.0 |
| 4. 30% B, 30% C, 40% D+E | 97 | 4 | B | 45.1 |
| 5. 60% B, 20% C, 20% D+E | 73 | 5 | B | 57.7 |
| 6. 20% A, 40% B, 20% C, 10% D+E | 58 | 6 | A | 138 |
| 7. 40% A, 30% B, 20% C, 10% D+E | 50 | 7 | A | 120 |
| 8. 60% A, 20% B, 20% C | 47 | 8 | A | 96 |

Source: <u>Analysis of Airport Capacity Criteria Used in Preparing the National Airport Plan (AC 150/5060-1A)</u>, Prepared by the Federal Aviation Administration, July 8, 1968.

TABLE 3.2-A(4). ARRIVAL FOLLOWED BY DEPARTURE PLUS DEPARTURE FOLLOWED BY ARRIVAL INTEROPERATION TIMES FROM AIRPORT CAPACITY ESTIMATES MIXED ARRIVALS AND DEPARTURES, SINGLE RUNWAY (VFR CONDITIONS)

| | | TIME FOR ARRIVAL FOLLOWED BY DEPARTURE FOLLOWED BY ARRIVAL (IN SECONDS) | | |
|---|---|---|---|---|
| OBSERVATION NUMBER | AIRCRAFT TYPE | EXIT RATING 1 | EXIT RATING 3 | EXIT RATING 5 |
| 1 | D+E | 66.7 | 75.0 | 93.5 |
| 2 + 3 | D+E | 66.2 | 77.9 | 95.6 |
| 2 + 3 | C | 124.2 | 134.6 | 163.9 |
| 4 | B | 103.3 | 122.4 | 192.8 |
| 5 | B | 127.0 | 144.1 | 184.7 |
| 6 | A | 295.2 | 318.9 | 325.9 |
| 7 | A | 252.9 | 271.9 | 266.6 |
| 8 | A | 220.4 | 230.1 | 249.9 |

Source: Airport Capacity Criteria Used in Preparing the National Airport Plan, (AC 150/5060-1A) Federal Aviation Administration, July 8, 1968.

departure to take place following an arrival will be determined solely by the time required for the arriving aircraft to exit from the active runway. In like fashion, it is assumed that the minimum time required for an arrival to take place following a departure will be determined solely by the time required for the arrival to travel the required separation standard following the departure.

Data collected from [1] have certain advantageous qualities, but there are several drawbacks to this information as well. The data explicitly treat the service time advantages of more extensive runway exits. The aircraft mix category approximate the categories used within the Airport Performance Model. In addition, the data elements in [1] have been in use for some time, and revised as required.

The problems associated with this source of information are also significant, however. The data reflect aircraft separation standards which are no longer in effect. A uniform 3-mile separation standard for arriving aircraft was in effect during the time that the data in the airport capacity study were gathered. The interarrival time estimates in Table 3.2-A(2) relfect aircraft service rates prior to the current arrival separation standards.[2] The data in the table are useful in simulating airport delays for activity prior to the fall of 1975, but must be altered to reflect the change in separation standards. Finally, the figures presented

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[2] As defined in Federal Aviation Administration Notice N 7110.431 dated 10/9/75 and effective November 1, 1975.

were derived based on a number of strong assumptions for interpretation of aggregate capacity data. The results obtained are not always internally consistent, as shown in different entries of Table 3.2-A(2).

Despite these difficulties, interoperation times from this data source were used in validating the Airport Performance Model using airport activity statistics for May of 1972 for EWR, JFK and LGA, as discussed in greater detail in Section 7.0 of this report. The departure followed by arrival and arrival followed by departure times were separated by making use of an approximation developed from data from a separate report [2]. Observations of activity at three airports revealed that the departure followed by arrival time for these airports was approximately 70% of the arrival followed by arrival time. This rough approximation was used to separate arrival followed by departure times from departure followed by arrival times in data shown in Table 3.2-A(4). The Airport Performance Model airside processing module uses information on both the lead and following aircraft types in developing interoperation times. Data from [1] were developed by focusing on only a single aircraft type. For internal consistency, data in Tables 3.2-A(2)-(4) altered to reflect the significance of both aircraft types. The mechanism which was used to perform this function is seen below:

$$2) \qquad t_{ij}^{\ell} = \frac{1}{2}\left(t_{ii}^{\ell} + t_{jj}^{\ell}\right)$$

where $t_{ij}^{\ell}$ is the minimum time required for operation type $\ell$ to take place given aircraft type i in the lead aircraft and aircraft type j follows.

The $t_{ii}^{\ell}$ and $t_{jj}^{\ell}$ terms were values listed in Tables 3.2-A(2) and (3) derived from Table 3.2-A(4) using the methodology previouslysed) for aircraft types i and j. For the validation runs, it was assumed that there was a good correspondence between aircraft types A, B, C, and D + E and the categories of Heavy Jet, Large Jet, Large Prop, and Small aircraft as used in the Airport Performance Model. The values for interoperation times used in the model validation of delay are shown in Table 3.2-A(5). The table of values shown are symmetric ($t_{ij} = t_{ji}$) which is appropriate for the technique of arriving at average hourly interoperation times (discussed in Section 3.3), when ij occurs as frequently as ji.

A second source of data examined in the course of this study was collected from observation of actual airport operations [2]. The sample statistics for these data are presented in Table 3.2-A(6). The statistics indicate the existence of considerable variation in inter-operation times as actually observed. In practically all instances the median observation (not shown in the table) is less than the sample mean, indicating strewness on the upper end of the distribution of observations. This phenomenon points out a possible shortcoming in using actual observations to estimate minimum aircraft service times. Many observations may occur as "slack times" when additional aircraft operations might take place if additional demand were present. It is difficult to determine if specific operations should be excluded from consideration because of this "slack time" which may be present in some of the interoperation time observations. The inherent variability of aircraft interoperation times makes the exclusion of outlying data

TABLE 3.2-A(5). INTEROPERATIONAL TIME DERIVED FROM AIRPORT CAPACITY ESTIMATES (IN SECONDS)

ARRIVAL FOLLOWING ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 130.0 | 102.0 | 95.0 | 79.7 |
| LARGE JET | 102.0 | 74.0 | 67.0 | 51.7 |
| LARGE PROP | 95.0 | 67.0 | 60.0 | 44.7 |
| SMALL | 79.7 | 51.7 | 44.7 | 29.5 |

DEPARTURE FOLLOWING DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 118.0 | 84.7 | 81.0 | 71.7 |
| LARGE JET | 84.7 | 51.4 | 47.5 | 38.4 |
| LARGE PROP | 81.0 | 47.5 | 44.0 | 34.7 |
| SMALL | 71.7 | 38.4 | 34.7 | 25.5 |

DEPARTURE FOLLOWED BY ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 81.4 | 62.2 | 60.6 | 55.0 |
| LARGE JET | 62.2 | 43.1 | 41.5 | 36.4 |
| LARGE PROP | 60.6 | 41.5 | 39.9 | 34.3 |
| SMALL | 55.0 | 36.4 | 34.3 | 28.7 |

ARRIVAL FOLLOWED BY DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 39.1 | 31.6 | 30.8 | 26.8 |
| LARGE JET | 31.6 | 24.1 | 23.3 | 19.3 |
| LARGE PROP | 30.8 | 23.3 | 22.5 | 18.5 |
| SMALL | 26.8 | 19.3 | 18.5 | 14.6 |

Source: Based on analysis of airport capacities for single runway operation during VFR conditions presented in <u>Airport Capacity Criteria Used in Preparing the National Airport Plan</u>, (AC 150/5060-1A) prepared by the Federal Aviation Administration, July 8, 1968. Data presented assume runway in use has exit rating of 1, as defined in the source. Fleet mix designations shown here are simplifications for fleet mix designations actually used in the source (see note on Table 3.2-A(1) ).

TABLE 3.2-A(6). OBSERVED INTEROPERATIONAL TIMES (IN SECONDS)

ARRIVAL FOLLOWING ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT: HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 129. (29) | 123. (35) | | |
| LARGE JET | 99 (29) | 101-109 (28-36) | 101-121 (31-37) | |
| LARGE PROP | 96 (30) | 98-116 (31-45) | 100-102 (30-39) | |
| SMALL | | | 44 (25) | 53 (27) |

DEPARTURE FOLLOWING DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT: HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 83 (27) | 65-69 (31-36) | | |
| LARGE JET | 66-85 (30-34) | 65-78 (28-32) | 60-71, 48* (30-35),(24)* | |
| LARGE PROP | | 88,57* (41),(46)* | | |
| SMALL | | | | 38 (26) |

*Indicates observations were taken for intersecting runway configurations - all other observations single runway configurations.
( ) Standard deviation

Observations from multiple airports are indicated by multiple entries.

Source: Technical supplement in Procedures for Determination of Airport Capacity, prepared by Douglas Aircraft Company, et al for the Federal Aviation Adminstration, May 1975.

TABLE 3.2-A(6). (Cont'd.)

ARRIVAL FOLLOWED BY DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 39* (29)* | 33* (32)* | | |
| LARGE JET | 29* (22)* | 34* (31)* | 36* (29)* | |
| LARGE PROP | 33* (27)* | 32* (29)* | | |
| SMALL | | | | |

DEPARTURE FOLLOWED BY ARRIVAL

| LEAD AIRPORT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 81 (39) | | | |
| LARGE JET | 63* (37)* | 59-73,59-63* (20-32),(36-39)* | 63* (39)* | |
| LARGE PROP | 71* (37)* | 59* (37) | 65* (37) | |
| SMALL | | | | 52 (30) |

*Indicates observations were taken for intersecting runway configurations - all other observations single runway configurations

( ) standard deviation

Observations from multiple airports are indicated by multiple entries

Source: Technical supplement in Procedures for Determination of Airport Capacity, prepared by Douglas Aircraft Company, et al for the Federal Aviation Administration, May 1975.

points particularly difficult. The standard deviation is large compared to the mean for the operation classes presented in the table, despite the fact that hundreds of observations were taken in deriving the statistics. This variation in processing time is a characteristic feature of the operation of aircraft on airport runways, which makes the determination of a single value for a specific processing interchange a difficult undertaking.

The observations in Table 3.2-A(6) are of interest since they reflect the actual attainable performance of the aircraft/airport controller system, rather than relying on theoretically attainable performance. Unfortunately, the sample is incomplete in that no statistics are presented for a number of aircraft interaction combinations. In addition, no distinction is presented for different runway exit taxiway configurations. Further, it is not clear whether the observations were taken during IFR or VFR conditions, or a combination of both. If the statistics were taken during both VFR and IFR conditions, this could explain a certain amount of the variance in the sample statistics. It would be desirable to segregate the interoperation times for IFR and VFR conditions in developing inputs for delay models such as the Airport Performance Model.

Table 3.2-A(7) shows the interoperation times used in another study [3] focusing on airport operating capacities. The values in the table were developed based on theoretical considerations of separation distances and flight speeds of different aircraft, but considerable effort was devoted to capturing the characteristics of actual airport operations. The initial airport data reflected differences in only two classes of aircraft, heavy

TABLE 3.2-A(7). INTEROPERATION TIMES DERIVED FROM AIRPORT CAPACITY ANALYSIS (SECONDS)

ARRIVAL FOLLOWING ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY | FOLLOWING AIRCRAFT NON-HEAVY |
|---|---|---|
| HEAVY | 115 | 142 |
| NONHEAVY | 85 | 85 |

DEPARTURE FOLLOWING DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY | FOLLOWING AIRCRAFT NON-HEAVY |
|---|---|---|
| HEAVY | 77 | 120 |
| NONHEAVY | 57 | 57 |

DEPARTURE FOLLOWED BY ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY | FOLLOWING AIRCRAFT NON-HEAVY |
|---|---|---|
| HEAVY | 63 | 58 |
| NON-HEAVY | 63 | 58 |

ARRIVAL FOLLOWED BY DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY | FOLLOWING AIRCRAFT NON-HEAVY |
|---|---|---|
| HEAVY | 60 | 60 |
| NONHEAVY | 52 | 52 |

Source: Performance Measurement System for Major Airports, prepared by Federal Aviation Administration, November 1975.

(greater than 3000,000 pounds gross takeoff weight) and nonheavy. Subsequently, the FAA developed an additional distinction in aircraft categories, breaking small aircraft (less than 12,500 pounds gross takeoff weight) out from other nonheavy aircraft. This distinction has been used to refine arrival followed by arrival restraint times in expansions of the original work.

Analysis of interoperation times shown in Tables 3.2-A(5)-(7) reveals a series of trends. In general, interoperation times shown shown in Table 3.2-A(5) for smal aircraft tend to be considerably shorter than times presented in the other tables. This phenomenon persists for all operation types, although reasonable correspondence exists for interoperation times for larger aircraft types. A second finding of the analysis of the three tables is that the derived figures in Table 3.2-A(7) tend to underestimate the observed times shown in Table 3.2-A(6) for all operations except for arrivals followed by departures. Based on these findings the interoperation times shown in Table 3.2-A(5) (which were used in model validation of historical delays at JFK, EWR and LGA based on 1972 delay and activity data) were adjusted for use in estimating delays currently occurring. The adjustments were made first to reflect changes in interarrival separation spacing requirements, and second, to correct for the apparent underestimates in interoperation times for small aircraft and apparent overestimates for several interoperation times for large aircraft which were apparently introduced when data were originally extracted from [1]. The adjusted interoperation times present in the Airport Performance Model are shown in Table 3.2-A(8). These times were derived primarily from observed in Table 3.2-A(6). When appropriate, interoperation times shown in

TABLE 3.2-A(8). ADJUSTED INTEROPERATION TIMES USED IN AIRPORT PERFORMANCE MODEL (SECONDS)

ARRIVAL FOLLOWED BY ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 130 | 150 | 170 | 190 |
| LARGE JET | 100 | 105 | 110 | 100 |
| LARGE PROP | 96 | 100 | 100 | 100 |
| SMALL | 96 | 85 | 44 | 53 |

DEPARTURE FOLLOWED BY DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 83 | 120 | 120 | 120 |
| LARGE JET | 75 | 70 | 65 | 65 |
| LARGE PROP | 106 | 88 | 65 | 65 |
| SMALL | 125 | 125 | 125 | 40 |

ARRIVAL FOLLOWED BY DEPARTURE

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 60 | 60 | 60 | 60 |
| LARGE JET | 52 | 52 | 52 | 52 |
| LARGE PROP | 52 | 52 | 52 | 52 |
| SMALL | 52 | 52 | 52 | 52 |

DEPARTURE FOLLOWED BY ARRIVAL

| LEAD AIRCRAFT | FOLLOWING AIRCRAFT HEAVY JET | LARGE JET | LARGE PROP | SMALL |
|---|---|---|---|---|
| HEAVY JET | 81 | 65 | 58 | 58 |
| LARGE JET | 63 | 65 | 58 | 58 |
| LARGE PROP | 63 | 58 | 58 | 58 |
| SMALL | 63 | 58 | 58 | 52 |

Table 3.2-A(6) were increased to reflect changes in separation spacings in 1975. When no observations were present, the methodology used to derive data in Table 3.2-A(7) was used, together with the aircraft speeds in Table 3.3-1 of the text and a set of aircraft performance assumptions.[3]

Model Calibration

The Airport Performance Model calibrates the table of interoperation times previously derived and is used as the basis for airport simulation and delay estimation. A first step in the process of performing the simulation is the calibration of the model to reflect the processing rate of the airport being evaluated. The processing rate for the airport will reflect the runway configuration, airport performance during different weather conditions, and other factors. The Airport Performance Model treats these airport specific conditions in a manner which can be generalized for all airports. The airport runway system is modeled as a single facility which serves both arrivals and departures. Differences in runway configuration, IFR processing capability or other factors are reflected in the processing rates for the airport system. The processing rates for a particular airport are developed outside the model and input at the beginning of a model run.

[3] It was assumed that roll to lift off time was 35 seconds for all aircraft classes, and it was assumed that runway occupancy time for arrivals was 60 seconds for Heavy Jets, 52 seconds for Large Jets and Large Props, and 45 seconds for Small aircraft. Because of the empirical basis for the separate interoperation times, combinations of them do not always give consistent results. For example, the sum of arrival-departure time plus departure-arrival time may be less than the arrival-arrival time shown for some aircraft combinations. The impact on delay of such inconsistencies is not considered to be large.

Because interoperation times differ between different aircraft types, the processing rate for an airport depends on the fleet mix in use at the airport. The airport fleet mix and processing rate are used to calibrate the elements of the table of interoperation times in the following manner:

$$3) \quad \alpha = (360/C) \cdot \left[ \sum_{n=1}^{4} \sum_{i=i}^{4} \sum_{j=1}^{4} f_n \cdot P_i \cdot P_j \ t_{ij}^{n} \right]^{-1}$$

where C is the processing rate of the airport in terms of operations per hour;

$f_n$ is the percentage of hourly operations of type n;

$P_i$ and $P_j$ are the percentage of all airport operations made by aircraft types i and j respectively;

$t_{ij}^{n}$ is the interoperation time for operation type n given aircraft type i is the lead aircraft and aircraft type j is the following aircraft, and;

$\alpha$ is the scaler calibration factor for adjusting the table of inter-operation times to reflect the processing rate of the airport.

This final term $\alpha$ relates the average time per operation at the airport based on the airport processing rate (3600/C is the average number of seconds taken between operations for an airport with an hourly processing rate of C) to the weighted average inter-operation time. The inter-operation times for different operations and aircraft types are combined for the four types of operations (arrival followed by arrival, etc.) based on the airport fleet mix percentages $P_i$ and $P_j$. This yields an average time for each of the four types of operations. These times are subsequently combined based on the percentage of times that each of the four types of operations takes place during an hour in which the airport is saturated with service demands ($f_n$ is this percentage) to yield an average processing time for all operations, which is compared to the average processing time from the airport capacity data.[4]

The calibration term $\alpha$ is multiplied by interoperation times for all aircraft combinations and operation types before the start of airport performance simulation. A separate fleet mix for each hour to be simulated is present on the airport demand file, and these values, together with the calibrated inter-operation times, are used to develop an average time for each of the four types of operations which can take place during the simulation for that hour. This process is mathematically represented below

$$4) \quad t_h^n = \sum_i \sum_j P_{ih} \cdot P_{jh} \cdot \alpha \cdot t_{ij}^n$$

where $t_h^n$ is the average airport service time for interaction type n for hour h;

$P_{ih}$ and $P_{jh}$ are the percentage of all operations in hour h scheduled to be made by aircraft types i and j respectively;

---

[4] In the Airport Performance Model, arrivals and departures are served alternately when aircraft are waiting to be served in both the arrival and the departure queue. For saturated conditions, it is assumed that 90% of operations will be for alternating arrivals and departures, and 10% will be for arrivals followed by arrivals or departures followed by departures. These assumptions are imbedded in $f_n$ terms for model calibration.

$\alpha$ is the airport processing rate calibration factor, and;

$t_{ij}^n$ is the time for interaction n to take place when aircraft type i is the lead aircraft and aircraft type j follows.[5]

The term $t_h^n$ is used as the processing time for all operations of type n which take place during hour h of the simulation. As the fleet mix changes hourly, a new $t_h^n$ term is generated.

For the simulation of activity for a year, the Airport Performance Model user is asked to input processing rates for IFR and VFR weather conditions. The model develops a separate calibration factor $\alpha$ for both weather conditions based on the procedure shown in Equation 3). The demand profile for airport activity contains information on weather conditions, and the model applies the appropriate calibration factor $\alpha$ to VFR and IFR days in simulating the annual performance of the airport.

The daily analysis model performs the calibration of inter-operation times in the same fashion as does the annual analysis model. The daily model permits the user to examine the impact of weather on airport activities in a more detailed fashion, however. The user can specify different airport processing rates for six different weather classifications.[6] The model develops separate calibration factors $\alpha$ for each different weather condition

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[5]Note that this relationship was presented in the text as Equation 1) in a slightly different form. By convention, $t_{ij}^n$ (the inter-operation time presented initially in the text) is the calibrated inter-operation time, and equals $\cdot t_{ij}^n$.

[6]These weather classifications include two types of VFR and four types of IFR. The ceiling and visibility measurements which define these six weather classes are presented in Ceiling-Visibility Climatological Study and System Enhancement Factors, prepared for the Federal Aviation Administration, June 1975.

Table 3.2-A(9). COMPARISON OF AIRPORT CAPACITY VARIATIONS FROM RUNWAY CONFIGURATION AND FLEET MIX VFR CONDITIONS, MIXED ARRIVALS AND DEPARTURES (AIRPORT CAPACITY IN OPERATIONS/HOUR)

| | RUNWAY CONFIGURATION | | | |
|---|---|---|---|---|
| FLEET MIX* | A | B | C | D |
| 100% D+E | 108 | 212 | 196 | 244 |
| 15% C, 85% D+E | 96 | 194 | 170 | 214 |
| 30% C, 70% D+E | 87 | 178 | 152 | 188 |
| 30% B, 30% C, 40% D+E | 76 | 158 | 129 | 140 |
| 60% B, 20% C, 20% D+E | 64 | 130 | 102 | 110 |
| 20% A, 40% B, 20% C, 20% D+E | 52 | 106 | 82 | 90 |
| 40% A, 30% B, 20% C 10% D+E | 49 | 88 | 68 | 78 |
| 60% A, 20% B, 20% C | 40 | 82 | 62 | 74 |

| CAPACITY ESTIMATE | STANDARD DEVIATION OF ERROR ESTIMATE |
|---|---|
| $C_B = 2.03\ C_A$ | 4.79 |
| $C_C = 1.67\ C_A$ | 9.03 |
| $C_D = 1.99\ C_A$ | 18.08 |

Note runway configuration definitions

A - single runway
B - parallel runway (mixed operations on both
C - 2 runways intersecting near threshold
D - open "V" configuration (operations away from apex)

*See TABLE 3.2-A(1) for an explanations of fleet mix desigantions.

Source: Airport Capacity Criteria Used in Preparing the National Airport Plan, (AC 150/5060-1A), prepared for the Federal Aviation Administration, July 8, 1968.

analyzed. Similarly, if either the annual or the daily delay estimating models are used to evaluate the delay performance of different airport runway configurations, the user will input the capacity for the configuration being examined. The model will respond by recalibrating the model for the new configuration before the activity simulation begins.

The assumption implicit in the calibration methodology is that the scalar calibration factor $\alpha$ will capture the processing rate characteristics of a particular runway configuration or weather condition with respect to the processing rate characteristics of a single runway operating during VFR conditions. This implies that the relationship will remain constant for the same runway/weather condition even for changes of mix. Consider an airport with a crossing runway configuration. If it is known that the airport can process 1.5 times the number of hourly operations which can be handled by a single runway for a specific reference fleet mix, then the calibration methodology assumes that the airport can handle 1.5 times the number of hourly operations which can be handled by a single runway for any other mix which might be considered. This assumption is generally supported by information in the airport capacity literature. Data on airport capacity for different runway configurations and airport mixes are presented in [1]. Table 3.2-A(9) shows data form this source comparing airport hourly capacity for different runway configurations and aircraft fleet mixes. The data in the table show that a crude ratio (taken by dividing the sum of capacities for a given runway configuration by the sum for the single runway configuration) will yield an estimate for capacity for the different runway configurations as a function of the capacity for a single runway configuration airport. The standard deviations of the estimated capacity figures are small compared to the mean capacity figures in the table (the largest standard deviation in the table is for the open "V" runway configuration which occurs less frequently in practice than do the other two configurations). This result is significant because the fleet mix statistics in the table vary widely, ranging from 100% small aircraft up to a fleet mix with 60% heavy aircraft. In spite of this wide variation, the capacity approximation technique performs well. It is unlikely that the fleet mix evaluated during an Airport Performance Model run will vary as significantly as do the fleet mixes represented in the table. This suggests that the calibration approach used in the Airport Performance Model will not introduce serious errors in processing times as the fleet mix being evaluated in the model changes for airports with runway configurations shown in the table. In the absence of additional airport capacity and fleet mix data for other airport configurations to confirm or reject the validity of this approach, it is assumed that the technique employed to calibrate interoperation times for airport capacity is valid for airport. with other runway configurations as well.

Calculation of Delay and Queuing Statistics

The aircraft processing model serves aircraft arrivals and departures based on the status of the arrival and departure queues, and with service times which are calibrated for the hourly fleet mix and the airport processing rate. The demand module develops a minute-by-minute schedule of aircraft arrivals and departures to be served. Delays are recorded in the airside processing module when an arrival or departure is scheduled to occur when the runway system is temporarily in use and cannot instantaneously serve the scheduled aircraft demand. The program accumulates the delays which occur for each aircraft arrival and departure which take place during the simulation and also maintains statistics on the length of the arrival and departure queues. The relationships which are used in making these calculations are presented below. The same methodology presented below was used in calculating delay and queuing statistics for the gate delay model as well.

The delay and queuing statistics are calculated from eight basic quantities. They are:

$N_i$ = the number of aircraft receiving service (i.e., landing, taking off) in hour i.

$\hat{Q}_i$ = the maximum number of aircraft in the queue during hour i

$\overline{Q}_i$ = the time-average of the number of aircraft in the queue during hour i

$N_i^D$ = the number of aircraft receiving service in hour i that experienced delay greater than 0 minutes

$\hat{\delta}_i$ = the maximum delay experienced by aircraft receiving service in hour i (minutes)

$\overline{\delta}_i$ = average delay for all aircraft serviced in hour i (minutes)

$\overline{\delta}_i^*$ = average delay of those aircraft serviced in hour i that experienced delay greater than 0 minutes (minutes)

$D_i$ = total delay of those aircraft serviced in hour i (minutes)

These quantities are calculated as follows: the queueing simulation routines produced $V_{IN}(t)$ and $V_{OUT}(t)$, the cumulative number of aircraft into and out of the queue at time t. These are integer step functions, with discontinuities at times $t_j$, $j = 1,2,3,...$, as illustrated in Figure 1. For hour i, which starts at $t = h_i$ and ends at $t = h_{i+1}$, $i = 1,2,3,..., 24$, the program calculates statistical quantities as follows:

$$N_i = V_{OUT}(h_{i+1}) - V_{OUT}(h_i)$$

$$\hat{Q}_i = \max_{h_i \le t \le h_{i+1}} Q(t)$$

$$\overline{Q}_i = \int_{t=h_i}^{h_{i+1}} Q(t)dt \Big/ (h_{i+1} - h_i)$$

where $Q(t) = V_{IN}(t) - V_{OUT}(t)$

$$\delta(K) = t_{OUT}(K) - t_{IN}(K), \qquad K = 1,2,3,...$$

where $t_{OUT}(K) = \min\{t | V_{OUT}(t) \ge K\}$

$$t_{IN}(K) = \min\{t | V_{IN}(t) \ge K\}$$

$$N_i^D = \sum_{K=1+K_i}^{K=K_{i+1}} \phi(K)$$

where $\phi(K) = \begin{cases} 1 \text{ if } \delta(K) > 0 \\ 0 \text{ if } \delta(K) = 0 \end{cases}$

$$K_i = V_{OUT}(h_i)$$

$$\hat{\delta}_i = \max_{K_i \leq K \leq K_{i+1}} \delta(K)$$

$$D_i = \sum_{K=K_i}^{K_{i+1}} \delta(K)$$

$$\overline{\delta}_i = D_i / N_i$$

$$\overline{\delta}_i^* = D_i / N_i^D$$

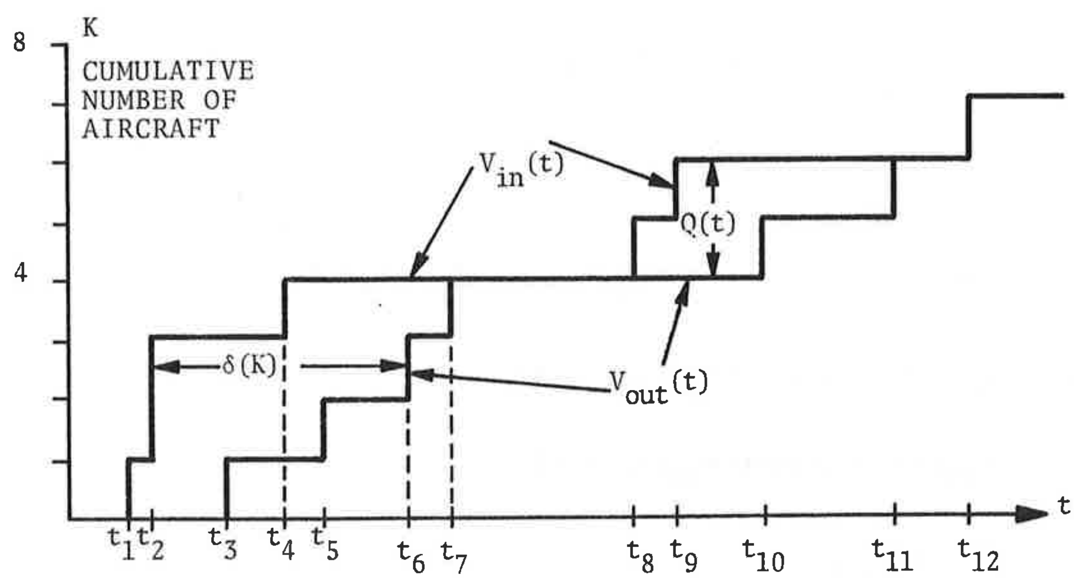


FIGURE 3.2-A(1). ILLUSTRATION OF CUMULATIVE FUNCTIONS $V_{IN}(t)$ AND $V_{OUT}(t)$

## REFERENCES

3.2-A(1). Airport Capacity Criteria Used in Preparing the National Airport Plan, Federal Aviation Administration, July 8, 1968.

3.2-A(2). Procedures for the Determination of Airport Capacity, prepared for the Federal Aviation Administration by Douglas Aircraft company in association with Peat, Marwick, Mitchell and Co., McDonnell-Douglas Automation Company, and American Airlines, Inc., May 1975.

3.2-A(3). Performance Measurement System for Major Airports, Federal Aviation Administration, November, 1975.

## APPENDIX 3.3-A

## MATHEMATICAL DEVELOPMENT OF THE GATE QUEUING MODEL

The Gate Model in the Airport Performance Model simulates the gate delay for a single carrier having as its traffic level the total traffic at the airport, and having asits complement of gates the total number of gates available at the airport. This, of course, is a simplification, for at most large airports there are several airlines each of which handles a portion of the traffic, and each of which has its own group of gatesthat it does not ordinarily share with its competition. The purpose of this Appendix is to explore the relation between the single airline model of the APM and the multiple-airline arrangement of real airports. The end result will be an adjustment in the number of gates in the APM's single airline simulation to bring it into better agreement with the multiple-airline case.

In the APM, aircraft enter an arrival gate queue from the runway, after landing. Aircraft also enter a departure gate queue from a fictitious aircraft storage area. Since the aircraft that has been in either queue longest is served first when a gate becomes available, there is, in effect, only one queue. The APM Gate Model, therefore, is a multiple server, single-queue simulation.

It is further assumed here that entries into the queue are Poisson distributed, that the gate service timesare constant, and the results of steady-state queuing theory may be used to approximate the results of the dynamic simulation in the APM. The last assumption, in particular, guarantees the approximate nature of the results.

With the above assumptions the steady-state results for an M/D/S queue may be applied (See, for example, Reference 3.B-1, p. 865 ff. In queuing theory notation, the M indicates Posson-distributed input, the D indicates constant service time, and the g indicates there are S servers in parallel). The expected queue length q depends on the number of servers, g, and the ratio $\rho$ of mean arrival rate $\lambda$ to mean service rate $\mu$, asfollows (Reference 3.B-2, p. 162):

$$q(\rho, g) = \frac{\rho/g}{1-\rho/g} \quad \frac{1}{f(\rho,g)} \quad \frac{g}{g+1} \quad \frac{1-(\rho/g)^{g-1}}{1-(\rho/g)g} \qquad (1)$$

where

$$f(\rho,g) = 1 + \rho^{-g} g! \, (1-{}^{\rho}/_{g}) \sum_{j=0}^{g-1} {}^{\rho^j}/_{j!} \qquad (2)$$

The expected waiting time t (including zero length waiting time) is

$$= q(\rho,g)/\lambda.$$

The formulas (1) and (2) will be applied first to the one-airline model (all gates at the airport pooledto serve the total airport traffic) and then to the case of N individual airlines each with $g_i$ gates at its disposal and a fraction$g_i/G$ of the total traffic

Let

G = total number of gates available at the airport

$\Lambda$ = mean demand rate for gate servicing for the entire airport (aircraft/hr)

N = number of airlines at the airport

$\mu$ = mean service rate for a single gate, assumed to be the same for all airlines (aircraft/hr)

$g_i$ = number of gates available for airline i

$\lambda_i$ = mean gate demand rate for the $i^{\underline{th}}$ airline (aircraft/hr)

$q_i$ = expected gate queue length for $i^{\underline{th}}$ airline (aircraft)

$t_i$ = expected gate waiting time per aircraft for the $i^{\underline{th}}$ airline (hours)

$Q_1$ = expected gate queue length for entire airport, single-airline model

$Q_N$ = expected gate queue length for entire airport, N - airline model

$T_1$ = expected gate waiting time per aircraft for entire airport, single-airline model

$T_N$ = expected waiting time per aircraft for entire airport, N - airline model

Further, $\rho_i = \lambda_i/\mu$ serves to define $\rho_i$. It should be noted that the waiting times do not include time in service, and that the mean queue lengths do not include those being served.

One-Airline Case

In this case g - G and $\rho = \Lambda/\mu$ in (1) and (2). Therefore, (1) becomes

$$Q_1 = \frac{\Lambda/\mu G}{(1-\Lambda/\mu G)} \left[1 + (1-\Lambda/\mu G) \sum_{x=1}^{G} G!/(G-x)!/(\Lambda/\mu)^x\right]^{-1} \frac{G}{G+1} \frac{1-(\Lambda/\mu G)^{G-1}}{1-(\Lambda/\mu G)^G} \quad (3)$$

The queue length $Q_1$ is a decreasing function of G for given values of $\Lambda/\mu$ and for $G > \Lambda/\mu$. Since $Q_1$ varies with G and with the ratio $\rho = \Lambda/\mu$, it is more accurately designated as $Q_1(G,\rho)$. Equation (2) becomes

$$T_1 = Q_1/\Lambda \quad (4)$$

N - Airline Case

In this case (1) and (2) are first applied to an individual airline (i) having $g_i$ gates. The assumption is made here that the number of gates $g_i$ is proportional to the hourly gate demand $\lambda_i$ for the airlines:

$$\lambda_i = K\, g_i$$

Where K is a constant for the airport determined by

$$K = \sum_{i=1}^{N} \lambda_i \Big/ \sum_{i=1}^{M} g_i$$
$$= \Lambda/G$$

With this value for $\lambda_i$, and assuming $\mu_i = \mu$,

$$\rho_i = \lambda_i/\mu$$

$$= \frac{\Lambda}{\mu G} g_i$$

$$= R\, g_i$$

Thereupon, (1) becomes

$$q_i = \frac{R}{1-R} \left[1 + (1-R) \sum_{x=1}^{g_i} g_i!/(g_i R)^x\right]^{-1} \frac{g_i}{g_i + 1} \frac{1-R^{g_i+1}}{1-R^{g_i}} \tag{5}$$

where

$$R = \Lambda/\mu G \quad , \qquad R < 1. \tag{6}$$

The quantity R is the ratio of mean hourly gate demand at the airport to the maximum total hourly processing rate $G\mu$. As expected, this ratio differs from airport to airport, as shown in Table 3.4-A(1) and discussed below under Numerical Examples.

When R is $\geq 1$, the formula (5) is invalid. In such case the mean arrival rate $\Lambda$ exceeds the total gate capacity $\mu G$, and the steady-state queue (if ever it could be observed) is "infinite" in length.

If R is given reasonable values, $q_i$ may be tabulated as a function of $g_i$. This is done in Table 3.4-A(2). The queue length drops as the number of gates available to the airline increases, even though the demand per gate is constant at $\Lambda/G$. This is due to the "pooling" phenomenon described previously.

The mean waiting time is obtained from (2) as

$$t_i = q_i/\lambda_i \tag{7}$$
$$= q_i/\frac{\Lambda g_i}{N}$$

TABLE 3.3-A(1). NUMBER OF AIRLINES, NUMBER OF GATES AND RATIO R OF DEMAND TO PROCESSING RATE AT THE 31 AIRPORTS OF THE APM

| Airport | N | G | R |
|---|---|---|---|
| ORD | 14 | 81 | .63 |
| ATL | 10 | 79 | .51 |
| JFK | 12 | 96 | .29 |
| LGA | 13 | 43 | .58 |
| SFO | 12 | 55 | .48 |
| LAX | 15 | 66 | .51 |
| DEN | 11 | 60 | .32 |
| PHL | 12 | 40 | .36 |
| EWR | 12 | 39 | .34 |
| MIA | 10 | 50 | .44 |
| DAL | 8 | 20 | .13 |
| DCA | 12 | 37 | .54 |
| PIT | 7 | 36 | .49 |
| BOS | 10 | 59 | .32 |
| CLE | 9 | 40 | .30 |
| DTW | 12 | 49 | .32 |
| MSY | 8 | 25 | .36 |
| LAS | 10 | 32 | .31 |
| HNL | 7 | 39 | .28 |
| STL | 9 | 35 | .48 |
| FLL | 5 | 18 | .35 |
| TPA | 8 | 39 | .24 |
| MSP | 9 | 37 | .34 |
| SEA | 10 | 35 | .30 |
| BAL | 9 | 19 | .37 |
| CLT | 5 | 16 | .37 |
| MKE | 8 | 20 | .37 |
| SLC | 6 | 21 | .27 |
| IAH | 9 | 41 | .28 |
| IAD | 11 | 28 | .19 |
| JAX | 5 | 15 | .24 |
| DFW | 9 | 69 | .39 |

TABLE 3.3-A(2). MEAN QUEUE LENGTH FOR AN AIRLINE HAVING $g_i$ GATES AND A FIXED DEMAND PER GATE[1]

| NUMBER OF GATES ($g_i$) | R=.30 | R=.50 | R=.70 | R=.90 |
|---|---|---|---|---|
| 1 | .429 | 1.000 | 2.333 | 9.000 |
| 2 | .198 | .667 | 1.922 | 8.526 |
| 3 | .100 | .474 | 1.641 | 8.171 |
| 4 | .053 | .348 | 1.429 | 7.878 |
| 5 | .029 | .261 | 1.259 | 7.625 |
| 6 | .016 | .198 | 1.120 | 7.401 |
| 7 | .009 | .152 | 1.002 | 7.200 |
| 8 | .005 | .118 | .902 | 7.015 |
| 9 | .003 | .092 | .815 | 6.845 |
| 10 | .002 | .072 | .739 | 6.687 |
| 11 | .001 | .057 | .672 | 6.539 |
| ⋮ | | ⋮ | ⋮ | ⋮ |
| 21 | .000 | .006 | .288 | 5.416 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 31 | .000 | .001 | .136 | 4.647 |

Notes: (1) D = fixed demand per gate = Aircraft per hour per gate = $\mu R$, where $\mu$ is the mean gate service rate (= 2/hr).
(2) This Table was generated from Equation (5).

## Distribution of Gates for N-Airline Case

Having assumed that an airline's demand is proportional to the number of gates it operates, the next question taken up is "How are the gates assigned to the airlines?" Rather than gather data to answer this question for each airport, a simplifying assumption is made: The G gates at the airport are assigned at random among the N airlines. The probability of an airline's receiving any particular gate is assumed to be 1/N, the same for all airlines. The probability of an airline's receiving exactly $g_i$ gates, therefore, is:

$$p\ (x=g_i) = (1/N)^{g_i}\ (1 - 1/N)^{G-g_i}\ G!/g_i!\ (G-g_i)! \qquad (8)$$

This probab8lity is multiplied by N and the resulting frequency distribution B assumed for $g_i$. It has mean G/N, the average number of gates per airline, and variance G(1-1/N)/N. The interpretation that will be placed on B is that it is the average number of airlines that have exactly $g_i$ gates at the airport. B may be written more explicitly as $B(N,G,g_i)$. It will be recognized as the binomial distribution, multiplied by N.

## Total Queue for N Airlines

Having estimated the mean queue length $q_i$ for an airline with $g_i$ gates, and having made an assumption for the distribution of gates among the N airlines, it is now possible to estimate $Q_N$, the mean total of the queues for the N airlines:

$$Q_N = \sum_{g_i=1}^{\infty} q(g_i,R) \cdot B(N,G,g_i) \qquad (9)$$

where $q\ (g_i,R)$ is the $q_i$ given in (5) and $B(N,G,g_i)$ is N times the probability given in (8). It is seen than $Q_N$ is a function of the number N of airlines, the number G of gates, and the ratio R of hourly demand to hourly processing rate as given in (6). Hence $Q_N$ may be more properly designated as $Q_N(N,G,R)$. Note that $\Lambda T_N = Q_N$.

Gate Adjustment Factor

The final step in the analysis is to select the number of gates G in the One-Airline case so that the corresponding mean queue length $Q_1$ equals the queue length $Q_N$ calculated for the N-Airline case. In other words, one must find an integer $G_E$ so that

$$Q_1 \ (G_E,\rho) = Q_N(N,G,R) \qquad (10)$$

where $Q_1$ is from (3) and $Q_N$ is from (9). The value $G_E$ so obtained is the effective number of gates to be used in the APM simulation.

Obviously, one expects $G_E \leq G$. Also, it is seen from (10) that $G_E$ depends only on N, G, and R, because $\rho$ is just $G \cdot R$. In the event that the actual distribution of gates among airlines in known for the airport of interest, it may be substituted for B in (9), but the expression (10) would be unaltered.

A simple numerical procedure is employed to solve (10). (Note that there may be no exact solution to (10) if $G_E$ is restricted to be integer). $G_E$ is set equal to G and the difference D is calculated:

$$D = Q_1 \ (G_E, \ \rho) - Q_N \ (N,G,R) \qquad (11)$$

If D is negative $G_E$ is reduced by unity and the procedure repeated. The solution is taken to be the first value of $G_E$ for which D is zero or positive. A somewhat improved solution is obtained if $G_E$ is taken to be the integer value for which $|D|$ is smallest.

Data for the Gate Model Adjustment

The data needed to find $G_E$ are, for each airport, the values of N, G, and R. Table 3.4-A(1) shows N, G, and R for the 31 airports in the APM data base. The number N of air carriers was taken to be the number of Certificated Route Carriers showing activity At the airport in 1974, as given in Table 7 of Reference 3.B-3. An adjustment for Supplemental and Intrastate carriers would improve these data. The number G of active loading points is taken from Table 2-1 in Section 2.2 of the present report. It includes an adjustment for international gates. The ration R in Table

3.4-A(1) was calculated as $\Lambda/\mu G$, assuming $\mu$ = 2.0 aircraft per hour and $\Lambda = V_A/365/14$, where $V_A$ is the annual air carrier and air taxi operations for 1974 at the airport of interest, as reported in the FAA Air Traffic Activity Statistics for CY1975. The division by 14 accounts for the busy hours of the day.

Despite the approximate nature of the data used to calculate it, the demand/capacity ratio R in Table 3.4-A(1) lies between .30 and .60 for 71% of the airports. The lower ratios lie towards the bottom of the list, which is in descending order of air carrier delays in 1973. This is expected since the higher the ratio R the greater demand relative to the capacity for the gates, and hence delays should increase with R. For all airports the restriction $0 \leq R < 1$ for finite steady-state queues is met.

Summary

Under the assumptions of 1) steady-state M/D/S queues, 2) demand proportional to gate allocation, and 3) random gate distribution to airlines, a correction was derived for the number of gates employed in the single-airline model to make it agree with the actual N-airline case. This reduced number of gates is employed in the APM single-airline simulation. The agreement of the resulting queues and delays with those actually observed is investigated in the gate validation tests described in the body of this report.

## REFERENCE 5 FOR APPENDIX A


3.3-A(1). Wagner, H.M. "Principles of Operations Research," Prentice-Hall, 1969.

3.3-A(2). Saaty, T.L., "Elements of Queueing Theory," McGraw Hill, 1961.

3.3-A(3). "Airport Activity States of Certificated Route Air Car-Carriers, " published by the Civil Aeronautics Board and the Federal Aviation Administration; for the 12 months which ended December 31, 1974.

# APPENDIX 3.4-A

## MATHEMATICAL FORMULATION OF ENERGY CONSUMPTION AND AIR POLLUTION EMISSIONS MODELS

| | Energy Consumption | Air Pollution Emissions |
|---|---|---|
| **ARRIVALS** | | |
| 1. Delays | (total hourly delay minutes) x (composite consumption rates for approach) $= \Sigma d_{Ai} \sum_{k} P_K^A \cdot E_A^K$ | No impact ($\geq$ 3,000 ft above ground level) |
| 2. Operation | $A \cdot \sum_{K} P_K^A \cdot t_A^K \cdot E_A^K$ | $A \cdot \sum_{K} P_K\, t_A^K\, E_A^K\, EI_A^K$ |
| 3. Taxi | $A \cdot t_T^A \cdot \sum_{K} P_K^A\, E_I^K$ | $A \cdot t_T^A \sum_{K} P_K\, E_I^K \cdot EI_I^K$ |
| 4. Gate Delay | | |
| For delays less than 10 minutes per arrival | $\sum_{i} d_{Gi} \cdot \sum_{K} P_K^A\, E_I^K$ | $\sum_{i} d_{Gi} \sum_{K} P_K\, E_I^K \cdot EI_I^K$ |
| For delays greater than 10 minutes | $[10 + \sum_{i} (\frac{d_{Gi}-10}{2})] \sum_{K} P_K^A\, E_I^K$ | $[10 + \sum_{i} (\frac{d_{Gi}-10}{2})] \sum_{K} P_K\, E_I^K \cdot EI_I^K$ |

| | Energy Consumption | Air Pollution Emissions |
|---|---|---|

DEPARTURES

1. Taxi

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $D \cdot t_T^D \sum_K P_K E_I^K$ | $D \cdot t_T^D \sum_K P_K E_I^K EI_I^K$ |

2. Runway Delay

- For gate hold procedures

For delays less than 10 minutes

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $\sum_i d_{Di} \sum_K P_K E_I^K$ | $\sum_i d_{Di} \sum_K P_K E_I^K EI_I^K$ |

For delays greater than 10 minutes

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $n_{10}^D \cdot 10 \cdot \sum_K P_K E_I^K$ | $n_i \cdot 10 \cdot \sum_K P_K \cdot E_{KI} \cdot EI_I^K$ |

- For no gate hold procedures

For delays less than 10 minutes

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $\sum_i d_{Di} \cdot \sum_K P_K \cdot E_I^K$ | $\sum_i d_{Di} \cdot \sum_K P_K \cdot E_I^K EI_I^K$ |

For delays greater than 10 minutes

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $\sum_i [10 + (\frac{d_{Di}-10}{2})] \cdot \Sigma P_K E_I^K$ | $\Sigma[10 + (\frac{d_{Di}-10}{2})] \sum_K P_K E_I^K EI_I^K$ |

3. Takeoff

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $D \cdot t_{TO} \cdot \Sigma P_K E_T^K$ | $D \cdot t_{TO} \cdot \Sigma P_K E_T^K EI_T^K$ |

4. Climb Out

| Energy Consumption | Air Pollution Emissions |
|---|---|
| $D \cdot \sum_K P_K t_c^K E_c^K$ | $D \cdot \Sigma P_K t_c^K E_c^K EI_c^K$ |

where

A and D are the number of hourly arrivals and departures, respectively

$P_K^A$ and $P_K^D$ are the percentages of aircraft operations on arrival and departure made by aircraft type K during the hour

$E_A^K$, $E_I^K$, $E_T^K$ and $E_c^K$ are the energy consumption rates in pounds of fuel per second for aircraft type K during a minute of approach, idle, takeoff and climbout respectively

$EI_A^K$, $EI_I^K$, $EI_T^K$ and $EI_c^K$ are the emission indices of air pollution in terms of pounds of emissions $X10^{-3}$ per pound of fuel consumed for aircraft type K during approach, idle, takeoff and climbout respectively.

$t_A^K$ and $t_c^K$ are the times required by aircraft type K to descend from 3,000 feet above ground level to touch down, and the time required to climb from liftoff to an altitude of 3,000 feet.

$t_{TO}$, $t_T^A$ and $t_T^D$ are, respectively, the time from brake release to liftoff (assumed constant for all aircraft types), the nominal no-delay taxi time from runway to gate on arrival, and the analogous nominal taxi time from gate to runway for departure.

$d_{Di}$, $d_{Ai}$ and $d_{Gi}$ are respectively the individual delays encountered by aircraft when taxing and queueing for runway depature, when holding prior to landing and when waiting for gate space for docking on arrival.

$n_{10}^{D}$ is the number of delays in excess of 10 minutes for aircraft waiting for runways for airport departure

APPENDIX 3.4-A

AIRCRAFT ENGINE CHARACTERISTICS

Aircraft Category: Small (less than 12,500 lbs. G.T.O.W.)

Representative Aircraft: Beech 99

Engine(s): 2 United Aircraft of Canada, Ltd. PT6A-27*

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Pollutant x $10^{-3}$/ Pound of Fuel) | | |
|---|---|---|---|---|
| | | HC | CO | $NO_x$ |
| Idle/Taxi | 4.91 | 101.6 | 115.3 | 1.98 |
| Approach | 9.05 | 22.7 | 34.8 | 4.65 |
| Climbout | 15.88 | 2.02 | 6.48 | 7.56 |
| Takeoff | 17.12 | 1.75 | 5.06 | 7.98 |

*Assumed comparable to the characteristics of the PT6A-41, which appear above.

Aircraft Category: Large Turboprop/Piston (greater than 12,500 lbs. (G.T.O.W.)

Representative Aircraft: Lockheed Electra

Engine(s): 4 Allison 501-D13**

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Emissions x $10^{-3}$/ Pound of Fuel) | | |
|---|---|---|---|---|
| | | HC | CO | $NO_x$ |
| Idle/Taxi | 40.68 | 17.6 | 43.6 | 3.53 |
| Approach | 76.03 | 1.96 | 5.10 | 7.49 |
| Climbout | 146.52 | 0.89 | 2.06 | 9.22 |
| Takeoff | 158.40 | 0.28 | 2.04 | 8.88 |

**Assumed comparble to the characteristics of the 501-D22A, which appears above.

Aircraft Category: Large 2 Engine Jet (greater than 12,500 lbs. G.T.O.W.)

Representative Aircraft: McDonnell Douglas DC-9, Series 50

Engine(s): 2 Pratt & Whitney JT8D-17

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Emissions x $10^{-3}$/ Pound of Fuel) HC | CO | $NO_x$ |
|---|---|---|---|---|
| Idle/Taxi | 38.40 | 11.4 | 40.9 | 4.0 |
| Approach | 92.40 | 0.80 | 10.4 | 8.2 |
| Climbout | 263.40 | 0.10 | 0.84 | 18.6 |
| Takeoff | 330.00 | 0.10 | 0.67 | 22.7 |

Aircraft Category: Large 3 Engine Jet (greater than 12,500 lbs. G.T.O.W.)

Representative Aircraft: Boeing 727-200

Engine(s): 3 JJ8D-17

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Emissions x $10^{-3}$/ Pound of Fuel) HC | CO | $NO_x$ |
|---|---|---|---|---|
| Idle/Taxi | 57.6 | 11.4 | 40.9 | 4.0 |
| Approach | 139.8 | 0.80 | 10.4 | 8.2 |
| Climbout | 393.0 | 0.10 | 0.84 | 18.6 |
| Takeoff | 492.6 | 0.10 | 0.67 | 22.7 |

Aircraft Category: Large 4 Engine Jet (greater than 12,500 lbs. G.T.O.W.)

Representative Aircraft: Boeing 707-320 B/C

Engine(s); 4 Pratt & Whitney JT3D-7

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Emissions x $10^{-3}$/ Pound of Fuel) | | |
|---|---|---|---|---|
| | | HC | CO | $NO_x$ |
| Idle/Taxi | 67.30 | 69.1 | 91.9 | 3.3 |
| Approach | 205.80 | 0.5 | 12.8 | 8.0 |
| Climbout | 546.00 | 0.1 | 1.1 | 14.4 |
| Takeoff | 663.60 | 0.1 | 0.5 | 19.1 |

Aircraft Category: 3 Engine Wide Body Jet

Representative Aircraft: McDonnell Douglas DC-10, Series 40

Engine(s): 3 Pratt & Whitney JT9D-20*

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Emissions x $10^{-3}$/ Pound of Fuel) | | |
|---|---|---|---|---|
| | | HC | CO | $NO_x$ |
| Idle/Taxi | 70.20 | 25.0 | 70.0 | 3.2 |
| Approach | 244.80 | 1.2 | 10.0 | 10.1 |
| Climbout | 690.00 | 0.16 | 0.80 | 22.3 |
| Takeoff | 840.00 | 0.21 | 1.0 | 30.0 |

*Assume characteristics are comparable to JT9D-7, which appear above.

Aircraft Category: 4 Engine Wide Body Jet

Representative Aircraft: Boeing 747

Engine(s): 4 Pratt & Whitney JT9D-7

| Operation | Fuel Consumption (Pounds/Minute) | Air Pollution Emissions (Pounds of Emissions x $10^{-3}$/ Pound of Fuel) HC | CO | $NO_x$ |
|---|---|---|---|---|
| Idle/Taxi | 93.6 | 25.0 | 70.0 | 3.2 |
| Approach | 326.4 | 1.2 | 10.0 | 10.1 |
| Climbout | 919.8 | 0.16 | 0.80 | 22.3 |
| Takeoff | 1120.2 | 0.21 | 1.0 | 30.0 |

Source: Munt, R., E. Danielson and J. Deimen, "Aircraft Technology Assessment Interim Report on the status of the Gas Turbine Program," U.S. Environmental Protection Agency, Dec. 16, 1975.

# 4. GROUNDSIDE MODELS

## 4.1 TERMINAL MODEL

The major purpose of this set of relationships is to transform airside activity (aircraft operations) into groundside passenger handling facility requirements. The groundside activity is similar to the airside in that activity takes place at hourly intervals. The program begins with the hourly aircraft movements as its basis:

1) $E_t = \sum_k (\text{A.C. DEP})_k^t \cdot \text{SEATS}_k \cdot \text{LF}_t^E \ (1 - \%C^E),$

2) $D_t = \sum_k (\text{A.C. Arr})_k^t \cdot \text{SEATS}_k \cdot \text{LF}_t^D \ (1 - \%C^D).$

This states that the enplaning and deplaning passengers at hour t, $E_t$ and $D_t$, are related to the aircraft arrivals and departures for hour t, information which is already in the model. Specifically, the passenger movements through the terminal are defined by the number of operations by aircraft type k, times the seating capacity on aircraft type k, times the appropriate load factor for the specific operations type and hour, and discounting the effect of passengers on-board the aircraft who do not enplane or deplane from the aircraft. These passengers are continuing passengers and the term $(1 - \%C^D)$ and $(1 - \%C^E)$ remove the effect of these passengers from estimates of deplaning and enplaning passengers respectively. The percentage of passengers continuing actually varies over the day and for passenger loads on arriving and departing flights. This variation is not captured in the current version of the APM, however, and a constant percentage is used for arriving and departing flights.

When hourly passenger movements have been derived, estimates of terminal facility requirements, by hours, can be produced:

3) $$MLSEATS_t = \xi \cdot E_t \left[1 + (1-\%T^E) \sum_j P_j^E \varepsilon_j\right],$$

4) $$MLAREA_t = 100 + 18\ MLSEATS_t\ .$$

These relations first estimate main lobby seating requirements as determined by hourly enplanements $E_t$, and other factors. The relationship assumes the needed main lobby seating will equal a certain fraction ($\xi$) of all hourly airport passengers and visitors. $\xi$ should be .20[1] if waiting areas will be provided for enplaning passengers, which will be true for most airports to be considered by this model. For airports with no gate waiting area, the fraction should be increased from 20% to 65%.[2] Relationship 3) recognizes that the number of "well wishers" or airport visitors accompanying an airport passenger will depend to a large extent on the airport access mode used. The term $\varepsilon_j$ is the number of airport visitors accompanying an enplaining passenger reaching the airport by mode j. The term $P_j^E$ is the percentage of enplaning passengers reaching the airport via mode j. The product sum in

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1. A middle range value from those suggested by an airport terminal design manual. See the Ralph M. Parsons Company The Apron and Terminal Building Planning Manual (prepared for the U.S. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service), Pasadena California, July, 1975, P. 4-11.

2. Ibid. P. 4-11. Once again, a middle range percentage was used here.

relation 3) is therefore the weighted average number of airport visitors per enplaning passenger. The (1 - %T) term reduces this average number by taking into consideration the fact that enplaning passengers who are transferring from another flight will typically not have visitors at the airport.

Relationship 4) transforms seating requirements in the main lobby into overall main lobby area requirements.[3]

The above calculations are for the main waiting lobby. Separate calculations for other terminal lobby areas are also made. Calculations for Ticketing Lobby requirements are shown below:

5) $FRONTAGE_t = .072 \sum_k (A.C.\ DEP)_k^t \cdot SEATS_k \cdot (1 - \%T)$

6) $TLAREA_t = 40 \cdot FRONTAGE_t$

Relation 5) relates hourly ticket counter frontage required for hour t to potential air passenger levels at that hour. As with 1), the passenger departures are related to aircraft movements by specific aircraft class which will take place during the hour, and the seating capacity of the different aircraft types. The counter frontage requirements are assumed to be independent of load factor, but the requirements are reduced by excluding transferring passengers (via the (1 - %T) term) who presumably do not require ticketing services.[4]

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3. Ibid. The calibration was taken from figure 4-8, p. 4-12.

4. Ibid. Calibrations taken from Figure 4-5, page 4-8.

Relationship 4) assumes that a waiting line and circulation area extending 40 feet from the counter space should be provided.[5]

Baggage claim areas are estimated using the two relationships below:

7) $LBELT_t = 146 + .323\ D_t(1-\%T)$

8) $BCAREA_t = 35 \cdot LBELT_t$

Relation 7) relates baggage claim lines claim distance (typically baggage display length or moving belt length) to hourly passenger deplanements $D_t$. Note that passengers deplaning but transferring to a continuing flight will typically not make use of the baggage claim facilities at their transferring airport. This explains the requirement reductions introduced by the (1 - %T) term.[6]

Relation 8) is an approximate relationship tying area requirements to luggage belt (or display) length requirements. The actual planning requirement vary somewhat depending on the precise luggage display technology in use, but the relationship used will not underestimate baggage claim area requirements.

4.2 ACCESS/EGRESS MODELS

The same general variables are used in determining parking, access and curb space requirements. A distinction between different types of parking must be made. The relations below devleop estimates for short term, long term, and employee parking. Short term parking is meant to capture parking requirements for

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5. Ibid, page 4-8. A middle range value for this sizing was taken.

6. Ibid. This was a modification of a nomograph for peak 20 minute deplanements greater than 500, but will apply to all passenger volumes. See Figure 4-22, pp. 4-30 for roughly equivalent relationship.

passengers who are brought to the airport and dropped off by friends or relatives who park for a short time until the passenger's plane departs, at which point the friends or relatives return to their car and leave the airport. Short term parking is also meant to capture parking requirements for passenger friends or relatives who drive to the airport, park, and greet the air passenger inside the terminal. After the passenger arrives, the group claims baggage, returns to the car, and departs from the airport. In the notation used here, the percentage of originating enplaning passengers and terminating deplaning passengers who use this airport access mode are $P_3^E$ and $P_3^D$. Total number of short term parking slots required for each hour is given by:

$$9)\quad SLOTS_t = (1-\%T)\Big[P_3^E\left(.172\ E_{t+1} + .553\ E_t + .020\ E_{t-1}\right)\left(1+\varepsilon_3\right)/\lambda_3^E + P_3^D\left(.003\ D_{t+1} + .302\ D_t + .063\ D_{t-1}\right)\left(1+\delta_3\right)/\lambda_3^D\Big]$$

This relationship recognizes the fact that in any given hour t, vehicles in the short term parking facility may be associated with enplaning passengers in hour t-1 (well wishers have not yet returned from the terminal to the parking lot), hour t (well wishers are still in terminal with the air passengers), or hour t+1 (passenger and air traveller arrived early for baggage check in and ticketing, etc.) Similarly, deplaning passengers greeted at

the airport at hour t-1, t, and t+1 could be associated with vehicles in the short term parking facility in hour t.[7]
The additional terms in the expression transform passengers into vehicles by considering vehicle load factor $\lambda_3^E$ and $\lambda_3^D$ for enplaning and deplaning passengers, mode 3, as well as vehicle loading through the number of greeters/well-wishers per deplaning and enplaning passengers by mode 3, $\delta_3$ and $E_3$ respectively. Note that the transferring passengers to enplane or deplane do not contribute to short term parking, and the (1 - %T) term makes this adjustment. The relationship further assumes that airport activity at hours t+2 or greater and hours t-2 and earlier will have no impact on short term parking at hour t.

Long term parking in this context is meant to reflect space requirements for enplaning air passengers who drive to the airport and park their automobiles at the airport. Upon returning from their travel, the passenger will deplane and return to their automobile in the airport lot and depart from the airport.

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7. The coefficients in the equation reflect preflight arrival times for both arrivals and departures as shown in Fay, D.R. An Evaluation of Alternative Terminal Designs for Airports, Unpublished M.S. Thesis, Massachusetts Institute of Technology (Cambridge, Mass.) 1971. Data were taken from actual airport data, and correspond to an average pre flight arrival time of 40 minutes for enplanements and 12 minutes for deplanements. These values are typical for high density air travel operations. The coefficients were derived by assuming that all traffic is distributed evenly into 4 discrete clusters of activity, occuring on the hour, and 15, 30 and 45 minutes after the hour. The analysis also assumes that baggage claim requires 15 minutes (after flight arrival) of passenger time, and the walk time from the terminal to the parking facility is 5 minutes.

The hourly change in long term parking requirements is the net inflow to the facility, or the additional spaces required by the arrival of new parkers minus the spaces opened up by the departure of previous parkers: the additional spaces required can be positive or negative for any given hour. The maximum number of long term parking spaces required over the course of a day will simply be the number of spaces occupied at the beginning of a day plus the maximum of the cumulutive net requirements over the day. At the end of the day, the number of spaces occupied in the long term parking facility will be the number of spaces occupied at the beginning of the day plus the cummulative net additional spaces required for each hour of the day summed over the 24 hours of the day.

For a determination of long term parking requirements based upon a simulation of a single day's activity, the number of spaces filled at the beginning of the day must be input. This number changes over the week, and seasonally, and the user may not have a reasonable estimate of this input. This restricts the usefulness of a daily simulation in estimating the total long term parking requirements. By a careful structuring of a multiple day simulation, the user may arrive at a better evaluation of long term parking requirements. Two outputs of the daily simulation which would be most useful in a multiple day simulation of long term airport parking space requirements are given below:

10) $$X_t = P_1^E\left[(1-\%T)\left(1+\varepsilon_1\right)/\lambda_1^E\right] \sum_{s=0}^{t} \left(.48\ E_s + .52\ E_{s-1}\right),$$

$$- P_1^D\left[(1-\%T)\left(1+\delta_1\right)/\lambda_1^D\right] \sum_{s=0}^{t} \left(.75\ D_s + .25\ D_{s-1}\right),$$

11) $$Y = P_1^E \left[ (1-\%T) \left(1+\varepsilon_1\right)/\lambda_1^E \right] \sum_{t=0}^{24} E_t - P_1^D \left[ (1-\%T) \left(1+\delta_1\right)/\lambda_1^D \right] \sum_{t=0}^{24} D_t .$$

Relationship 10) is the net additional parking spaces required (over and above those occupied at the beginning of the day) up to hour t. By considering all values for $X_t$ over the course of the day, the analyst can find the maximum net increase in long term parking (as defined above) to enter or leave the airport, mode 1. The relationship ignores transferring enplanements and deplanements who will not use the airport facilities, so that (1 - %T) term is included in the model. The average group size per vehicle is captured through the $(1 + E_1)/\lambda^E$, and $(1 + \delta_1)/\lambda_1^D$ terms. Relationship 9) recognizes that the vehicles entering the lot at hour t will be for enplanements scheduled for hour t and hour t+1, accounting for the $E_s$ and $E_{s+1}$ terms, where s is a dummy variable for time. Similarly, vehicles leaving the parking facility at hour t will consist of passengers who deplaned at hour t, plus a number who deplaned at hour t-1 who were delayed in leaving the parking facility until hour t by baggage claim and airport to lot walk time.[8]

Relationship 11) is a simplification of 10), which outputs the net increase (or decrease) in long term parking spaces occupied at the end of a single day's operations. The logic of the relationship is similar to that in 10), but without the hourly detail which is unnecessary for this daily calculation. If the user

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8. Coefficients in relation 9) assume preflight arrival times as used in Fay, op. cit., with an average preflight arrival time of 40 minutes, and a 15 minute average baggage claim and terminal to auto walk time.

desired a multiple day simulation of long term parking requirements, he would start with an empty lot, calculate Y at the end of the first day and use this value as the number of vehicles in the lot at the beginning of the second day. By repeating this process, the analyst can develop an accurate measure of fluctuations in parking requirements, given the pertinent input data (inbound and outbound aircraft and automobile load factors, access and egress mode splits, the percentage of air passengers flying into and out of an airport to terminate, continue on the same flight, transfer to another flight, etc.).

Long term parking requirements can be estimated in a less detailed, more aggregate fashion using an econometric relationship relating parking space requirements to annual enplanements. This relationship is shown below:

$$\text{12)} \quad \text{LT PARK} = 1087 + 0.00247\ (1+\%T^{E})\ P_1^{E}\left[\sum_{i=1}^{365}\ \sum_{t=1}^{24}\ E_{it}\right]$$

This relationship is based on the recent parking and enplanement statistics of 11 U.S. airports.[9] The double summation is meant to represent the emplanements for each of the 24 hours of the day, for all 365 days of the year. This element of the program should only be used when an annualized sum of the program has been made.

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9. Including LAX, JFK, ORD, SFO, BOS, LGA, MIA, EWR, DTW, DCA and CLE. $R^2$ was 0.698 with 9 degrees of freedom. Percentage connecting passengers, and recent parking capacity were taken from Parsons, op. cit. San Francisco mode split data were taken from Parsons, Brinckerhoff-Tudor-Bechtel, The San Francisco Airport Access Project: Summary Report, prepared in Cooperation with Wilbur Smith and Associates and Kirker, Chapman, Consultants, San Francisco, California, May, 1972. Mode split statistics for other airports were taken from Parsons, op. cit.

Total annualized enplanements can be derived from the annualized airport operations data.

The employee parking requirements are derived through a simplified procedure. The distribution of arrivals and departures is fairly regular for employee parking because of the shift phenomenon. Actual maximum design levels for employee parking will occur during shift changes for multiple shift airports. The number of employee parking spaces required at any hour t is given by:

13) $$E\ PARK_t = \sum_{s=0}^{t} L_s^i f_1/\phi_1 - \sum_{s=0}^{t} L_s^o f_1/\phi_1$$

The format of this relation is similar to that shown in 10), with hourly lot occupancy being determined by the cumulative inflow minus the cumulative outflow. The terms in the relationship are $L_s^i$ and $L_s^o$, the total employees inbound and outbound from the airport in hour s, $f_1^i$ and $F_1^o$, the mode split for employees inbound and outbound using mode 1 (private autos driven to the airport and parked during the shift), and $\phi_1$, the load factor (in terms of passengers per vehicle) for mode 1. The employee mode split and the vehicle load factors have been estimated through airport access studies for different airports, but the number of employees, and their distribution of airport arrivals and departures may be more difficult to determine. The number of employees at an airport varies considerably, and is influenced by the level of airport traffic, the number of airlines serving the airport, the existance of airline corporate management centers at the airport and other factors. A guide to the number of workers employed at a single airport can be derived from the relationship below:

$$14)\quad EMP = 1920 + 0.001299 \left[ \sum_{i=1}^{365} \sum_{t=1}^{24} E_{it} \right]$$

This relationship was derived from analysis of employment patterns at 10 airports[10] with annual enplanements (the double summation term) less than 8 million. The analyst can use this relationship for cases in which the number of employees working at an airport is not known. When the employment level of an airport is known or estimated, the time distribution of employees entering and leaving the airport can be approximated by specifying the shift distribution for the work force. For example, if the shift changes occur at hours 0, 8, and 16, and the percentage of total workers employed in the three shifts were $\psi_1$, $\psi_2$ and $\psi_3$, then $\psi_1$ EMP employees would flow into the airport during the hour before hour 0 and flow out of the airport in the hour after hour 8, and so on for the second and third shifts. This procedure terminates with estimates of the $L_s^i$ and $L_s^o$ variables appearing in 13).

Many airport access modes will make use of curbspace at the airport terminal for discharging and picking up air passengers and their greeters/well-wishers. The relationships for determining

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10. LGA, BOS, DCA, EWR, DTW, DAL STL, CLE, CVG, and ONT. $R^2$ was 0.659. The quality of the regression declined as airports with higher emplanement levels were included in the analysis. Data were taken from Parsons, op. cit. p. 5-18.

the number of lots for different vehicle types for enplaning and deplaning passengers are given below:

$$15)\quad E\ SLOTS_t^k = \alpha_c\left(1-\%T^E\right)\sum_{j\varepsilon k} P_j^E\left(1+\varepsilon_j\right)\tau_j^E\left(.48\ E_t + .52\ E_{t+1}\right)/\lambda_j^E,$$

$$16)\quad D\ SLOTS_t^k = \alpha_c\left(1-\%T^D\right)\sum_{j\varepsilon k} P_j^D\left(1+\delta_j\right)\tau_j^D\left(.75\ D_t + .25\ D_{t-1}\right)/\lambda_j^D$$

These relationships develop estimates of the required curb space for each vehicle type k by considering the load factor $\lambda^E$, and $\lambda^D$, and vehicle loadings $(1 + \varepsilon_j)$ and $(1 + \delta_j)$ for enplaning and deplaning passengers, and the pre flight arrival patterns and post flight departure patterns (including enplanements in hour t+1 and deplanements in hour t-1 in determining curb space requirements in hour t).[11] The number of slots is modified by the percentage enplaning and deplaning passengers who transfer to other flights through the (1 - %T) term, and the mode split by different modes. Terms which have not previously appeared are $\tau_j^D$, and $\tau_j^E$ curb dwell time (in fractions of an hour units) and $\alpha_c$, the design peaking factor for capturing variation in the flow of traffic at curbside during an hour. The linear distance required for curb space at hour t is given by the relations

$$17)\quad LE\ CURB_t = \sum_{j\varepsilon k} \mu_k \cdot E\ SLOTS_t^k$$

$$18)\quad LD\ CURB_t = \sum_{j\varepsilon k} \mu_k \cdot D\ SLOTS_t^k$$

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11. Preflight arrival distributions were taken from Fay *op. cit.* and post flight airport departure distributions were derived using the assumption that baggage claim and terminal to auto walk time combined is 20 minutes. These distributions are compatible with those used above in other relationships.

In these formulas, $M_k$ is the length of a single curb slot for a vehicle of type k.

Highway capacity for adequate airport access service is difficult to determine because of traffic from nonairport users who may share highway facilities with passengers and workers bound for the airport. The approach used below considers only airport related traffic in deriving airport access highway capacity needs:

$$19)\quad \text{I LANES} = \alpha_H\Bigg[\sum_{j=1}^{7} \gamma_j\left(.48\ E_t + .52\ E_{t+1}\right)\left(1-\%T^E\right)\left(1+\varepsilon_j\right)P_j^E/\lambda_j^E + \sum_{j=2}^{3} \gamma_j\left(1-\%T^D\right)\left(.9\ D_t + .1\ D_{t+1}\right)\left(1+\delta_j\right)P_j^D/\lambda_j^D + \sum_{j=1}^{7} \gamma_j L_t^i\ f_j/\phi_j + \sum_{j=2}^{3} \gamma_j L_t^o\ f_j/\phi\Bigg]/\eta$$

$$20)\quad \text{O LANES}_t = \alpha_H\Bigg[\sum_{j=1}^{7} \gamma_j\left(.75\ D_t + .25\ D_{t-1}\right)\left(1-\%T^D\right)\left(1+\delta_j\right)P_j^D/\lambda_j^D + \gamma_2 P_2^E\left(.52\ E_t + .48\ E_{t+1}\right)\left(1-\%T^E\right)\left(1+\varepsilon_2\right)/\lambda_2^E + \gamma_3 P_3^E\left(.92\ E_t + .08\ E_{t-1}\right)\left(1-\%T^E\right)\left(1+\varepsilon_3\right)/\lambda_3^E + \sum_{j=1}^{7} \gamma_j L_t^o\ f_j/\phi_j + \gamma_2 L_t^i\ f_2/\phi_2\Bigg]/\eta$$

The two relationships above simply account for the different traffic components. Relationship 19) indicates the inbound traffic lanes will carry all originating enplaning passengers using ground access modes, vehicles traveling to the airport to pick up deplaning passengers, all employees inbound to the airport by ground modes, and vehicles moving to the airport to pick up outgoing employees. Similarly, the terms in relationship 20) indicate that outbound highway lanes will cary vehicles for all deplaning passengers, vehicles moving from the airport which have previously dropped off enplaning passengers, all vehicles carrying outbound employees moving by highway modes and all vehicles which have previously dropped off inbound airport employees.[12] The term $\alpha_H$ represents a design peaking factor which captures non-uniformity in hourly traffic flows in planning capacity requirements. The $\gamma_j$ factor which appears in 19) and 20) is the number of equivalent automobiles made up by one vehicle of mode j. The $\eta$ term in the denominator for both 20) and 21) is the auto equivalent vehicle capacity per lane-hour of airport access and egress highway.

12. Coefficients associated with enplanements and deplanements at different time periods were derived by assuming preflight arrival patterns for enplaning passengers and deplaning passenger greeters to be uniform with those used in Fay _op. cit._ It was further assumed that curb drop off and pickup time was 5 minutes, and baggage claim and terminal to auto walk time was 15 minutes.

## REFERENCES

4-1. R. M. Parsons Company, The Apron and Terminal Building Planning Manual, (prepared for the Federal Aviation Administration, Systems Research and Development Service), Pasadena, California, July 1975.

4-2. Fay, D. R., An Evaluation of Alternative Terminal Design for Airports (unpublished M.S. Thesis), Massachusetts Institute of Technology, Cambridge, Massachusetts, 1971.

# 5. DATA BASE

## 5.1 INTRODUCTION

In order to calculate daily and annual delays based on profiles of demand, traffic volumes, and weather at each of the airports listed in Table 5.1-1, separate data files were created for each of the 31 airports. The following data bases were implemented in the creation of the files:

1. Official Airline Guide Flight Stage Schedules (OAG)
2. FAA Tower Statistics
   - Form 7230.1 Tower Data
3. National Weather Service Ceiling and Visibility Data

Two additional data bases were used in the validation of the model. They are listed below:

1. CAB ER-586 Service Segment Data
2. New York CATER Data for Kennedy, LaGuardia, and Newark

The following sections describe each of the data bases, their content, sources, formats, availabilty, and frequency of reporting.

TABLE 5.1-1

LIST OF AIRPORTS IN AIRPORT PERFORMANCE

MODEL DATA BASE

| | |
|---|---|
| BOS | Boston |
| DCA | Washington National |
| BAL | Baltimore |
| EWR | Newark |
| JFK | Kennedy |
| LGA | LaGuardia |
| IAH | Houston |
| PHL | Philadelphia |
| PIT | Pittsburgh |
| IAD | Dulles International |
| FLL | Fort Lauderdale |
| JAX | Jacksonville |
| MIA | Miami International |
| MKE | Milwaukee (Mitchell) |
| TPA | Tampa International |
| ATL | Atlanta |
| CLT | Charlotte, N.C. |
| ORD | Chicago (O'Hare) |
| DTW | Detroit (Metro Wayne) |
| MSP | Minneapolis - St. Paul |
| CLE | Cleveland |
| STE | St. Louis (Lambert Field) |
| MSY | New Orleans |
| DAL | Dallas (Love Field) |
| DEN | Denver |
| SLC | Salt Lake City |
| LAX | Los Angeles |
| SFO | San Francisco |
| LAS | Las Vegas (McCarren) |
| SEA | Seattle - Tacoma |
| HNL | Honolulu International |

## 5.2 CREATION OF AIRPORT FILES

### 5.2.1 Official Airline Guide (OAG)

The OAG Fight Stage data tapes were implemented primarily to generate the following inputs to the model, for each of the 31 airports:

- Minute-by-minute daily profiles to obtain demand for departures and arrivals
- 15-minute profiles used by the clustering routines (See Section 6.3)
- Hourly aircraft mix
- Arrival/Departure ratio to apportion non-scheduled profile into arrivals and departures.

Schedules of all flights are submitted by the scheduled airlines to the Reuben Donnelley Corporation twice monthly, and magnetic tapes of the schedules are developed for the FAA and leased to various government agencies. The content of the data tapes is as follows:

- For each flight segment flown by U.S. certificated air carriers, foreign-flag, intrastate, and supplemental air carriers, air taxi operators or other airlines scheduling five or more flights per month, a flight record is included, categorized by route segment, airline, flight number, aircraft type, class of service, frequency of operation, and scheduled hour for departure and arrival. A complete record format is shown in Figure 5.2.1.

From a total of approximately 60,000 OAG records per month, those records whose origin or destination was one of the 31 included in the model were extracted before further processing began.

The Donnelley Corporation produces the Flight Stage tapes under contract to the FAA, initiated in 1971. The data are drawn from a larger data base, referred to as the ACTS system (Airline Codes, Tariffs, and Schedules), and is produced twice monthly-on the first and fifteenth of each month. Copies of the tapes are sent to three government agencies listed below for various aviation projects:

1. DOT-Transportation Systems Center
2. FAA-National Aviation Facility Experimental Center (NAFEC)
3. FAA-Data Processing Center

Investigation of these sources of the data revealed that only one monthly data tape was available per quarter for the years 1972 and 1973, and was located only at the NAFEC data tape library. Data were available for the months of February May, August, and November. Although data for more recent years were located at all three sources, the decision was made to utilize the tapes for these years to correspond with the 1972-1973 Tower data tapes described in Section 5.2.2. The decision to use the available quarterly data instead of more recent monthly data was based on the knowledge that airline schedules follow seasonal patterns, and the four available months for these two years were representative of demand throughout the year. Furthermore, since the annualization process required no more than three representative or typical daily profiles of demand for each of the airports, it would be more efficient to process only four months of data per year instead of twelve. Although processing of the OAG initially included both 1972 and 1973, data, results of the clustering process described in Section 6.2, indicated that the typical daily profiles should be derived from only one year's worth of OAG data, chosen to be 1973.

### 5.2.2 FAA Tower Traffic Data

The FAA Tower data, extracted from FAA Form 7230.1, were implemented to generate the following inputs to the model:

- ° Frequency distribution of volume at each airport for the major traffic components - Air Carrier, Air Taxi, General Aviation, and Military.
- ° Average volume and average mix for scheduled and non-scheduled traffic in both IFR and VFR categories of weather.
- ° Estimates of non-scheduled aircraft mix.

Towers located at the airports are required to record daily counts of all operations for the major traffic components, and submit the daily totals monthly to the FAA on Form 7230.1. The data are subsequently sent to Systems Consultants, Inc., where it is keypunched, edited, and stored on magnetic tape for further processing and tabulations. Data were sent to TSC by Systems Consultants for the years 1972-1973, for all towered airports in the U.S. The content of the data is presented below:

Daily totals for each airport are given for nine (9) aircraft operations for each of the 365 (1972) or 366 (1973) days of the year. The aircraft operations are:

1. Air Carrier - Itinerant
2. Air Taxi - Itinerant
3. General Aviation - Itinerant
4. Military - Itinerant
5. Total Itinerant
6. General Aviation - Local
7. Military - Local
8. Total Local
9. Total Operations

No identification is made on these tapes of airports and no demarcation between data for different airports is given. An airport directory, giving the airport name, number, and location was sent to TSC on card-deck and print-out form for both years, and provides key to the order of the airports on the tape. The data on the tapes is stored in the same order as in the airport directory. Two days of data are on each record, the first 183 records on the tape are data for the first airport, the next 183 records for the second airport, etc. The data are stored on 4 magnetic tapes per year for the 347 airports reporting in 1972 and 353 reporting in 1973. A complete record format is shown in Figure 5.2-2 and partial listing of the airport directory in TABLE 5.2-1. Identification of the column numbers for the airport directory is given below:

1. Airport ID
2. Region Number
3. Region Name
4. State Number
5. State Name
6. Airport Location
7. Top 50 airports (yes = 1)
8. Hub size (1 = large hub)
   (2 = medium hub)
   (3 = small hub)
   (4 = non-hub)
9. Airport Numbers

As in the case of the OAG tapes, data for the 31 airports modelled by the system had to be extracted before further processing was undertaken.

### 5.2.3 Weather Data

The National Weather Service Climatological data was processed for the following purposes:

TABLE 5.2-1. OAG FORMAT DATA-- RECORD LAYOUT DESCRIPTION

FILE OR TAPE TITLE:

CONTROL #
TAPE #

TAPE CHARACTERISTICS: DENSITY:____BPI TRACKS:_____ PARTY: ( ) ODD ( ) EVEN
CODE:
RECORD STRUCTURE: ( )FIXED LENGTH ________ ( )VARIABLE LENGTH______
NO OF RECORDS ________ NO. OF BLOCKS______

| FIELD NO. | FIELD NAME | LOCATION FROM | LOCATION TO | FIELD SIZE | DATA TYPE | DATA CODE | COMMENTS |
|---|---|---|---|---|---|---|---|
| 1 | Departure Country | 1 | 3 | 3 | N | | World Area Code |
| 2 | Filler | 4 | | | | | |
| 3 | Departure Airport Code | 5 | 7 | 3 | A | | FAA Code |
| 4 | Filler | 8 | 9 | | | | |
| 5 | Departure Time-Local | 10 | 13 | 4 | A | | Local Leave Time |
| 6 | Departure Time-GMT | 14 | 17 | 4 | A/N | | GMT Leave Time |
| 7 | Arrival Country | 18 | 20 | 3 | N | | World Area Code |
| 8 | Filler | 21 | | | | | |
| 9 | Arrival Airport Code | 22 | 24 | 3 | A | | FAA Code |
| 10 | Filler | 25 | 26 | | | | |
| 11 | Arrival Time-Local | 27 | 30 | 4 | A/N | | Local Arrive Time |
| 12 | Flag Code | 31 | | 1 | N | | Flag code in relation to its pattern of service |
| 13 | Arrival Time-GMT | 32 | 35 | 4 | A/N | | GMT Arrival Time |
| 14 | Equipment Type | 36 | | 1 | A | | J=Jet, P=Propeller, T=Propeller, T=Turboprop |

FIGURE 5.2-1. (Cont'd.)

| FIELD NO. | FIELD NAME | LOCATION FROM | LOCATION TO | FIELD SIZE | DATA TYPE | DATA CODE | COMMENTS |
|---|---|---|---|---|---|---|---|
| 15 | Equipment Code | 37 | 39 | 3 | A/N | | ATA Code describing the type of equipment |
| 16 | Filler | 40 | | | | | |
| 17 | Carrier | 41 | 42 | 2 | A | | ATA Code |
| 18 | Flight Number | 43 | 47 | 5 | A/N | | ATA Code |
| 19 | Class of Service | 48 | 52 | 5 | A | | |
| 20 | Days of Service | 53 | 59 | 7 | N | | Each position will contain a '1' if if service is scheduled and a '0' if not. |
| 21 | Suppress Code | 60 | 60 | 1 | N | | Contains an '1' if stage is suppressed for any reason |
| 22 | Type of Operator | 61 | | 1 | A | | T= Commuter Air Carrier, Air Taxi<br>I= Intra-state<br>Blank= Sched. Air Carrier or other |
| 23 | Elapsed Time | 62 | 65 | 4 | N | | |
| 24 | Effective Date | 66 | 69 | 4 | N | | 66-67= Month 68-69= Day |
| 25 | Discontinued Date | 70 | 73 | 4 | N | | 70-71= Month 72-73= Day |
| 26 | Departure Latitude | 74 | 79 | 6 | N | | |
| 27 | Departure Longitude | 80 | 85 | 6 | N | | |
| 28 | Arrival Latitude | 86 | 91 | 6 | N | | |
| 29 | Arrival Longitude | 92 | 97 | 6 | N | | |
| 30 | Filler | 98 | 105 | 8 | | | |
| 31 | Record Mark | 106 | | 1 | A | | |

TABLE 5.2-2. TOWER TRAFFIC DATA FORMAT-- RECORD LAYOUT DESCRIPTION

FILE OR TAPE TITLE: CONTROL #

TAPE #

TAPE CHARACTERISTICS: DENSITY:____BPI TRACKS:_____ PARTY: ( ) ODD ( ) EVEN

CODE:

RECORD STRUCTURE: ( )FIXED LENGTH ________ ( )VARIABLE LENGTH_____

NO OF RECORDS ________ NO. OF BLOCKS______

| FIELD NO. | FIELD NAME | LOCATION FROM | TO | FIELD SIZE | DATA TYPE | DATA CODE | COMMENTS |
|---|---|---|---|---|---|---|---|
| 1 | Air Carrier - Itinerant | 1 | 7 | 7 | N | | |
| 2 | Air Taxi - Itinerant | 8 | 14 | 7 | N | | |
| 3 | General Aviation - Itinerant | 15 | 21 | 7 | N | | |
| 4 | Military - Itinerant | 22 | 28 | 7 | N | | |
| 5 | Total Itinerant | 29 | 35 | 7 | N | | |
| 6 | General Aviation - Local | 36 | 42 | 7 | N | | |
| 7 | Military - Local | 43 | 49 | 7 | N | | |
| 8 | Total Local | 50 | 56 | 7 | N | | |
| 9 | Total Operations | 57 | 63 | 7 | N | | |
| 10 | Same as Fields 1-9 for Second Day in the record (fields 10–18) | 64 | 70 | | | | |
| 11 | | 71 | 77 | | | | |
| 12 | | 78 | 84 | | | | |
| 13 | | 85 | 91 | | | | |
| 14 | | 92 | 98 | | | | |
| 15 | | 99 | 105 | | | | |
| 16 | | 106 | 112 | | | | |
| 17 | | 113 | 119 | | | | |
| 18 | | 120 | 126 | | | | |

TABLE 5.2-3. 1973 AIRPORT DIRECTORY

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| BDR | 1 | NEW ENGLAND | 7 | CONN. | BRIDGEPORT | 0 | 4 | 1 |
| HVN | 1 | NEW ENGLAND | 7 | CONN. | NEW HAVEN | 0 | 4 | 2 |
| BDL | 1 | NEW ENGLAND | 7 | CONN. | WINDSOR LOCKS | 0 | 2 | 3 |
| BGR | 1 | NEW ENGLAND | 19 | MAINE | BANGOR INTERNATIONAL | 0 | 4 | 4 |
| PWM | 1 | NEW ENGLAND | 19 | MAINE | PORTLAND | 0 | 3 | 5 |
| BED | 1 | NEW ENGLAND | 21 | MASS. | BEDFORD | 1 | 1 | 6 |
| BOS | 1 | NEW ENGLAND | 21 | MASS. | BOSTON | 1 | 1 | 7 |
| HYA | 1 | NEW ENGLAND | 21 | MASS. | HYANNIS | 0 | 4 | 8 |
| ACK | 1 | NEW ENGLAND | 21 | MASS. | NANTUCKET | 0 | 4 | 9 |
| EWB | 1 | NEW ENGLAND | 21 | MASS. | NEW BEDFORD | 0 | 4 | 10 |
| OWD | 1 | NEW ENGLAND | 21 | MASS. | NORWOOD | 0 | 1 | 11 |
| BAF | 1 | NEW ENGLAND | 21 | MASS. | WESTFIELD | 0 | 4 | 12 |
| ORH | 1 | NEW ENGLAND | 21 | MASS. | WORCESTER | 0 | 4 | 13 |
| MHT | 1 | NEW ENGLAND | 29 | NEW HAMP. | MANCHESTER | 0 | 4 | 14 |
| PVD | 1 | NEW ENGLAND | 39 | RHODE ILD | PROVIDENCE | 1 | 3 | 15 |
| BTV | 1 | NEW ENGLAND | 45 | VERMONT | BURLINGTON | 0 | 4 | 16 |
| ILG | 2 | EASTERN | 8 | DELAWARE | GREATER WILMINGTON | 0 | 4 | 17 |
| DCA | 2 | EASTERN | 51 | D.C. | WASHINGTON NATIONAL | 1 | 1 | 18 |
| ADW | 2 | EASTERN | 20 | MARYLAND | ANDREWS AIR FORCE BASE | 0 | 1 | 19 |
| BAL | 2 | EASTERN | 20 | MARYLAND | BALTIMORE INTERNATIONAL | 0 | 2 | 20 |
| ACY | 2 | EASTERN | 30 | NEW JERSEY | ATLANTIC CITY | 0 | 4 | 21 |
| MMU | 2 | EASTERN | 30 | NEW JERSEY | MORRISTOWN | 0 | 1 | 22 |
| EWR | 2 | EASTERN | 30 | NEW JERSEY | NEWARK | 0 | 1 | 23 |
| TEB | 2 | EASTERN | 30 | NEW JERSEY | TETERBORO | 0 | 4 | 24 |
| TTN | 2 | EASTERN | 30 | NEW JERSEY | TRENTON | 0 | 4 | 25 |
| ALB | 2 | EASTERN | 32 | NEW YORK | ALBANY COUNTY | 0 | 2 | 26 |
| BGM | 2 | EASTERN | 32 | NEW YORK | BINGHAMPTON | 0 | 3 | 27 |
| BUF | 2 | EASTERN | 32 | NEW YORK | BUFFALO | 0 | 2 | 28 |
| ELM | 2 | EASTERN | 32 | NEW YORK | ELMIRA | 0 | 4 | 29 |
| FRG | 2 | EASTERN | 32 | NEW YORK | FARMINGDALE | 0 | 1 | 30 |
| ISP | 2 | EASTERN | 32 | NEW YORK | ISLIP | 1 | 1 | 31 |
| JFK | 2 | EASTERN | 32 | NEW YORK | JOHN F KENNEDY INTERNATIONAL | 1 | 1 | 32 |
| LGA | 2 | EASTERN | 32 | NEW YORK | LA GUARDIA | 1 | 1 | 33 |
| IAG | 2 | EASTERN | 32 | NEW YORK | NIAGARA FALLS | 0 | 2 | 34 |
| ROC | 2 | EASTERN | 32 | NEW YORK | ROCHESTER | 0 | 2 | 35 |
| FOK | 2 | EASTERN | 32 | NEW YORK | SUFFOLK COUNTY AIRPORT * NON-FAA * | 0 | 4 | 36 |
| SYR | 2 | EASTERN | 32 | NEW YORK | SYRACUSE | 0 | 2 | 37 |
| UCA | 2 | EASTERN | 32 | NEW YORK | UTICA | 0 | 4 | 38 |
| HPN | 2 | EASTERN | 32 | NEW YORK | WHITE PLAINS | 1 | 1 | 39 |
| ABE | 2 | EASTERN | 38 | PENN. | ALLENTOWN | 0 | 3 | 40 |
| ERI | 2 | EASTERN | 38 | PENN. | ERIE | 0 | 3 | 41 |
| HAR | 2 | EASTERN | 38 | PENN. | HARRISBURG | 0 | 3 | 42 |
| LNS | 2 | EASTERN | 38 | PENN. | LANCASTER | 0 | 4 | 43 |
| MDT | 2 | EASTERN | 38 | PENN. | MIDDLETON | 0 | 3 | 44 |
| PNE | 2 | EASTERN | 38 | PENN. | NORTH PHILADELPHIA | 0 | 1 | 45 |
| PHL | 2 | EASTERN | 38 | PENN. | PHILADELPHIA | 1 | 1 | 46 |
| AGC | 2 | EASTERN | 38 | PENN. | PITTSBURG ALLEGHENY | 0 | 1 | 47 |
| PIT | 2 | EASTERN | 38 | PENN. | PITTSBURG GREATER | 1 | 1 | 48 |
| RDG | 2 | EASTERN | 38 | PENN. | READING | 0 | 4 | 49 |
| AVP | 2 | EASTERN | 38 | PENN. | WILKES BARRE | 0 | 3 | 50 |
| IPT | 2 | EASTERN | 38 | PENN. | WILLIAMSPORT | 0 | 4 | 51 |
| CHO | 2 | EASTERN | 46 | VIRGINIA | CHARLOTTSVILLE ALBEMARLE | 0 | 4 | 52 |
| LYH | 2 | EASTERN | 46 | VIRGINIA | LYNCHBURG | 0 | 4 | 53 |
| PHF | 2 | EASTERN | 46 | VIRGINIA | NEWPORT NEWS | 0 | 3 | 54 |
| ORF | 2 | EASTERN | 46 | VIRGINIA | NORFOLK | 0 | 2 | 55 |
| RIC | 2 | EASTERN | 46 | VIRGINIA | RICHMOND | 0 | 3 | 56 |
| ROA | 2 | EASTERN | 46 | VIRGINIA | ROANOKE | 0 | 3 | 57 |
| IAD | 2 | EASTERN | 46 | VIRGINIA | WASHINGTON DULLES INTERNATIONAL | 0 | 1 | 58 |
| CRW | 2 | EASTERN | 48 | W.VIRGINIA | CHARLESTON | 0 | 3 | 59 |
| CKB | 2 | EASTERN | 48 | W.VIRGINIA | CLARKSBURG BENEDUM | 0 | 4 | 60 |
| HTS | 2 | EASTERN | 48 | W.VIRGINIA | HUNTINGTON | 0 | 3 | 61 |
| MGW | 2 | EASTERN | 48 | W.VIRGINIA | MORGANTOWN | 0 | 4 | 62 |

- To determine which days of 1972 and 1973 experienced predominately VFR or IFR weather
- To separate the daily traffic volumes as reported on the Tower tapes into VFR or IFR categories, which were processed separately

The data were obtained from the National Climatic Center which has archived weather observation recorded since 1941 at National, Air Force, and Naval Weather Service Stations in support of airport operations. Contents and formats of the data have been altered periodically during these years because of changes in observing and recording practices. In order to facilitate the handling of these large masses of data, and provide for a more uniform reporting system, the FAA, in cooperation with the Climatological Services of the Weather Bureau, Air Force, and Navy Stations devised the tape format for the data now being collected, called the Tape Data Family - 14 (TDF-14). It is this source from which the data for the model were drawn.

The data, for the years 1970-1974 referred to as airways surface observations, are recorded on an hourly basis by military or National Weather Service stations. Currently, there are approximately 300 reporting stations throughout the U.S. which send the weather observations monthly to the National Climatic Center. A complete listing of the stations for which Climatological Data are currently being issued is shown in Figure 5.2-3.

Reporting of the data by the stations to the NCC has been reduced from 24 observations per day, to 8 observations per day, taken at 3-hourly intervals, although hourly observations are still recorded.

The data digitized by NCC contain such observations as

## TABLE 5.2-4. STATIONS FOR WHICH LOCAL CLIMATOLOGICAL DATA ARE ISSUED

**ALABAMA**

- abc Birmingham
- abc Huntsville
- abc Mobile
- abc Montgomery

**ALASKA**

- abc Anchorage
- abc Annette
- abc Barrow
- abc Barter Island
- abc Bethel
- abc Bettles
- abc Big Delta
- abc Cold Bay
- abc Fairbanks
- abc Gulkana
- abc Homer
- abc Juneau
- abc King Salmon
- abc Kodiak
- abc Kotzebue
- abc McGrath
- abc None
- abc St. Paul Island
- abc Summit
- abc Talkeetna
- abc Unalakleet
- abc Yakutat

**ARIZONA**

- abc Flagstaff
- abc Phoenix
- abc Tucson
- abc Winslow
- abc Uma

**ARKANSAS**

- abc Fort Smith
- abc Little Rock

**CALIFORNIA**

- abc Bakersfield
- abc Bishop
- ac Blue Canyon
- ac Eureka
- abc Fresno
- abc Long Beach
- abc Los Angeles AP
- ac Los Angeles Civic Center
- abc Mt. Shasta
- abc Oakland
- abc Red Bluff
- abc Sacramento
- abc Sandberg
- abc San Diego
- San Francisco
  - abc Airport
  - ac City
- abc Santa Maria
- abc Stockton

**COLORADO**

- abc Alamosa
- abc Colorado Springs
- abc Denver
- abc Grand Junction
- abc Pueblo

**FLORIDA**

- ac Apalachicola
- abc Daytona Beach
- abc Fort Myers
- abc Jacksonville
- abc Key West
- ac Lakeland
- abc Miami
- abc Orlando
- abc Pensacola
- abc Tallahassee
- abc Tampa
- abc W. Palm Beach

**GEORGIA**

- abc Athens
- abc Atlanta
- abc Augusta
- abc Columbus
- abc Macon
- ac Rome
- abc Savannah

**HAWAII**

- abc Hilo
- abc Honolulu
- abc Kahului
- abc Lihue

**IDAHO**

- abc Boise
- abc Lewiston
- abc Pocatello

**ILLINOIS**

- ac Cairo
- Chicago
  - abc Midway AP
  - abc O'Hare AP
- abc Moline
- abc Peoria
- abc Rockford
- abc Springfield

**INDIANA**

- abc Evansville
- abc Fort Wayne
- abc Indianapolis
- abc South Bend

**IOWA**

- abc Burlington
- abc Des Moines
- abc Dubuque
- abc Sioux City
- abc Waterloo

**KANSAS**

- abc Concordia
- abc Dodge City
- abc Goodland
- abc Topeka
- abc Wichita

**KENTUCKY**

- abc Lexington
- abc Louisville

**LOUISIANA**

- abc Alexandria

**MASSACHUSETTS**

- abc Boston
- ac Blue Hill Obs.
- abc Worcester

**MICHIGAN**

- abc Alpena
- Detroit
  - abc City Airport
  - abc Detroit Metro AP
- abc Flint
- abc Grand Rapids
- abc Houghton Lake
- abc Lansing
- ac Marquette
- abc Muskegon
- abc Sault Ste. Marie

**MINNESOTA**

- abc Duluth
- abc Int'l. Falls
- abc Minneapolis-St. Paul
- abc Rochester
- abc St. Cloud

**MISSISSIPPI**

- abc Jackson
- abc Meridian

**MISSOURI**

- abc Columbia
- abc Kansas City
- abc St. Joseph
- abc St. Louis
- abc Springfield

**MONTANA**

- abc Billings
- abc Glasgow
- abc Great Falls
- abc Havre
- abc Helena
- abc Kalispell
- abc Miles City
- abc Missoula

**NEBRASKA**

- abc Grand Island
- abc Lincoln
- abc Norfolk
- abc North Platte
- abc Omaha
- abc Scottsbluff
- ac Valentine

**NEVADA**

- abc Elko
- abc Ely
- abc Las Vegas
- abc Reno
- abc Winnemucca

**NEW HAMPSHIRE**

- abc Concord
- ac Mt. Washington

**NEW JERSEY**

- Atlantic City
  - abc Airport

**NEW YORK (Cont.)**

- abc Buffalo
- New York
  - abc Central Park
  - abc J.F. Kennedy Int'l. AP
  - abc LaGuardia Field
- abc Rochester
- abc Syracuse

**N. CAROLINA**

- abc Asheville
- abc Cape Hatteras
- abc Charlotte
- abc Greensboro
- abc Raleigh
- abc Wilmington

**N. DAKOTA**

- abc Bismark
- abc Fargo
- abc Williston

**OHIO**

- abc Akron-Canton
- Cincinnati
  - ac Abbe Obs.
  - abc Airport
- abc Cleveland
- abc Columbus
- abc Dayton
- abc Mansfield
- abc Toledo
- abc Youngstown

**OKLAHOMA**

- abc Oklahoma City
- abc Tulsa

**OREGON**

- abc Astoria
- abc Burns
- abc Eugene
- abc Meacham
- abc Medford
- abc Pendleton
- abc Portland
- abc Salem
- abc Sexton Summit

**PACIFIC ISLANDS**

- abc Guam
- abc Johnston
- abc Korror
- abc Kwajalein
- abc Majuro
- abc Pago Pago
- abc Ponalpe
- abc Truk (Moen)
- abc Wake
- abc Yap

**PENNSYLVANIA**

- abc Allentown
- abc Erie
- abc Harrisburg
- abc Philadelphia
- Pittsburgh
  - abc Airport
  - ac City

**SOUTH DAKOTA**

- abc Aberdeen
- abc Huron
- abc Rapid City
- abc Sioux Falls

**TENNESSEE**

- abc Bristol
- abc Chattanooga
- abc Knoxville
- abc Memphis
- abc Nashville
- ac Oak Ridge

**TEXAS**

- abc Abilene
- abc Amarillo
- abc Austin
- abc Brownsville
- abc Corpus Christi
- abc Dallas-Ft. Worth
- abc Del Rio
- abc El Paso
- abc Fort Worth
- ac Galveston
- abc Houston
- abc Lubbock
- abc Midland
- abc Port Arthur
- abc San Angelo
- abc San Antonio
- abc Victoria
- abc Waco
- abc Wichita Falls

**UTAH**

- ac Milford
- abc Salt Lake City
- abc Wendover

**VERMONT**

- abc Burlington

**VIRGINIA**

- abc Lynchburg
- abc Norfolk
- abc Richmond
- abc Roanoke
- ab Wallop Island

**WASHINGTON**

- abc Olympia
- abc Quillayute Ap
- abc Seattle-Tacoma Ap
- ac Seattle Urban Site
- abc Spokane
- abc Stampede Pass
- ac Walla Walla
- abc Yakima

**WEST INDIES**

- abc San Juan, P.R.

**W. VIRGINIA**

- abc Beckley
- abc Charleston
- abc Elkins

# TABLE 5.2-3. (Cont'd.)

CONNECTICUT
abc Bridgeport
abc Hartford

DELAWARE
abc Wilmington

DISTRICT OF COLUMBIA
abc Washington-National AP
abc Washington-Dulles Int'l AP

abc Baton Rouge
abc Lake Charles
abc New Orleans
abc Shreveport

MAINE
abc Caribou
abc Portland

MARYLAND
abc Baltimore

a State Marina
abc Newark
ac Trenton

NEW MEXICO
abc ALBUQUERQUE
ac Clayton
abc Roswell

NEW YORK
abc Albany
abc Binghamton

abc Wilkes-Barre Scranton AP
abc Williamport

RHODE ISLAND
ac Block Island
abc Providence

S. CAROLINA
Charleston
abc Airport
a City
abc Columbia
abc Greenville-Spartanburg

abc Huntington
ac Parkersburg

abc Green Bay
abc La Crosse
abc Madison
abc Milwaukee

WYOMING
abc Casper
abc Cheyenne
abc Lander
abc Sheridan

a. Monthly Summary issued.
b. Monthly Summary includes available 3-hourly observations. Published if 5 or more available per day.
c. Annual Summary issued.

ceiling height, horizontal visibility, wind speed and direction, sky cover, temperature, and dew point. The data, required by the model and obtained at TSC, included only the ceiling and visibility elements of the original tapes. Further information pertaining to the contents and structure of the complete data base, as well as the codes and definitions used in digitizing the data, is documented in the user's manual, TDF-14 Surface Observations, available through the NCC.

A record format of the data tape giving the ceiling and visibility fields extracted from the original tape is shown in Figure 5.2.4. TSC received data for only 30 airports of the 31 requested. Ft. Lauderdale is not currently reporting climatological data. The decision was made to insert Miami weather as a substitute for Ft. Lauderdale's because of the geographical proximity of the two cities.

TABLE 5.2-5. CEILING AND VISIBILITY DATA FORMAT-- RECORD LAYOUT DESCRIPTION

| FIELD NO. | FIELD NAME | LOCATION FROM | LOCATION TO | FIELD SIZE | DATA TYPE | DATA CODE | COMMENTS |
|---|---|---|---|---|---|---|---|
| 1 | WBAN Station Number | 1 | 5 | 5 | N | | Station Identifier<br>Permanently Assigned to Station |
| 2 | Reporting Year | 6 | 7 | 2 | N | | Last Two Digit of the Yera |
| 3 | Reporting Month | 8 | 9 | 2 | N | | 01 = Jan., 02 = Feb.,---, 12 = Dec. |
| 4. | Reporting Day | 10 | 11 | 2 | N | | Day of Month, 01-30 |
| 5 | Reporting Hour | 12 | 13 | 2 | N | | Recorded as Hour of Clock |
| 6 | Filler | 14 | 14 | 1 | N | | 00 - 23 Local Standard Time |
| 7 | Ceiling Height | 15 | 17 | 3 | N | | Codes Described in TDF-14 Manual |
| 8 | Horizontal Visibility | 18 | 20 | 3 | N | | Codes Described in TDF-14 Manual |

## 5.3 DELAY VALIDATION DATA

### 5.3.1 CAB ER-586 Data

The Civil Aeronautics Board ER-586 Service Segment Data was implemented to estimate the following parameters required to validate the APM:

- Nominal times for all route segments terminating at the three (3) New York airports - Kennedy (JFK), LaGuardia (LGA), and Newark (EWR).
- Total airborne delay for all flights terminating at JFK, LGA, and EWR, calculated as a function of airport, aircraft type (jet and nonjet), and hour of day.[1]

Economic Regulation 586 requires each certificated air carrier to transmit to the CAB, on a monthly basis, certain operating statistics for each flight segment of each flight itinerary. Each record of the data base categorized by origin, destination, airline, flight number, and aircraft type, includes monthly totals for departures, scheduled and performed, revenue aircraft miles flown, seats available, pounds available, revenue passengers enplaned, transported, and deplaned by class of service, revenue cargo enplaned, and pounds transported. The records also include information for successive downline points beyond the current segment in the complete routing of the itinerary. The data have been collected since July, 1971, and are compiled by the CAB on magnetic tape. Unlike the former data bases described, the data are restricted for a period of one year as far as public use in concerned, to protect air carriers' competitive positions. Federal agencies, however, can submit a written request to the CAB for the Service Segment Data, which is reviewed and usually granted. The data are made available by National Archives and Records Service (NARS), in

[1] Calculated for May, 1972.

Washington, D.C. approximately 90 days after the close of each month.

The monthly data used in the validation were available at the TSC Data Tape Library, where the data are stored in a Binary format for 1971 through 1975. The month of May, 1972 was chosen on which to perform the validation. However, the months of April, May, June, and July were actually processed to select the nominal flight times for each route segment. Total delay for a given route segment was calculated directly from the CAB tape, and a breakdown of total delay as a function of scheduled hour of arrival for a given airport and aircraft type was obtained by merging the OAG schedule tape with the ER-586 tape for the same month. A complete description of the procedure followed in obtaining these estimates is available in the report - Hourly Airborne Delay at EWR, JFK, and LGA, (KHL-TSC-76-1399). A complete record layout of the data is shown in Figure 5.3.-1. and explanatory notes of the data are given at the end of the record layout.

### 5.3.2 CATER Data

The May 1972 CATER data (Collection and Analysis of Terminal Records) for the three New York airports was used in the validation of the model to derive the following:

- Hour-by-hour runway configurations for each day of May, 1972
- Hour-by-hour weather profiles for the same days, categorized into 6 classifications of weather in terms of ceiling and visibility
- Representative profile for non-scheduled operations (general aviation and military)

The Air Traffic Control Service, in attempting to monitor

TABLE 5.3-1. CAB SERVICE SEGMENT DATA FORMAT

| Field # | Field Name | Data Type | No. of Words | Data Bounds* |
|---|---|---|---|---|
| 1 | Base Reference Code | A | 1 | B or R |
| 2 | City Code 1 | N | 1 | 5D |
| 3 | Airport Designator Code 1 | N | 1 | 1D |
| 4 | World Area Code 1 | N | 1 | 3D |
| 5 | Alpha Airport Code 1 | A | 1 | A3 |
| 6 | Reporting Segment Count | N | 1 | 1-10 |
| 7 | City Code 2 | N | 1 | 5D |
| 8 | Airport Designator Code 2 | N | 1 | 1D |
| 9 | World Area Code 2 | N | 1 | 3D |
| 10 | Alpha Airport Code 2 | A | 1 | A3 |
| 11 | Date YY Year | N | 1 | 72-? |
| 12 | Date MM Month | N | 1 | 1-12 |
| 13 | Carrier Operation Code | A | 1 | A2 |
| 14 | Carrier Name Code | A/N | 1 | A3 |
| 15 | Number of Downline Points | N | 1 | 1-10 |
| 16 | Service Class | A | 1 | A,C,E or G |
| 17 | Aircraft Group Code | N | 1 | 1-9 |
| 18 | Aircraft Type Code | N | 1 | 01-99 |

*Data Bound abbreviations:
- 1D = 0-9 i.e. 1 decimal digit
- 5D = up to 5 decimal digits 0-99999
- A3 = 3 alpha characters
- 0-10 = positive integers from zero to ten
- 24A1 = 24 single alpha characters

TABLE 5.3-1. (Cont'd.)

| Field # | Field Name | Data Type | No. of Words | Data Bounds |
|---|---|---|---|---|
| 19 | Cabin Configuration Code | N | 1 | 1-3 |
| 20 | Flight Number | A/N | 1 | A4 |
| 21 | Subsidy Elig-inelig Code | N* | 1 | 0-2 |
| 22 | Reference Flight Number | A/N | 1 | A4 |
| 23 | Service Segment Position | N | 1 | 1-70 |
| 24 | Interairport Distance | N | 1 | 4D |
| 25 | Revenue Aircraft Departures Scheduled X520 | N | 1 | 0-32 |
| 26 | Scheduled Revenue Aircraft Departures Performed X521 | N | 1 | 0-32 |
| 27 | Actual Revenue Aircraft Departures Performed X511 | N | 1 | 0-32 |
| 28 | Revenue Aircraft Departures Performed Extra Section X512 | N | 1 | 0-32 |
| 29 | Revenue Aircraft Miles Scheduled X430 | N | 1 | 6D |
| 30 | Revenue Aircraft Miles Flown Scheduled X411 | N | 1 | 6D |
| 31 | Revenue Aircraft Miles Flown Extra Section X412 | N | 1 | 6D |
| 32 | Seats Available - First Class X311 | N | 1 | 5D |
| 33 | Seats Available - Coach X312 | N | 1 | 5D |
| 34 | Pounds Available X270 | N | 1 | 7D |
| 35 | Revenue Aircraft Hours (Airborne) X610 | N | 1 | 5D |
| 36 | Revenue Aircraft Hours (Ramp to Ramp) X630 | N | 1 | 5D |
| 37 | Revenue Passengers Transported First Class X131 | N | 1 | 5D |

*In 1974 this is 1 ALPHA character

TABLE 5.3-1 (Cont'd.)

| Field # | Field Name | Data Type | No. of Words | Data Bounds |
|---|---|---|---|---|
| 38 | Revenue Passenger Transported Coach X132 | N | 1 | 5D |
| 39 | Non-Revenue Passengers Transported X150 | N | 1 | 5D |
| 40 | Revenue Pounds Transported Passenger X231 | N | 1 | 7D |
| 41 | Revenue Pounds Transported U.S. Mail Priority X233 | N | 1 | 6D |
| 42 | Revenue Pounds Transported U.S. Mail Non-priority X234 | N | 1 | 6D |
| 43 | Revenue Pounds Transported Foreign Mail X235 | N | 1 | 6D |
| 44 | Revenue Pounds Transported Express X236 | N | 1 | 6D |
| 45 | Revenue Pounds Transported Freight X237 | N | 1 | 7D |
| 46 | Non-revenue Pounds Transported X250 | N | 1 | 6D |
| 47 | Non-revenue Passengers Enplaned X120 | N | 1 | 5D |
| 48 | Revenue Passengers Enplaned First Class X111 | N | 1 | 5D |
| 49 | Revenue Passengers Enplaned Coach. This total includes all non-first class revenue passengers X112 | N | 1 | 5D |
| 50 | Revenue Cargo Pounds Enplaned U.S. Mail Priority X213 | N | 1 | 6D |
| 51 | Revenue Cargo Pounds Enplaned U.S. Mail Non-priority X214 | N | 1 | 6D |
| 52 | Revenue Cargo Pounds Enplaned Foreign Mail X215 | N | 1 | 6D |

TABLE 5.3-1. (Cont'd.)

| Field # | Field Name | Data Type | No. of Words | Data Bounds |
|---|---|---|---|---|
| 53 | Revenue Cargo Pounds Enplaned Express X216 | N | 1 | 7D |
| 54 | Revenue Cargo Pounds Enplaned - Freight X217 | N | 1 | 7D |
| 55 | City Name 1 | A/N | 5 | 5A4 |
| 56 | City Name 2 | A/N | 5 | 5A4 |
| 57 | Error Indicators | A | 6 | 24A1 |
| Word # | The following eight fields constitute a repeating segment. They must appear at least once in each record, and may appear as many as 10 times. | | | |
| 71,79, | First Down Line Airport Same as Destination Point of Segment | A | 1 | A3 |
| 72,80, | Revenue Passenger Deplaning First Class | N | 1 | 5D |
| 73,81, | Revenue Passenger Deplaning Coach | N | 1 | 5D |
| 74,82, | Revenue Cargo Pounds Deplaning U.S. Mail Priority | N | 1 | 6D |
| 75,83, | Revenue Cargo Pounds Deplaning U.S. Mail Non-priority | N | 1 | 6D |
| 76,84, | Revenue Cargo Pounds Deplaning Foreign Mail | N | 1 | 6D |
| 77,85, | Revenue Cargo Pounds Deplaning Express | N | 1 | 6D |
| 78,86, | Revenue Cargo Pounds Deplaning Freight | N | 1 | 7D |

Note: Record length = 70 + 8 times the number of downlines.
Minimum record = 78 words.
Maximum record = 150 words.
Average record = 86 words.
Minimum characters = 324 per record
Average characters = 368 per record

TABLE 5.3-1. (Cont'd.)

NOTES

| Field Name | Field Description |
|---|---|
| Base Reference Code | Contains a value "B" or "R" indicating whether the first airport in the record is the segment origin or destination, respectively. |
| City Code | Five digit code which corresponds to the alphabetic name spelling of the city. |
| Airport Designator | Differentiates between airports of multiple airport city. |
| World Area Code | Three digit code which specifies in what particular area of world a city is located; 0xx represents the United States. |
| Alpha Airport Code | Standard three letter airport code. |
| Reporting Segment Count | A count of the number of repeating segments occurring in this record; inserted during processing. |
| Number of Downline Points | Number of stops after this origin. |
| Service Class | A = First class only<br>C = Coach only<br>E = Mixed first class and coach<br>G = Cargo only |
| Cabin Configuration Code | 1 = Passenger only<br>2 = Cargo only<br>3 = Passenger-cargo combined |
| Subsidy Elig-Inelig Code | Space = eligible*<br>1 = ineligible<br>2 = partly eligible |
| Error Indicators | Twenty-four one-character error fields. |

*In 1974 ALPHA characters were used.

a portion of the Air Traffic System, collects operational data at Kennedy, Newark, and LaGuardia airports. All flight activity at these airports is recorded on controller strips by the FAA Tower personnel and transmitted daily by Teletype machines to the computer facility at Aeronautical Radio, Inc. (ARINC). The content of the data reported is as follows: Each record constitutes an aircraft operation, either arrival or departure, indicating the date, time, and type of operation, the airline, flight number, aircraft type, major traffic component (air carrier, air taxi, general aviation, military), existing weather conditions, ceiling visibility, speed, sky cover, and runway used. Preliminary processing and editing of the data is accomplished at ARINC, and daily reports, such as hourly runway activity, daily comments and hourly weather remarks, are delivered directly to the FAA. At the end of each month, a master tape of accumulated daily data is created. It is a copy of these tapes from which the data required by the validation was extracted.

ARINC has been collecting these data since 1970, and all monthly tapes are made available from the FAA Data Systems Division, AMS-630. A complete record format is shown in Figure 5.3-1, and an element description in Table 5.3-2.

## 5.4 DATA SOURCES FOR AIRSIDE MODEL PARAMETERS

The data sources for the Airside Model are described in Section 3. AIRSIDE MODELS. These include the gate as well as capacity and demand data sources.

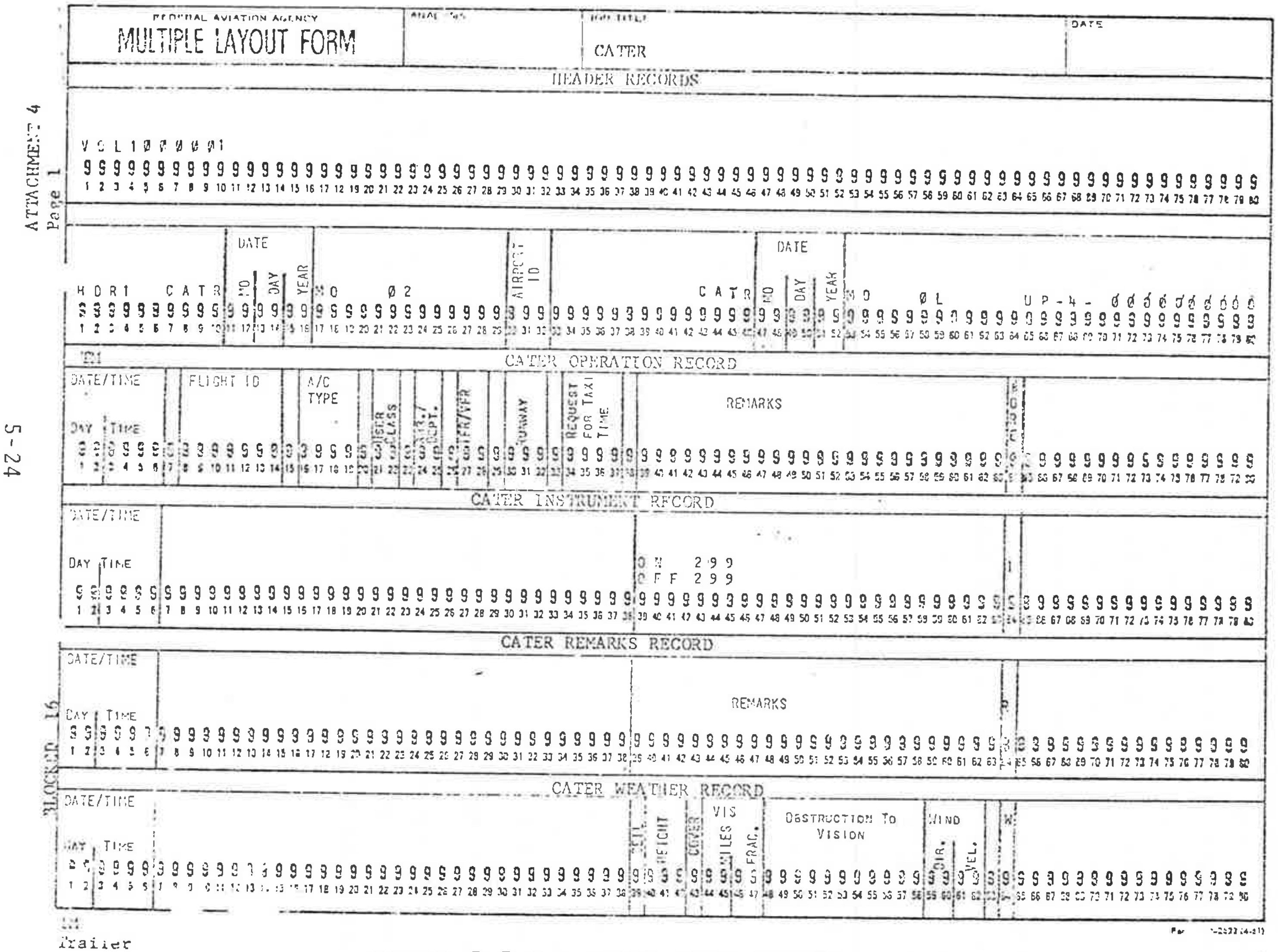


FIGURE 5.3-1. CATER DATA FORMAT

## TABLE 5.3-2. CATER DATA ELEMENT DESCRIPTION

### HEADER RECORD DATA

1. Date - 6 numeric characters representing the last day of the data month - MMDDYY.

2. Airport ID - Three alpha characters identifying the airport where data was collected.

   Possible Values:

   JFK - Eastern Time Zone
   EWR - Eastern Time Zone
   LGA - Eastern Time Zone
   DCA - Eastern Time Zone
   ORD - Central Time Zone
   Blank (JFK) - Eastern Time Zone

### OPERATIONAL RECORD DATA

1. Date/Time

   A. Day - Numeric day of month.
   B. Time - Greenwich (GMT) time recorded in 2400 hour notation.

2. Flight ID - Identification of arriving and departing flights, left justified. Example: AA123, N1234, NYA23, etc,

3. A/C Type - Arriving/Departing aircraft type designation, left justified. Example B707, PA12, etc.

4. User Class

   A. First Position

      A - Aircarrier.
      S - Scheduled air taxi.
      G - General Aviation.
      M - Military

   B. Second Position

      H - Helicopter.
      Blank - Fixed Wing

TABLE 5.3-2. (Cont'd.)

5. ARR/DEPT.

   A. First Position

      A - Arrival.
      D - Departure.

   B. Second Position
      L - Low Approach.
      M - Missed Approached.
      T - Touch + Go.
      G - Go Around.
      C - Gear Check.

6. IFR/VFR

   A. First Position
      I - IFR (Instrument Flight Rule).
      V - VFR (visual Flight Rule).

   B. Second Position
      L - Local Operation
      Blank - Itinerant Operation

7. Runway - Runway Identification, left justified. Example: 26R, 80L, 24, etc.

8. Request for Taxi Time - GMT that a departing flight requests taxi clearance.

9. Remarks - Free format remarks about a specific flight.

10. E or ƀ

    A. ƀ (Blank) indicates an operational record.

    B. E indicates an error record was generated and this record, with duplicate coding, is to cancel it out.

INSTRUMENT RECORD

Format as indicated. This record is to indicate when weather conditions dictate use of instrument approach procedures or release from instrument approach procedures. I in position 64 is the record identifier.

TABLE 5.3-2. (Cont'd.)

REMARKS RECORDS

Free format remarks about airport conditions. R in position 64 is the record identifier.

WEATHER RECORD

1. DATE/TIME - Same as operational record.
2. Ceil - Method of obtaining ceiling height.
   - A - Aircraft
   - B - Balloon
   - E - Estimated.
   - M - Measured.
   - R - Radar
   - W - Indefinite.

3. Height - Ceiling height in hundreds of feet.
   - 100 - 10000 Feet
   - 10 - 1000 Feet
   - 1 - 100 Feet

4. Cover- Sky cover.
   - C - Clear
   - S - Scattered
   - B - Broken
   - O - Overcast
   - X - Obscuration

5. VIS - Prevailing Visibility.
   - Miles - Whole Miles
     - 10 - 10 Miles
     - 1 - 1 Mile

   - Frac. - Fractions of Miles (in sixteenths)
     - 10 - 10/16 mile
     - 1 - 1/16 mile

6. Obstruction to Vision - Series of codes which describe any combination of obstruction to vision.
   Example: A - Hail
   BD - Blowing Dust etc.

7. Wind
   - A. DIR. - Direction of wind in tens of degrees.

     Example: 10 - 100 Degrees
     1 - 10 Degrees

TABLE 5.3-2. (Cont'd.)

B. VEL. - Velocity in knots.

Example: 10 - 10 knots.
 1 - 1 knot.

8. W. Weather Record Identifier

## 5.5 DATA SOURCES FOR GROUNDSIDE MODEL PARAMETERS

This section documents the source of data used internally in the groundside models of the airport performance model. The documentation will follow the order of presentation used in Section 4., Groundside Models. The hourly estimate of passenger enplanements and deplanements is the driving force in most groundside capacity calculations. The estimates of these activity levels were taken by altering the number of hourly aircraft arrivals and departures (as input to the model from the airside data base) to terms involving passengers. The aircraft fleet mix, seating capacity, load factor at the airport and a correction for the number of transient, continuing or through passengers are used in developing enplanement and deplanement estimates from aircraft movement data. Aircraft seating capacity data by aircraft type were developed by weighting the seating capacity of aircraft types within the fleet mix categories used here by the number of the aircraft reported to be in U.S. domestic service as of 1975. The aircraft capacities by fleet mix type are developed in Section 3.6, and the results of this analysis are presented in Table 5.5-1 below.

Load factors at the 31 airports treated by this study were taken from the Congressional Airport Congestion Study (reference 5.5-1) when possible and assumed to be 50% for airports for which no data were available. Data are presented in Section 3.

The percentage of all air passengers who will arrive and depart from the airport on the same aircraft are referred to as continuing, transient or through passengers. The groundside model developed in this study assumes that these passengers will not influence groundside access or terminal passenger handling system use. The total passenger volume is adjusted for this assumption in treating system requirements. The

TABLE 5.5-1 AIRCRAFT SEATING CAPACITY BY CLASS

| FLEET MIX TYPE | SEATING CAPACITY |
|---|---|
| H4W HEAVY A-ENGINE WIDE BODY | 346. |
| H3 HEAVY 3 ENGINE JET | 299.0 |
| H4S HEAVY 4 ENGINE STANDARD & STRETCHED | 157.4 |
| L3 LARGE 3 ENGINE JET | 115.7 |
| L2 LARGE 2 ENGINE JET | 101.1 |
| LP LARGE PROPELLER | 49.3 |
| S,O SMALL, OTHER* | 6.0 |

*SMALL AND OTHER AIRCRAFT CATEGORIES ARE ASSUMED TO CARRY 3.0 PASSENGERS ON THE AVERAGE (SEE SECTION 3.6) AN AVERAGE SEATING CAPACITY OF 6.0 ASSUMES A 50% LOAD FACTOR FOR THOSE AIRCRAFT CATEGORIES.

percentage of all passengers flying into each of the 31 airports treated who are continuing passengers was estimated by analyzing the CAB 586 Service Regiment records for the second quarter of 1974. The results of this analysis are presented in Table 5.5-2 below.

Given the enplanements and deplanements at the airports, the loads on airport facilities can be evaluated. It should be noted that connecting or transferring passengers will not place loads on a subset of airport terminal and access facilities , and it is appropriate to delete these passengers from airport facility use estimates in specific instances. Estimates of the percentage of airport passenger enplanements at selected airports who transfer planes prior to enplaning were obtained by comparing data banks 1 and 13 of the <u>CAB Origin-Destination Survey of Airline Passenger Traffic</u> domestic edition for the second quarter of 1974, and are presented in Table 5.5-3.

The access mode of passengers traveling to and from airports has a direct impact on the volume of activity faced by different components of the airport system. Eight different categories of access modes have been identified by this study as having in some way a unique pattern of impacts on different airport components. The different modes of access and egress are presented in Table 5.5-4. The National Transportation Study of 1974 provides data for characteristic use patterns for a number of these modes at a number of airports, and data for other airports was taken from a recent DOT study (reference 5.5-4). The available airport and data are presented in Table 5.5-5. To develop data in the format described by Table 5.5-4, a series of assumptions were made about the composition of the modes split categories shown in 5.5.5. It was assumed that Taxi/Limo passengers be evenly divided between the two separate

TABLE 5.5-2 CONTINUING PASSENGERS AT SELECTED U.S. AIRPORTS

| AIRPORT CODE | CONTINUING PASSENGERS (%) | AIRPORT CODE | CONTINUING PASSENGERS (%) |
|---|---|---|---|
| ATL | 4 | LAS | 9 |
| BAL | 13 | LAX | 7 |
| BOS | 4 | LGA | 2 |
| CLE | 8 | MIA | 2 |
| CLT | 13 | MKE | 17 |
| DFW | 10 | MSP | 5 |
| DCA | 6 | MSY | 12 |
| DEN | 8 | ORD | 4 |
| DTW | 7 | PHL | 9 |
| EWR | 3 | PIT | 12 |
| FLL | 3 | SEA | 8 |
| HNL | 5 | SFO | 4 |
| IAD | 15 | SLC | 10 |
| IAH | 11 | STL | 11 |
| JAX | 18 | TPA | 14 |
| JFK | 3 | | |

Source: Analysis of U.S. CAB Service Segment Data For 2nd Quarter, 1974.

TABLE 5.5-3 TRANSFERRING PASSENGERS AT SELECTED U.S. AIRPORT HUBS

| AIRPORT CODE | TRANSFERRING PASSENGERS (%) | AIRPORT CODE | TRANSFERRING PASSENGERS (%) |
|---|---|---|---|
| ATL | 72 | LAS | 18 |
| BAL | 8 | LAX | 22 |
| BOS | 9 | LGA | 18 |
| CLE | 26 | MIA | 5 |
| CLT | 39 | MKE | 19 |
| DFW | 54 | MSP | 26 |
| DCA | 40 | MSY | 25 |
| DEN | 46 | ORD | 46 |
| DTW | 15 | PHL | 15 |
| EWR | 18 | PIT | 42 |
| FLL | 2 | SEA | 19 |
| HNL | 31 | SFO | 22 |
| IAD | 40 | SLC | 31 |
| IAH | 17 | STL | 38 |
| JAX | 16 | TPA | 18 |
| JFK | 18 | | |

Source: Analysis of Tables 1 and 13 of CAB Origin-Destination Survey of Airline Passenger Traffic, second quarter, 1974.

TABLE 5.5-4 AIRPORT ACCESS/EGRESS MODES DEFINED FOR USE IN THE AIRPORT PERFORMANCE MODEL

1. Auto - Parked by passenger at airport (long term)
2. Auto - Passenger dropped off/picked up at curb, no parking at the airport
3. Auto - Passenger dropped off/picked up at curb, greeters/well-wishers use short-term parking at airport
4. Taxi
5. Bus
6. Limo
7. Rental Car
8. Other non-highway modes.

## TABLE 5.5-5. AIRPORT ACCESS/EGRESS CHARACTERISTICS[1]

| AIRPORT CODE | ACCESS MODE (%) | | | | | AIRPORT CODE | ACCESS MODE (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUTO | TAXI/LIMO | BUS | RAIL | OTHER | | AUTO | TAXI/LIMO | BUS | RAIL | OTHER |
| ATL | 88 | 9 | 3 | - | - | LAS | 51 | 36 | 13 | - | - |
| BAL* | 78 | 21 | 1 | - | - | LAX | 78 | 14 | 8 | - | - |
| BOS | 67 | 19 | 4 | 7 | 3 | LGA | 36 | 51 | 12 | - | 1 |
| CLE | 53 | 18 | - | 19 | 10 | MIA | 68 | 27 | 5 | - | - |
| CLT* | 80 | 20 | - | - | - | MKE* | 76 | 23 | 1 | - | - |
| DFW | 85 | 14 | 1 | - | - | MSP | 74 | 25 | 1 | - | - |
| DCA* | 78 | 16 | 2 | - | - | MSY | 68 | 29 | 2 | - | 1 |
| DEN | 86 | 6 | 7 | - | - | ORD | 50 | 22 | 20 | - | 8 |
| DTW | 83 | 14 | 2 | - | 1 | PHL | 63 | 26 | 11 | - | - |
| EWR | 68 | 18 | 13 | - | 1 | PIT | 86 | 13 | 1 | - | - |
| FLL | 85 | 15 | - | - | - | SEA | 85 | 9 | 6 | - | - |
| HNL | 69 | 29 | 2 | - | - | SFO | 72 | 16 | 12 | - | - |
| IAD* | 85 | 14 | 1 | - | - | SLC* | 79 | 20 | 1 | - | - |
| IAH | 79 | 14 | 7 | - | - | STL | 74 | 12 | 9 | - | 5 |
| JAX* | 83 | 16 | 1 | - | - | TPA* | 78 | 21 | 1 | - | - |
| JFK | 48 | 36 | 12 | - | 1 | | | | | | |

(1) Data taken from 1974 National Transportation Study unless marked by asterisk(*).

* Data taken from Ellis, W.W., N.C. Booker and I.S. Feldstein, Forecasts of Landside Airport Acess Traffic at Major U.S. Airports to 1990 prepared for U.S. Department of Transportation, Federal Aviation Administration, Washington D.C., Feb. 1976. Data listed as "most reasonable" for 1973 were used.

modes. For the sake of the Airport Performance Model groundside component, "rail" and "other" from Table 5.5-5 were combined into the single "other" category in Table 5.5-4. The single category "auto" in table 5.5-5 is therefore comprised of categories 1, 2, 3, and 7 in Table 5.5-4. It was assumed that 70% of the auto category derived by the National Transportation Study would be allocated to category 1 of Table 5.5-4, and the remaining 30% be allocated evenly to categories 2, 3 and 7. While this allocation is somewhat arbitrary, it is consistent with the general findings of other airport access studies.

The airport visitors greeting arriving passengers or bidding farewell to departing passengers place loads on terminal facilities. The number of airport visitors per air passenger varies considerably, but empirical studies have found correlations between this statistic and the ground transportation mode used by air passengers. Passengers moving to and from the airport by auto tend to generate a larger number of airport visitors than do passengers using taxis and other public transport modes. Average airport visitor per air passenger statistics, shown in Table 5.5-6 have been generated using previously developed survey results and certain simplifying assumptions.

The activities scheduled to take place at an airport at a given hour affect related airport activities at other hours. This phenomenon is reflected in certain relationships in the Airport Performance Model. For example, short-term parking slots required at a given hour are influenced by arrivals and departures for a range of hours based on early arrivals and delayed departures from the airport. Table 5.5-7 shows patterns of early arrivals prior to departure at selected airports. The distribution pattern developed for the Metroport

TABLE 5.5-6 AIRPORT VISITORS PER AIR PASSENGER

| AIRPORT ACCESS/ EGRESS MODE | FOR ENPLANING PASSENGERS | FOR DEPLANING PASSENGERS |
|---|---|---|
| 1. Auto - Long-term parking | 0.96 | 1.03 |
| 2. Auto - Passenger dropped off or picked up, no parking involved | 2.10 | 2.06 |
| 3. Auto - Passenger dropped off or picked up short-term parking | 2.10 | 2.06 |
| 4. Taxi | 0.0 | 0.0 |
| 5. Bus | 0.29 | 0.14 |
| 6. Limo | 0.29 | 0.14 |
| 7. Rental Car | 0.0 | 0.0 |
| 8. Other, Non-Highway Mode | 0.29 | 0.14 |

Source: Based on analysis of tabulated data in Washington-Baltimore Airport Access Study, Abt Associates, May 1968. Assumptions made about certain modes.

TABLE 5.5-7 PREFLIGHT AIRPORT ARRIVAL TIME DISTRIBUTIONS (IN MINUTES)

| CUMULATIVE PERCENT OF PASSENGERS ARRIVING BEFORE TIME GIVEN | AIRPORT | | | |
|---|---|---|---|---|
| | BOSTON LOGAN | LONDON HEATHROW(1) | METROPORT (2) | AT LOUNGES (3) |
| .1 | 103 | 75 | 64 | 38 |
| .2 | 85 | 64 | 55 | 32 |
| .3 | 78 | 59 | 50 | 27 |
| .4 | 73 | 57 | 42 | 24 |
| .5 | 66 | 52 | 40 | 22 |
| .6 | 60 | 48 | 38 | 20 |
| .7 | 57 | 43 | 37 | 18 |
| .8 | 45 | 39 | 33 | 17 |
| .9 | 35 | 23 | 20 | 12 |

Source:


(1) A.M. Lee, Applied Queuing Theory (New York: Macmillan, 1968).

(2) W.R. Lange, "The Design and Operation of VTOL Metroports" (unpublished Thesis, M.I.T. Department of Aeronautics and Astronautics, June, 1970).

(3) R. Horonjeff and J. Paulin, ASCE Proc., Vol. 95, Transportation Engineering Journal, No. TE 2 paper 6537, May 1969, pp 267-277.

simulation (shown as column 3 in the table) was used in developing short-term parking requirements.

The number of passengers per airport access vehicle was used to translate passenger and airport visitor statistics into units of vehicles. Mean values were used in this transformation, and values used for this approximation were taken from different airport access and urban transportation studies. Values used in the Airport Performance Model for vehicle loading characteristics appear in Table 5.5-8.

Employee travel to the airport must be considered in access system considerations. It is assumed that employees have an access pattern in which 90% of all workers travel to the airport by private auto and 10% use transit. Average vehicle loading of 1.1 persons per auto is also assumed to be in effect. It is further assumed in the pattern of airport arrivals and departures follows the distribution outlined in Table 5.5-9. These findings conform to a comparative study of travel patterns at U.S. airports.

When the total number of airport employees is not known, the Airport Performance model estimates this quantity based on employment trends at other U.S. Airports. Data used to develop this relationship are shown in Table 5.5-10. The relationship used to estimate employment levels is based on the level of annual enplaned passengers at the airport, and was estimated by ordinary least squares regression techniques.

Curb-side parking requirements are dependent on the duration of stay at the curb and length of curb space. The values used in the Airport Performance for curb dwell time are supported in several cases by actual studies of passenger vehicle dwell time at U.S. airport terminals. It was assumed that average dwell time for taxis, buses and limos would be 2, 4, and 5 minutes respectively. Passenger car dwell times

TABLE 5.5-8 AIRPORT ACCESS VEHICLE LOADING CHARACTERISTICS USED IN AIRPORT PERFORMANCE MODEL

| AIRPORT ACCESS/ EGRESS MODE | FOR ENPLANING PASSENGERS | FOR DEPLANING PASSENGERS |
|---|---|---|
| 1. Auto - Long-term Park | 1.79 | 1.79 |
| 2. Auto - Passenger dropped off or picked up, no parking involved | 2.5 | 2.3 |
| 3. Auto - Passenger dropped off or picked up, short-term parking | 2.5 | 2.3 |
| 4. Taxi | 1.4 | 1.5 |
| 5. Bus | 20.0 | 20.0 |
| 6. Limo | 7.0 | 8.0 |
| 7. Rental Car | 1.79 | 1.4 |

Source: Port of New York Authority (now Port Authority of New York and New Jersey) Domestic Inflight Survey 1967-1968; Simpson and Curtim Ground Access to Philadelphia International Airport - Now to 1992, 1968; and other sources.

TABLE 5.5-9 HOURLY DISTRIBUTION OF EMPLOYEE TRAVEL TO AND FROM AIRPORTS (%)

| HOUR ENDING | INBOUND EMPLOYEES | OUTBOUND EMPLOYEES |
|---|---|---|
| 1 AM | 0 | 3 |
| 2 | 0 | 1 |
| 3 | 0 | 1 |
| 4 | 1 | 1 |
| 5 | 1 | 0 |
| 6 | 6 | 1 |
| 7 | 28 | 1 |
| 8 | 14 | 5 |
| 9 | 4 | 2 |
| 10 | 3 | 3 |
| 11 | 3 | 3 |
| 12 NOON | 1 | 4 |
| 1 PM | 4 | 2 |
| 2 | 6 | 1 |
| 3 | 9 | 3 |
| 4 | 3 | 7 |
| 5 | 1 | 25 |
| 6 | 1 | 7 |
| 7 | 2 | 5 |
| 8 | 2 | 4 |
| 9 | 2 | 4 |
| 10 | 3 | 4 |
| 11 | 5 | 5 |
| 12 MIDNIGHT | 1 | 8 |
| TOTAL | 100 | 100 |

Source: Keefer, L.E. Urban Travel Patterns for Airports Shopping Centers, and Industrial Plants (National Cooperative Highway Research Program Report No. 24) Figure 4, p. 13.

TABLE 5.5-10 AIRPORT EMPLOYMENT AT SELECTED U.S. AIRPORTS

| AIRPORT CODE | EMPLOYMENT ($x10^3$) | ANNUAL ENPLANEMENTS ($x10^6$) |
|---|---|---|
| BOS | 10.2 | 4.78 |
| CLE | 4.0 | 2.74 |
| DCA | 8.5 | 5.6 |
| DTW | 6.0 | 3.69 |
| CVG | 1.7 | 1.34 |
| DAL | 14.0 | 7.0 |
| EWR | 6.0 | 3.41 |
| LGA | 8.61 | 7.01 |
| ONT | 3.35 | 0.51 |
| STL | 2.5 | 3.07 |

Employment = 1920 + 0.0012 99 (Annual Enplanements)
[3.884]

$R^2$ =0.659

t - statistic indicates the regression coefficient is significant at the .01 level

DATA SOURCE: R.M. Parsons Company, The Apron and Terminal Building Planning Manual, Washington D.C., 1975.

were assumed to be 3.72 minutes on the average.[1] Curb lengths were assumed to be 18 feet for private autos and taxis, 25 feet for limosines and 45 feet for buses.

Highway capacity requirements were based on required vehicle flows and vehicle capcity per lane hour. Limosines were assumed to be equivalent to 1.5 passenger cars and buses were assumed equivalent to 2.5 passenger cars in highway flow characteristics. Lane capacity was assumed to be 1800 vehicles per lane hour.[2]

A peaking factor of 1.5 was applied to calculations of highway and curb space requirements. This is equivalent to the assumption that one half of the activity in an hour will take place in the peak 20 minutes of that hour.

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[1]This is the mean of a distribution developed by an undergraduate research project S. Peck "Airport Passenger Flow - Curb Study" prepared for seminar 166, M.I.T. Department of Aeronautics and Astronautics.

[2]This is consistent with data reported in Highway Capacity Manual, 1965 Highway Research Board Special Report 87, pp. 22-29.

## 5.6 METHOD OF REVISING AIRPORT DATA FILES

### 5.6.1 Introduction

When the problem of revising the current data base, derived from 1972-1973 OAG, Tower, and Weather data, is adressed, two different aspects must be considered:

- ° Expansion of the data base to include 1972-1973 data for a "new" airport not currently modelled in the system
- ° Update of the data base by regenerating the airport files from more recent years of data

The following two sections will address these topics, and outline briefly the procedures required to obtain the desired revisions.

### 5.6.2 Expanding Airport Files

Expansion of the data base to include data for an airport not currently in the model for the years 1972-1973, requires no new acquisition of OAG data or Tower data. Both of these data bases which TSC acquired and converted for use on the TSC PDP-10 at the start of the project have data for all FAA towered airports servicing scheduled air carriers. The data for the new airport must only be extracted from the four monthly tapes initially utilized. Ceiling and visibility tapes data for the desired airport must then be obtained from the National Climatic Center and converted for use in TSC inhouse computer. Upon completion of minor program modifications, the programs can be run on the new data, which separate the days into IFR/VFR categories, generate the daily demand profiles, perform the clustering, average the profiles for the clusters, and create the daily and annalization files. A detailed description of program modifications required for this revision is fully documented in the Report "Composite Traffic Volume

Profiles for the Airport Performance Model - KHL-TSC-76-1406 - Section 7."

### 5.6.3 Updating Airport Files

Updating the data base for the purpose of creating the airport files from more recent data will be more costly than the expansion process as described above. All primary data sources, - OAG, Tower, and Weather data - will have to be acquired for the new year and converted for use on the TSC Computer. The data for the airports will then be extracted, computer programs modified, and run on the new data. The process for update and program modifications are documented in the report "Composite Traffic Volume Profiles, Section 7."

An update might be required if, at any time, more recent data is deemed to be more representative of future demand at the airports. It should also be noted that all months of OAG data for 1974 through the present are available at TSC, if processing a full year's worth of data is desired in place of only four months for 1973 initially input to the model.

## REFERENCES


5.2-1. Department of Commerce, National Oceanic and Atmospheric Administration, TDF-14, Surface Observations, October, 1975.

5.3-1. Department of Transportation, Hourly Airborne Delay at EWR, JFK, and LGA, Report No. KHL-TSC-76-1399, April, 1976.

5.5-1. "Congressional Airport Congestion Study" prepared by the Bureau of Economics and the Bureau of Operating Rights, supported by the Automated Information System Division of the Bureau of Accounts and Statistics, as requested by the Committee on Appropriation of the House of Representatives issued December, 1970.

5.5-2. Highway Capacity Manual, 1965 Highway Research Board Special Report 87, National Academy of Sciences, National Research Council, Washington D.C. 1965.

5.5-3. Keefer, L.E. "Urban Travel Patterns for Airports, Shopping Centers and Industrial Plants" (National Cooperative Highway Research Program Report No. 24) National Research Council National Academy of Sciences-National Academy of Engineering, 1966.

5.5-4. Ellis, W.W., M.C. Bodier and I.S. Feldstein, "Forecast of Landside Airport Access Traffic at Major U.S. Airports of 1990", prepared for the U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C. February, 1976.

5.5-5. Rusioni Clerici, I. Aren't Airport Planners Forgetting About Transfers (unpublished M.S. Thesis, M.I.T. Department of Civil Engineering) January 1976.

5.5-6. Lange, W.R., The Design and Operation of VTOL Metroports (unpublished Engineer's Thesis M.I.T. Department of Aeronautics and Astronautics) June 1970.

5.5-7. Parsons, R.M. and Company, The Apron and Terminal Building Planning Manual (prepared for the U.S. Department of Transportation, Federal Aviation Administration) Washington, D.C. July 1975.

5.5-8. Fay, D.R., An Evaluation of Alternative Terminal Designs for Airports (unpublished M.S. Thesis M.I.T. Department of Civil Engineering) 1971.

REFERENCES (CONTINUED)

5.5-9. "Public Transportation to Airports," Highway Research Record Number 330 Highway Research Board, National Research Council National Academy of Sciences, - National Academy of Engineering, Washington D.C. 1970.

5.5-10. "Airport Landside Capacity," Special Report 159, Transportation Research Board National Research Council, National Academy of Sciences, Washington D.C. 1975.

5.6-1. See Volume II.

# 6. ANNUALIZATION PROCESSES

## 6.1 SUMMARY

Annual delay is simply the total delay which occurs over the 365 days of a typical year at an airport. In order to use the daily delay model to calculate annual delay, but to run it less than 365 times, a smaller number of typical days in terms of variables affecting delay is required. The process of analysis and reduction of up to two years of data to produce a maximum of 54 typical days is called annualization.

The annualization process concentrates on the five variables below:

1. Arrival and departure patterns (profiles)
2. Volume of operations
3. Aircraft mix
4. Arrival to departure ratio
5. Weather patterns (profiles)

Historical observations of the variables are obtained for the years 1972 and 1973 from the OAG, NCC weather, FAA tower, and CATER tapes.

The annualization process begins with the production of three typical scheduled daily arrival and departure profiles for a year using the statistical method of hierarchical clustering. The number of days of a year represented by each profile is determined and retained. Typical arrival to departure ratios and aircraft mixes are associated with the typical arrival and departure profiles.

Next the weather tapes are used to determine which days of the two-year period were predominantly VFR and which were IFR. By comparing the tower tapes with the weather tapes, the volumes from the tower tapes are then divided into two groups, one for VFR days, the other for IFR days. For each group of volumes, nine typical pairs of daily volumes of scheduled operations and non-scheduled operations are determined along with their probability of occurrence throughout the year. In addition, information from the tower tapes is used, in part, to develop estimates for the non-scheduled aircraft mixes.

The CATER tapes provide a non-scheduled daily activity pattern by the half-hour for each of the three New York airports. The average of these is used to represent non-scheduled activity at all 31 airports.

To form the typical days for an airport, the three typical scheduled daily arrival and departure profiles, the two weather types, the non-scheduled daily activity pattern, and the nine typical volume pairs, are joined to produce every possible combination or 3 x 2 x 1 x 9 = 54 typical days. The frequency of occurrence of each of the profiles, weather types, and volume pairs is used to determine how many days each typical day represents. Thus, an airport's characteristics over an entire year can be represented by only 54 typical days.

## 6.2 ASSUMPTIONS

In order to proceed with the annualization process, some broad assumptions about the nature of the data are necessary.

1. It must be assumed that the years for which the data was chosen, 1972 and 1973, are representative years for airport characteristics. The assumption is reasonable in that these years were a period of high airport activity similar to the present and do not exhibit the effects of the oil embargo which occurred in late 1973.

2. The assumption that scheduled and non-scheduled patterns of operations are independent of weather is necessary in order to derive multiplicatively the combinations of typical scheduled daily arrival and departure profiles with weather profiles. Patterns of operations should not be confused here with actual volumes of operations, since the

latter depend heavily on weather conditions. In simpler terms, this assumption means that the shape of the distribution of operations throughout a day remains the same regardless of the weather conditions. Peak hours and lulls will occur at the same times in both good and poor conditions.

3. Since many of the statistical techniques employed in the annualization process involve averaging, it must be assumed in most cases that the delay resulting from an average or typical day equals the average of the delays for individual days.

## 6.3 OAG PROCESSING

The purpose of the OAG tapes is to provide the model with typical scheduled air traffic characteristics including the shape of the distributions of arrivals and departures over the day, and the aircraft mix. The analysis of the scheduled characteristics is based on only the four months of available data for each year, February, May, August and September, one month from each season.

The first step in the processing is the creation of scheduled daily arrival and departure profiles for each day of the 8 available months. The scheduled daily arrival profile consists of 1440 observations, one for each minute of the day. An observation represents the fraction of the day's total operations which are arrivals occurring in that minute. The scheduled daily departure profile has an analogous definition. The arrival and departure profiles are combined to form a daily profile, each observation of which represents the fraction of the day's total operations occurring in that minute.

The OAG tapes are used to calculate four other statistics on a daily basis:

1. The hourly arrival to departure ratio is the number of arrivals occurring during an hour divided by the number of departures occurring in the same hour.

2. Eight categories of aircraft mix are calculated.

3. The daily peaking factor is defined to be half of the greatest number of operations occurring in any 120 consecutive minutes of the day.

4. Hourly concentration is the percent of the hour's operations occurring in the busiest 4 minutes of the hour, not necessarily consecutive minutes.

The creation of typical daily profiles requires that groups of individual profiles with similar shapes be formed. A statistical technique that can be used when comparing the shapes of a large number of distributions is called hierarchical clustering or hierarchical cluster analysis[1]. The cluster algorithm computes the distance[2] between every possible pair of distributions. It joins the two (or more) distributions with the smallest distance between them into a group, averages the two distributions, and using the average, recalculates the distances between the average and every other distribution. A new group may be formed or the first group may be expanded at this point. The algorithm continues until all the distributions form one large group. The printed output from the clustering program used for this project consists of a tree or dendogram which enables the progressive formation of the groups or clusters to be observed. By examining the output at the point where three clusters exist, for example, it is possible to determine which individual distributions are contained in each cluster. The clusters have the property that any distribution within a cluster is more similar to other distributions in that cluster than it is similar to distributions in other clusters.

In the case of the clustering of the eight months of daily profiles, it was necessary to make several decisions regarding the details of clustering before the actual computer processing

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[1] Theodore S. Glickman and Michael A. Grossman, "Hierarchical Clustering Applied to Commodity Flow Census Data", U.S. DOT/TSC, material on file, 1975.

[2] In this application of clustering the particular distance measure used is Euclidean distance, to be discussed later.

could begin. First, it was decided to collapse the minute-by-minute daily profiles into 15-minute segments for clustering purposes only. The excessive detail or "noise" caused by the minute-by-minute observations might obscure general similarities among the profiles. Also, the smaller length of the collapsed daily profiles would save on computer costs. Second, it was decided to use daily profiles which were based on both arrivals and departures in the cluster analysis, rather than clustering arrivals separately from departures. This procedure would eliminate the possibility of complications resulting in later processing if separate arrival clusters and departure clusters did not contain the same days. Figure 6-1, a graph of the daily profile for Chicago for January 25, 1975, is a sample of a daily profile as it is used in the cluster analysis. Third, Euclidean distance was chosen as the measure for similarity between the shape of two distributions. If the 15 minute observations for daily profile 1 are $x_i$, $i=1,...,96$, and for daily profile 2 are $y_i$, $i=1,...,96$, then Euclidean distance is defined as $\sqrt{\sum_{i=1}^{96} (x_i-y_i)^2}$. This measure is the most commonly used measure for distances between distributions in the literature on cluster analysis.

Because cluster analysis has never been used on OAG daily profiles before, some preliminary investigations were performed on daily profiles to determine the effects of clustering and to answer some questions on the nature of the OAG schedules.

Initially, an experiment was conducted to observe the effects on the clusters of normalizing the daily profiles. As explained earlier, the daily profiles are composed of observations which are the fraction of the day's operations occurring in each time segment. These profiles are called normalized profiles. Un-normalized profiles are composed of the actual number of operations occurring in each time segment. Clustering was performed on the same months of data using both normalized and un-normalized daily profiles for January, February and March of 1975 for five different airports, Chicago, Boston, Cleveland, Miami and Seattle, and the results were

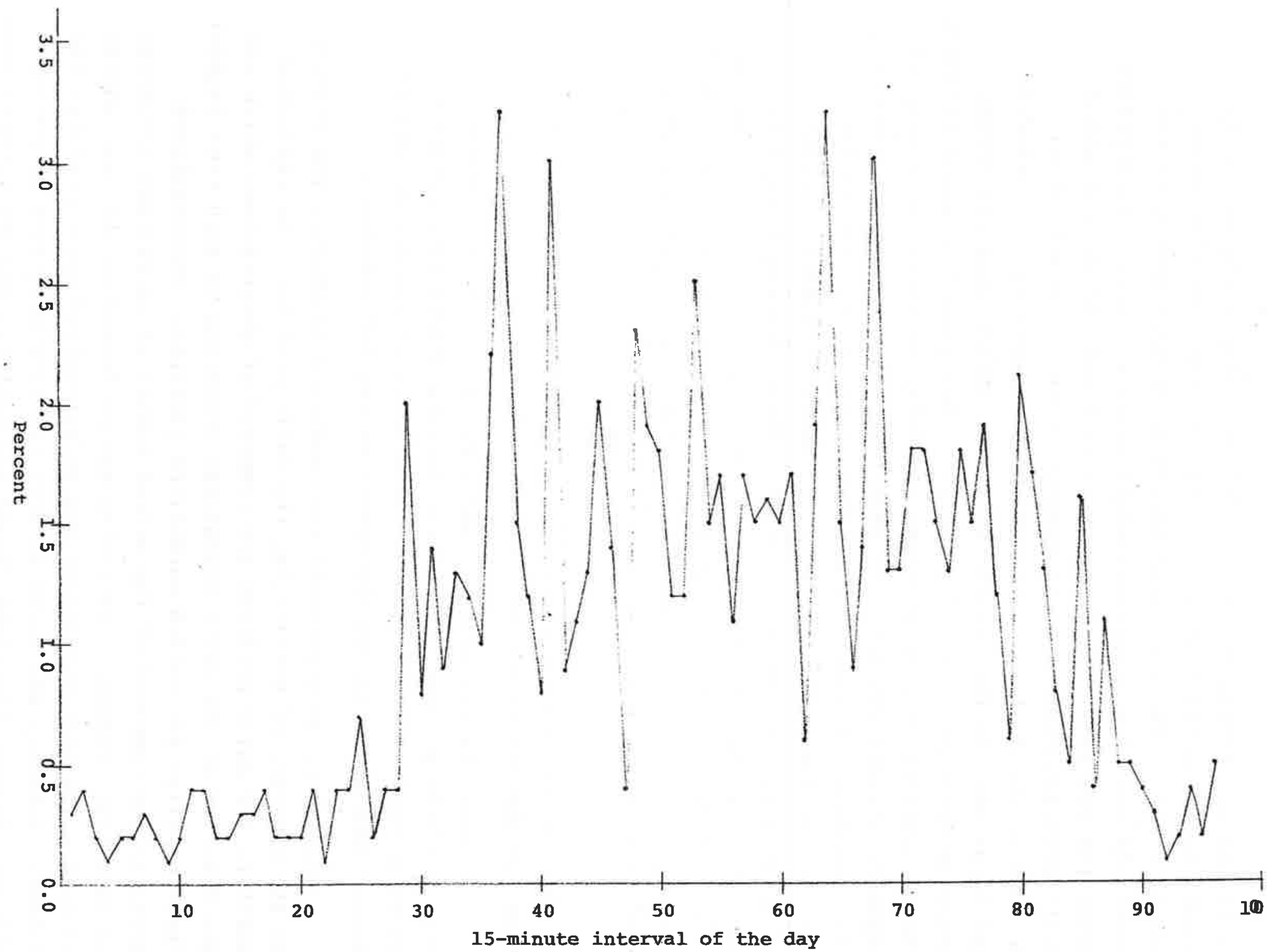


FIGURE 6-1. GRAPH OF THE DAILY PROFILE FOR CHICAGO O'HARE AIRPORT FOR JANUARY 25, 1975

compared. In both cases, the cluster structure was identical for the five airports. This result seems to indicate two things, both of which would require further research to prove conclusively: (1) The clusters will be composed of the same days whether or not normalized daily profiles are used. (2) Since un-normalized profiles merely contain information about the shape of the distribution, the volume of scheduled operations at an airport for a day does not affect the shape of the distribution of the operations across the day. Because of these indications, normalized profiles were chosen to represent the shape of the scheduled distribution of operations over a day.

Next the behavior of the OAG schedule was studied within single months for the same five airports. Figure 6-2 is an example of the results obtained. This particular dendogram is for Chicago O'Hare airport for the month of February, 1975, but all the airports exhibited similar patterns of clustering. The dendogram can be read from left to right. The numbers on the far left are the values of the distance measures at which two daily profiles or two clusters joined together. The next numbers represent the days of the month of February. The horizontal and vertical lines show how the clusters take shape. The distance of each vertical line from the left of the page is proportional to the distance measure between the two clusters or daily profiles it is joining. The numerous clusters at the left of the page are joined together until only one cluster remains at the right of the page. For example, at the top of the dendogram, days 08 and 01 join together with a distance measure between them of .06 to form a cluster of two days. Figure 6-2 shows that seven clusters initially form, one for each day of the week. As the clusters merge, the weekdays tend to cluster together, while the Saturday cluster and Sunday cluster stand apart until the final cluster is formed. This indicates that within a month, the airlines maintain similar patterns for scheduled flights during the weekdays, but alter their weekend flight patterns so that Saturday schedules and Sunday schedules are not only different from the weekday schedules but also from each other.

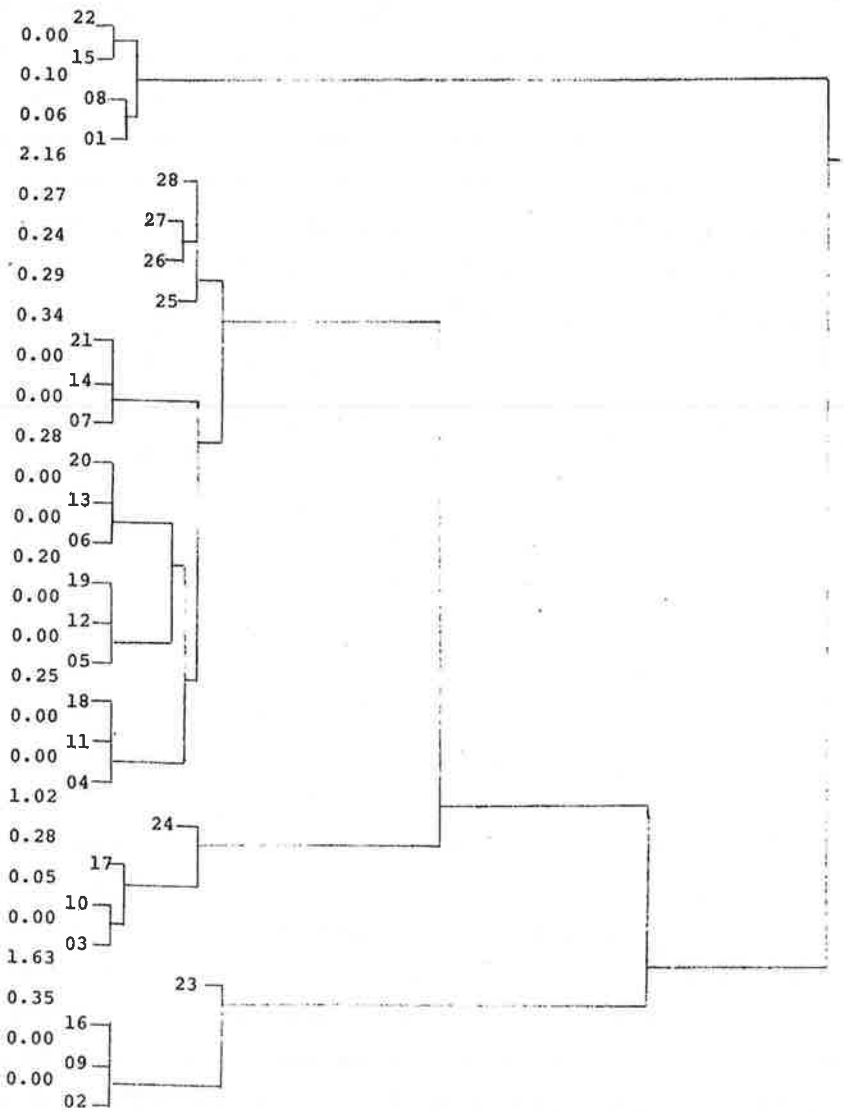


FIGURE 6-2. DENDOGRAM FOR SCHEDULED AIRPORT TRAFFIC AT CHICAGO O'HARE AIRPORT DURING FEBRUARY 1975

The seasonal characteristics of the OAG schedules were examined next. Since the typical scheduled daily profiles must be derived from only one month from each season of 1972 and 1973, it was decided to investigate first just how much information will be lost by the absence of the remaining 8 months of each year. A comparison was made of the ideal method (3 months per season) versus the method to be used in the actual processing (1 month per season). Three months of the 1975 winter season were clustered for the five airports and the resulting clusters compared with those for February alone. For most of the five airports the same weekday - Saturday - Sunday pattern emerged as the single month pattern described previously. That is, weekdays for January, February and March formed one cluster, Saturday for the three months, the second, and Sundays for the three months, the third. A correlation study was conducted to determine the similarity of the 3-month clusters to the 1-month clusters with results as shown in Table 6-1. The clusters were compared at the three cluster stage. In addition, individual daily profiles were compared to their corresponding clusters from February. Correlation (r) is a statistical measure which ranges in value from -1 to +1 and measures how closely two series of numbers are related. As r approaches +1, the movements of the two series begin to correspond more closely. The numbers shown in Table 6-1 indicate that the 3-month clusters correlate highly with the 1-month clusters. It can be concluded that 1-month clusters will adequately represent a season. Figure 6-3 is the 3-month dendrogram corresponding to Figure 6-2 for Chicago O'Hare, showing the similarity in cluster structure between the two (weekday, Saturday, Sunday pattern).

Cluster analysis was next tried on a single year's data (1 month from each season) for several airports. The results from this analysis showed the existence of a strong seasonal pattern throughout the year which outweighed differences among weekend days and weekdays. The cluster structure for both years 1972 and 1973 and for all airports tried was:

## TABLE 6-1. CORRELATION ANALYSIS

| City | 3-Month Cluster | February Cluster | Correlation r | Single Day | February Cluster | Correlation r |
|---|---|---|---|---|---|---|
| CHICAGO | 1 | 1 | .9983 | February 18 | 1 | .9997 |
| | 2 | 2 | .9979 | January 26 | 2 | .9949 |
| | 3 | 3 | .9976 | March 29 | 3 | .9886 |
| BOSTON | 1 | 1 | .9915 | February 18 | 1 | .9987 |
| | 2 | 2 | .9898 | January 26 | 2 | .9802 |
| | 3 | 3 | .9856 | March 29 | 3 | .9355 |
| CLEVELAND | 1 | 1 | .9924 | | | |
| | 2 | 2 | .9247 | March 19 | 1 | .9640 |
| | 3 | 3 | .9927 | | | |
| | 1 | 2 | .9678 | January 6 | 1 | .9371 |
| | 2 | 1 | .9441 | January 26 | 3 | .9828 |
| MIAMI | 4 | 1 | .9946 | March 29 | 1 | .9747 |
| | 1 | 2 | .9826 | | | |
| | 2 | 2 | .9960 | January 6 | 2 | .9756 |
| | 3 | 2 | .9880 | February 18 | 2 | .9909 |
| | 1 | 3 | .9713 | February 6 | 3 | .9774 |
| | 2 | 3 | .9850 | | | |
| SEATTLE | 1 | 1 | .9877 | January 6 | 1 | .9370 |
| | 1 | 3 | .9727 | February 14 | 1 | .9974 |
| | 2 | 2 | .9857 | | | |
| | 3 | 1 | .9429 | February 15 | 2 | .9997 |
| | 3 | 2 | .9167 | February 15 | 3 | .9736 |
| | 3 | 3 | .9411 | | | |

KEY

| Numbers | Days of |
|---|---|
| 1 - 31 | January |
| 32 - 59 | February |
| 60 - 90 | March |

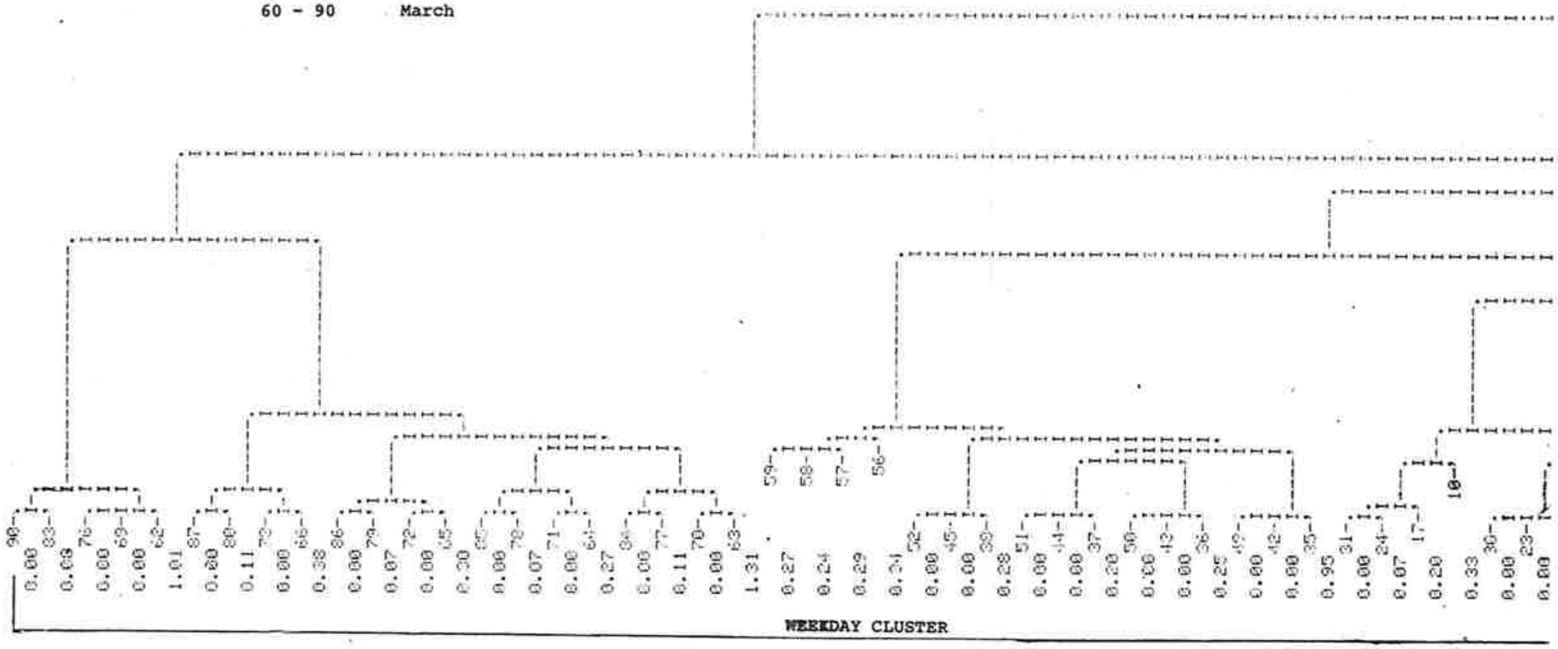


FIGURE 6-3. THREE-MONTH DENDROGRAM FOR CHICAGO O'HARE, JANUARY - MARCH 1975

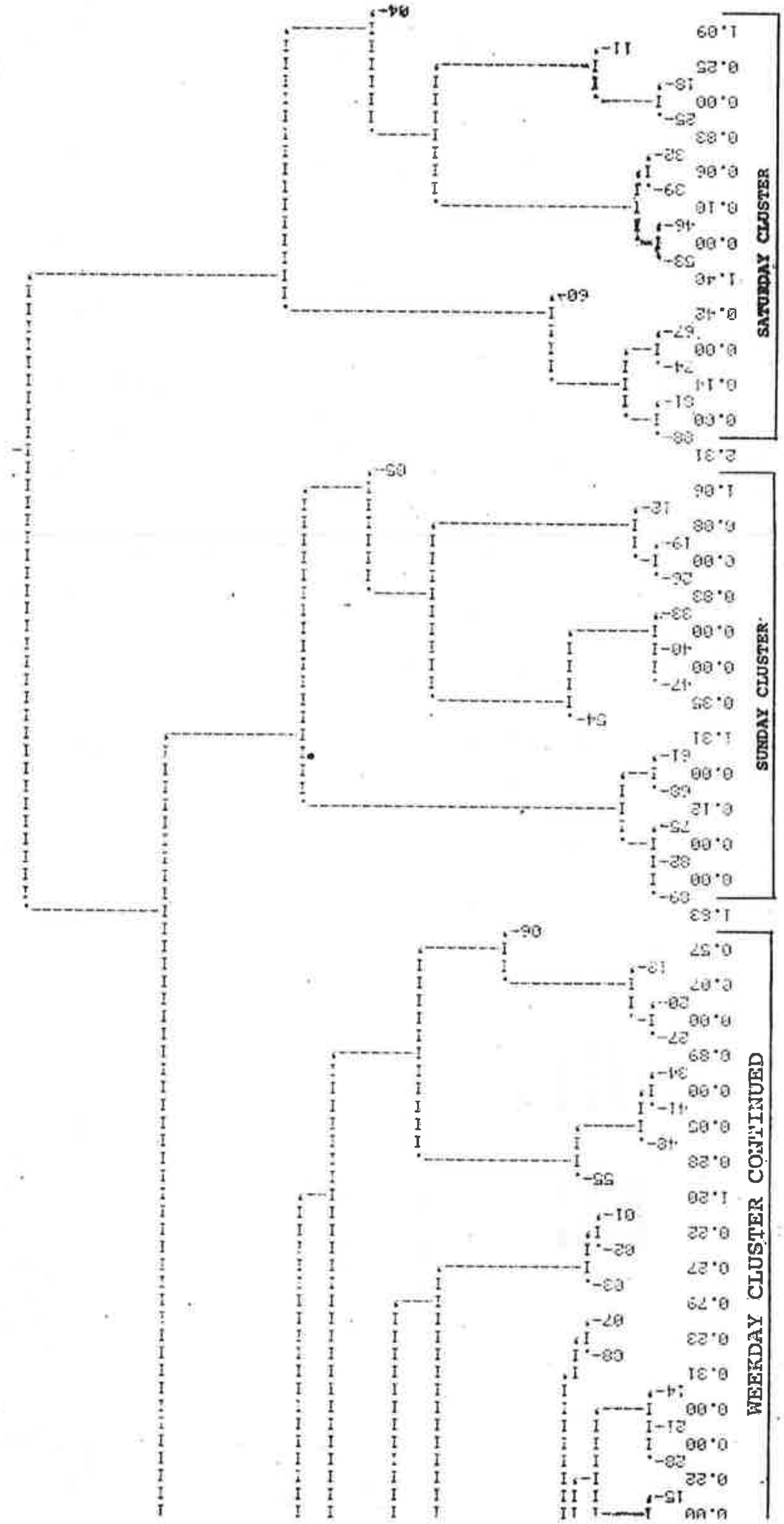


FIGURE 6-3. (Cont'd.)

| | |
|---|---|
| Cluster 1 | February |
| Cluster 2 | May, August |
| Cluster 3 | November |

Thus when clustering a year's data, differences among days of the week are no longer as important as differences among seasons.

However, the clustering of two year's data yielded some interesting and unexpected results for all the airports involved. As an example, the three cluster stage for Boston was as follows:

| | |
|---|---|
| Cluster 1 | February, 1972 |
| Cluster 2 | May, August, 1972 |
| Cluster 3 | November, 1972, and all of 1973 |

If the seasonal pattern of clustering seen in the single-year clusters were dominant from year to year, one would have expected when clustering two years that February 1972 and February 1973 form one cluster, November 1972 and November 1973 form one cluster, etc. The fact that this did not occur seems to indicate that the OAG schedule changes through time override any seasonal patterns that might occur within an individual year. The two-year cluster pattern shows that only months next to each other in time cluster together. A correlation study was performed on the three Boston clusters with the results shown below in Table 6-2.

TABLE 6-2. CORRELATION ANALYSIS ON BOSTON CLUSTERS FROM 1972 AND 1973

| CLUSTER PAIR | CORRELATION R |
|---|---|
| 1,2 | .8824 |
| 2,3 | .8796 |
| 1,3 | .8468 |

Clusters that are close to each other in time (1,2 and 2,3) exhibit higher correlations than nonconsecutive clusters (1,3). The implication is that a trend in OAG scheduling is occurring which causes dissimilarities in the daily profiles from year to year. While it is not possible during the course of the current project to investigate the nature of the trend due to constraints on time and money, it may be of interest and importance to invest further effort in this area in the future. Clustering on daily profiles which have been collapsed into hourly segments, thereby reducing the noise level, may help to provide new insight into the general trend, if there is one.

Upon conclusion of these five preliminary analyses, enough insight was gained into the nature of the OAG schedules that production could begin. After the discovery of the possible trend in OAG schedules from year to year, it was decided to cluster on only one year's data, the most recent year available, namely 1973. This decision, together with a decision to stop at the three cluster stage, would produce clusters with meaningful seasonal interpretations.

The clustering output for each airport consists of the three final clusters and the days of the year included in each cluster. The minute by minute daily profiles and associated information are recovered and formed into groups which correspond to the three clusters. The statistics are then converted to the form required for use in the model. First, the minute by minute daily arrival profiles for each cluster are averaged to form a typical daily arrival profile. Similarly, a typical daily departure profile is formed for each cluster. The hourly arrival to departure ratios are calculated for each cluster. The hourly aircraft mixes for days in each cluster are averaged across the days to produce hourly average aircraft mix for the cluster. Hourly concentrations are averaged by the hour across the days to form hourly average concentration for the cluster. Finally, the arrival peaking factor is determined by taking the maximum daily peaking factor of all OAG days.

## 6.4 NCC WEATHER TAPES PROCESSING

The purpose of the NCC weather tapes is to provide a means to separate VFR days from IFR days so that distinctive characteristics of each can be recognized and so that the relative proportion of VFR and IFR days for each airport can be determined.

The tapes contain observations taken in 3-hour intervals for every day of 1972 and 1973 on ceiling height and visibility range. The first step in the processing of the tapes is to assign a weather category to each ceiling and visibility observation. The category definitions appear below in Table 6-3.

TABLE 6-3. WEATHER CATEGORY DEFINITIONS[1]

| Category | | Definition (Ceiling in ft., Visibility in mi.) |
|---|---|---|
| VFR | | ≥ 1500 ft.[2] and 3 mi. |
| IFR | 0 | <1500 ft. and/or 3 mi., but ≥ 400 ft. and 1 mi. |
| IFR | I | < 400 ft. and/or 1 mi., but ≥ 200 ft. and 1/2 mi. |
| IFR | II | < 200 ft. and/or 1/2 mi., but ≥ 100 ft. and 1/4 mi. |
| IFR | III | < 100 ft. and/or 1/4 mi. |

A day is then classified as VFR if at least 5 out of the 6 weather observations from 6 AM to 9 PM are VFR. Otherwise, the day is said to be IFR. Finally, the relative proportions of VFR and IFR days over the two-year period are calculated for each airport.

Typical daily weather patterns are assumed for VFR and IFR days. The VFR profile consists of 24 hours of VFR weather; the IFR profile consists of 24 hours of Category 0 weather. The relative proportions of VFR and IFR days are assigned to the VFR and IFR weather profiles, respectively.

## 6.5 TOWER TAPES PROCESSING

The purpose of the tower tapes is to provide the model with typical scheduled and non-scheduled volume pairs which might occur over a period of a year as well as the frequency of

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[1] Ceiling-Visibility Climatological Study and Systems Enhancement Factors (Washington, 1975), p. 15.

[2] This altitude may vary depending on the minumum approach altitude for the airport.

occurrence for each pair. In addition, data from the tower tapes is used in the calculation of non-scheduled aircraft mix. The tower tapes contain data measuring actual occurrences at an airport. As such, volumes of operations and types of aircraft being flown can be expected to depend on weather conditions. Therefore, volume pairs and non-scheduled aircraft mixes are calculated separately for VFR and IFR days.

The first step in the processing of the tower data is to separate the records for VFR days from the records for IFR days. This is accomplished by assigning the weather classifications for the days of 1972 and 1973 (See Section 6.4) to the days of the tower tapes and forming two groups, VFR and IFR. The groups of days are then processed separately. The VFR processing is described below; IFR days are processed analogously.

The VFR processing begins with the formation of a two-dimensional distribution of scheduled volumes versus non-scheduled volumes for 1972 and 1973 days. Since the tower data records do not contain scheduled and non-scheduled figures specifically, these figures must be approximated from the available information. Scheduled volumes are approximated by the sum of air carrier and air taxi operations; non-scheduled volumes are approximated by the sum of general aviation and military operations.

Once the distribution is formed, it is discretized into nine compartments as illustrated in Figure 6-4. The number of days in each box is counted and divided by the total number of VFR days in 1972 and 1973, producing relative frequencies for each box. An average scheduled volume and an average non-scheduled volume is calculated for each box; these averages become the nine volume pairs for VFR weather.[1]

An average non-scheduled mix is also calculated for each box. First, non-scheduled mix must be calculated for all the individual days. Estimates of aircraft mixes for local and

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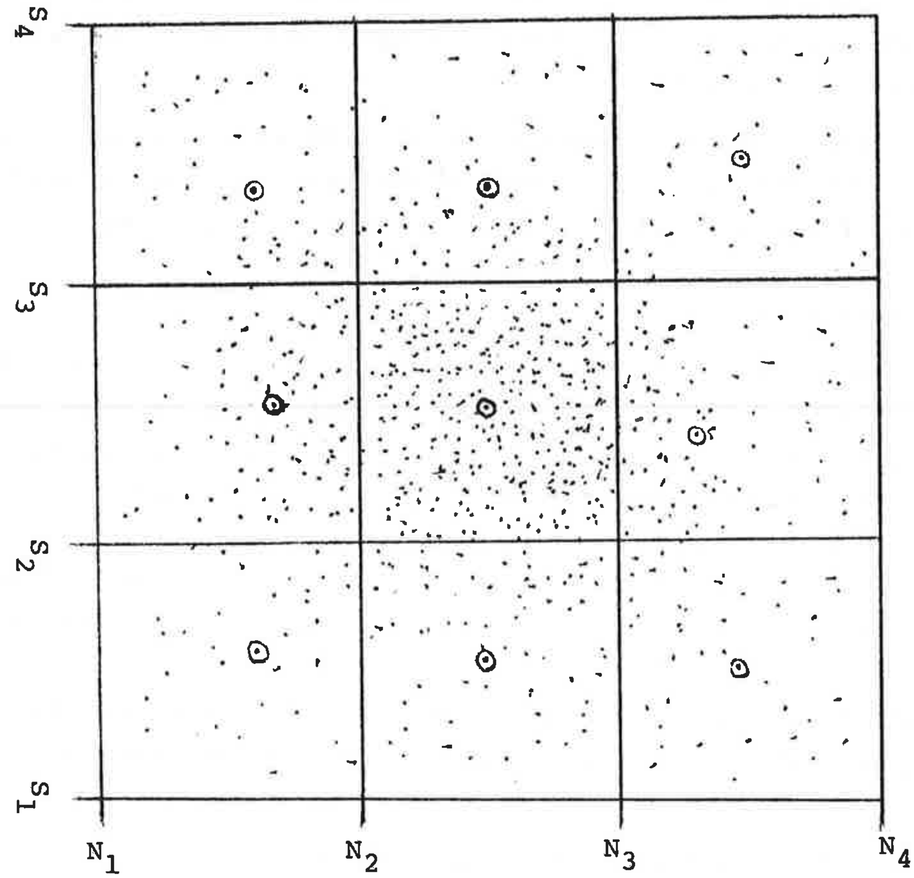
[1] It is possible to have an empty box, in which case the number of volume pairs is reduced.




ʘ Average Point for Box
. Individual Day
$N_i$ Non-Scheduled Volume Boundaries for Boxes
$S_i$ Scheduled Volume Boundaries for Boxes

FIGURE 6-4. ILLUSTRATION OF TOWER DATA PROCESSING itinerant general aviation and military operations are multiplied by the number of corresponding operations for that day and divided by the total number of non-scheduled operations for the day. This produces a mix for one day's non-scheduled aircraft. The mixes for the days in each box are then averaged to produce the average non-scheduled mix per box.

This processing is repeated for the IFR group of days, so that nine scheduled/non-scheduled volume pairs and associated non-scheduled mixes result for both VFR days and IFR days.

## 6.6 CATER TAPES PROCESSING

The purpose of the CATER tapes processing is the production of a non-scheduled typical daily profile which can be used for all the airports in the study. Unlike scheduled operations, estimates of which are obtained from the OAG, non-scheduled operations are not reported for all airports. The CATER tapes minute-by-minute observations are summarized to provide half-hour observations of the number of non-scheduled flights at the three New York airports of Kennedy, LaGuardia and Newark. The tapes are available for May, 1972. It was decided that the average half-hour daily profile for these three airports should be used to represent non-scheduled profiles at all 31 airports.

The non-scheduled profile is calculated by:

1. averaging the half-hour observations of the number of non-scheduled flights at an individual airport across the 31 days of May, 1972
2. summing the half-hour averages across the three New York airports
3. dividing the half-hour sums by the total of the 48 half-hour sums

A graph of the non-scheduled profile is shown in Figure 6-5.

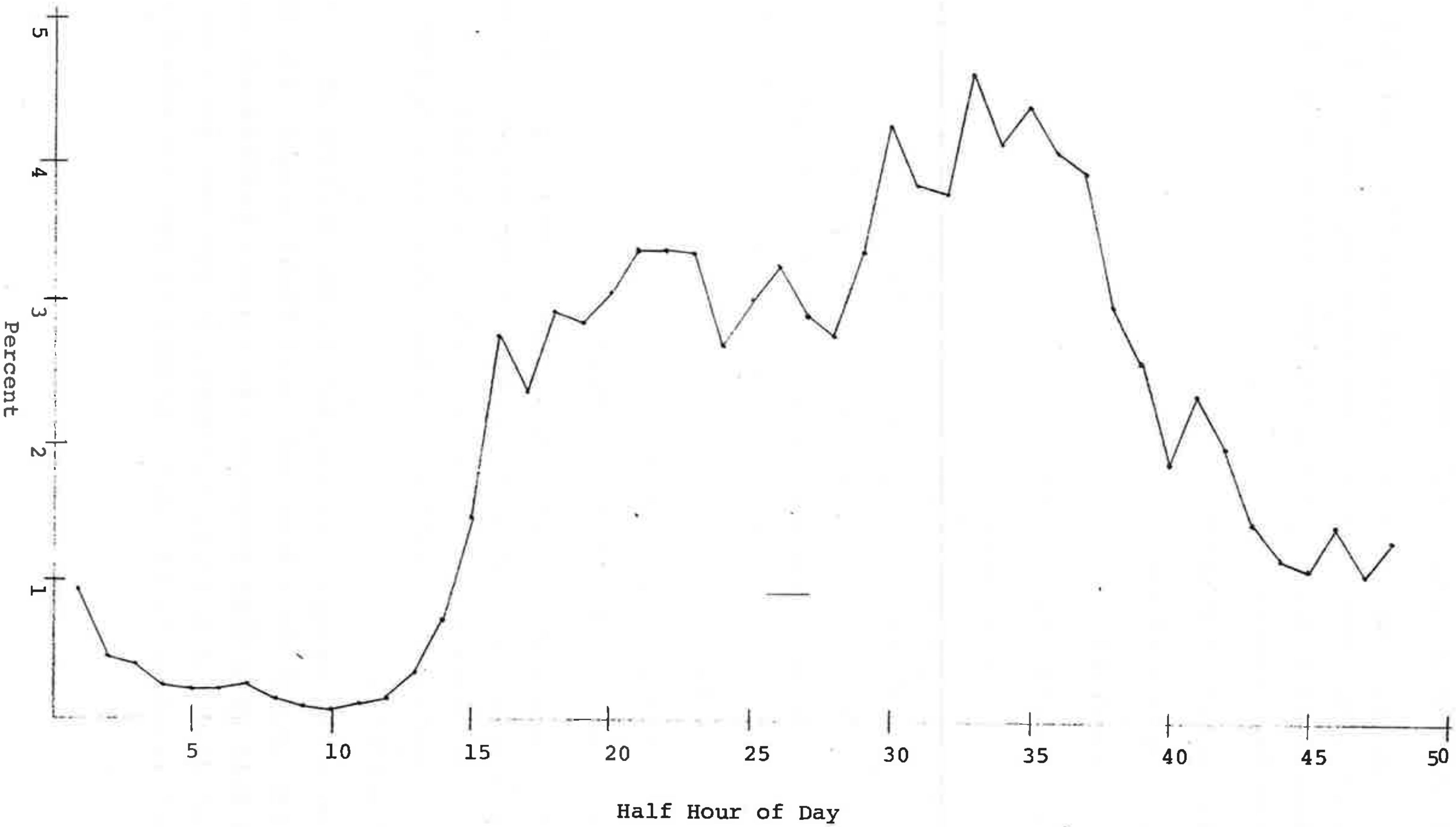



FIGURE 6-5. NON-SCHEDULED TYPICAL DAILY PROFILE

## 6.7 FORMATION OF ANNUAL DATA BASE

The annual data base is created once the processing described in the previous four sections has been completed. The data base is composed of a series of typical days for an airport in terms of the five characteristics:

1. activity patterns
2. volume of operations
3. aircraft mix
4. arrival to departure ratio
5. weather patterns

With each typical day is the number of days of a year it represents, otherwise known as the weight of the day.

The typical days are formed by merging the output from the processing of the OAG, CATER, tower and weather tapes. The mergers will be described in this section in the following sequence:

1. tower, OAG
2. tower, OAG, weather
3. tower, OAG, weather, CATER

Each time a merger occurs, the airport's typical characteristics obtained from the sources being merged are matched so that every possible combination of characteristics is accounted for. Then the intermediate probability for the occurrence of each combination is calculated.

Once the mergers are completed, the typical days are placed into the annual data base and their final weights are calculated. The annual data base provides the airport performance model with typical days for a year; the model is run once for each typical day and weighted by the day's weight to produce annual delay.

The OAG data and tower data merger associates the typical scheduled daily activity profiles with the typical scheduled/non-scheduled volume pairs. Since the typical daily profiles are assumed independent of weather, they are combined with both the VFR and IFR volume pairs. The nine VFR volume pairs are combined with the three daily profiles to produce 27 combinations of volume and shape. Likewise, the nine IFR volume pairs and the three daily profiles form 27 combinations. A total of 54 VFR and IFR combinations is formed.

Before the description of the calculation of the intermediate probability for the occurrence of each combination, two things must be recalled:

1. For each of the three typical scheduled daily profiles created for an airport, a distribution of the scheduled volumes for the days associated with the profile was created and the percent of total OAG days that the profile represents was calculated.

2. The relative frequency or probability of the occurrence of each of the scheduled/non-scheduled volume pairs for both VFR and IFR days was calculated.

The stops of the intermediate probability calculations are described below:

1. Referring to Figure 6-4, the interval $(S_i, S_{i+1})$ is determined for the volume pair;

2. The percent of scheduled volumes associated with Profile 1 lying in this interval is determined;

3. The percent of OAG days represented by Profile 1 is retrieved;

4. The probability of the occurrence of the volume pair is retrieved;

5. The numbers from 2, 3, and 4 are multiplied (2 x 3 x 4) to produce the probability of the volume pair occurring with Profile 1;

6. Steps 2 through 5 are repeated for Profile 2 and again for Profile 3;

7. Steps 1 through 6 are repeated for all VFR and IFR volume pairs.

In this manner every combination of volume pair and profile has an intermediate probability of occurrence associated with it.

The next merger is that of the weather profiles with the tower-OAG combinations. Since there are only two weather profiles, one for VFR weather and one for IFR weather, the merger involves merely combining the VFR weather profile with the VFR tower-OAG combinations and combining the IFR weather profile with the IFR tower-OAG combinations. To determine the new intermediate probabilities for the VFR combinations, the tower-OAG intermediate probabilities must be multiplied by the relative proportion of VFR days calculated in Section 6.4. Similarly, the new intermediate probabilities for the IFR days can be calculated. This merger results in combinations of volume pair/daily profile/weather profile and the intermediate probability of the occurrence of each combination.

Finally, the CATER data non-scheduled profile is merged with the tower-OAG-weather combinations. Since there is only one non-scheduled profile, the profile is merely attached to the volume pair/daily profile/weather profile and the probabilities of occurrence do not change. The number of combinations remains 54.

The typical days that appear in the final annual data base for each airport are created from these combinations. The intermediate probability for each combination is multiplied by 365 to produce the final weight for each typical day. The contents of the annual data base by typical day are:

1. daily activity pattern (separate arrival and departure patterns)
2. aircraft mix (scheduled and non-scheduled)
3. arrival to departure ratio
4. concentration
5. volume of operations (scheduled and non-scheduled)
6. weather profile
7. weight.

Along with the typical days, a header file is produced containing:

1. average daily volume (air carrier, air taxi, general aviation, military)
2. number of typical days for that airport[1]
3. annual peaking factor.

[1] This number can be less than 54 if there exists a box from the tower data containing no days with scheduled and non-scheduled volumes falling in the intervals associated with that box.

## REFERENCES


6.-1. Ceiling - Visibility Climatological Study and Systems Enhancement Factors, U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Springfield: National Technical Information Service, 1975.

6.-2. Glickman, Theodore S. and Michael A. Grossman, "Hierarchical Clustering Applied to Commodity Flow Census Data," U.S. DOT/TSC, material of file, 1975.

# 7. MODEL VALIDATION

The models developed to estimate airport performance characteristics are based upon data from a large number of sources. The models are esentially practical in nature, and their quality must be judged by their performance in practice. Accordingly, an exercise to evaluate the performance of the models in estimating airport delays was designed and implemented as part of the research for this project. Realism and accuracy of delay estimates of the Airport Performance Model are very important to the usefulness of the model in evaluating the economic desirability of specific airport investments, and as a result the model validation exercise focuses on delay estimate.

For the validation, the Airport Performance Model was run for specific airports over specific historical time periods, and the delay estimates output from the Model were compared with historical airport delay data actually collected for the identical time period. The quality of the models would be reflected by their ability to produce delay estimates consistent with delay data previously collected. To perform the validation, historical airport delay data sources were identified, the airport and time period for analysis were selected, and detailed data necessary to simulate airport operations were gathered for Kennedy, Newark and LaGuardia airports. Subsequently, the model runs were made and output was analyzed. The validation methodology and findings of the analysis are discussed in the following sections of this chapter.

## 7.1 HISTORICAL AIRPORT DELAY DATA

Airport delay statistics can be obtained directly or indirectly from a number of different sources, although there typically are differences in terminology, degree of periodic tabulation, extent of coverage and other important data characteristics. Airport delay data used in this study were taken from the airport delay statistics collected by the Port Authority of New York and New Jersey (PANYNJ) and from analysis of the Service Segment data collected monthly by the U.S. Civil Aeronautics Board.

### PANYNJ Data

The PANYNJ airport delay data base covers LaGuardia, Kennedy and Newark airports and includes time duration statistics for a great number of airports operations. The existence of this data base was a major reason for the selection of these three airports for validation. The types of airport delays which were of greatest concern in the validation were runway delays on landing and take-off, and data elements reflecting these types of delay were available from PANYNJ for LGA, JFK, and EWR. Landing delays were estimated by the data element "Total Excess Elapsed Time" which is defined to be "actual block time less scheduled block time." This statistic includes delays of all types between the time an aircraft leaves the gate at an upline station and the time it docks at the gate of the Port Authority airport. The basis for comparison is the scheduled block time for the flight, with time in excess of scheduled block time defined here to be delay. Takeoff delays for the three airports were estimated by subtracting a nominal or expected ground time (which is an estimate of ground time for no take-off delays) from actual take-off ground time. In the

PANYNJ delay reports, ground time is defined as the time from gate departure to liftoff. The delay times for both arrivals and departures are presented by the PANYNJ monthly, but observations are broken out separately by hour for the month. Nominal ground times were defined by this study to be the smallest average ground time observation for fours with more than 10 departures for the month under consideration.

There are several shortcomings inherent in using the PANYNJ delay data base in validation of delay outputs of the Airport Performance Model. Only four airlines actively participated in the data collection exercise (Air Canada, Eastern, Pan American and TWA) and the analyst must assume that the data reported by these airlines is representative of total operations at the three airports and can be expanded to describe total operations at the airports. In addition, arrival delay estimates from PANYNJ include delays on departure from up-line stations and gate delays at the Port Authority airports as well as the actual runway delays upon arrivals. Only the latter is of interest, but it is impossible to isolate the magnitude of this element of delay from the PANYNJ data. Finally, delays must be estimated by comparing actual times with scheduled times. In fact, a certain "slack time" is present in flight schedules to correspond with anticipated delays at peak activity periods. Because this "slack time" is built into airline schedules, true delay will be underestimated when actual block time is contrasted with scheduled block time.

CAB Data

Historical airport delay estimates from PANYNJ were augmented by delay estimates from the CAB Service Segment data base[1] because of the limitations of the PANYNJ delay data. These delay estimates were made by evaluating records of air time for many non-stop flights from EWR, JFK and LGA. The CAB 586 Service Segment data are reported by the scheduled air carriers monthly, and for each flight number, the airline reports (among other things) total number of flights made and total airborne hours during the month. The ratio of these two terms, average air time per flight, will vary among different flights serving the same two airports. This variation will be due to an extent to differences in wind conditions at high altitudes, flight plans, etc., but it is assumed that the major source of variation will be because of delays on landing. Flights on a city pair market which are scheduled to arrive at off-peak hours tend to have lower average airborne times than do flights which arrive at peak hours because of the variation in landing delays over the course of a day. The methodology for estimating landing delays at Newark, LaGuardia and Kennedy from the CAB Service Segment data base involved several steps discussed below:

- All airports with non-stop service to EWR, JFK and LGA during a specified four month period were isolated on the data base.
- For each distinct flight number, the average airborne time was established.

[1] This data base is described in greater detail in Chapter 5.

- The minimum average airborne flight time for each airport pair (DTW-LGA, ORD-LGA, DTW-EWR, etc.) was identified. Certain routes were served by both jet and prop aircraft, and flight times by different aircraft service types were treated separately. Thus, BOS-LGA with jet service was considered separately from BOS-LGA with prop service. In determining the minimum flight time it was necessary to avoid erroneous data entries (zero flight times were reported for a number of flights, for example) and precautions were taken to insure the minimum flight times were reasonable.

- Average arrival delays for the month being validated were estimated by subtracting minimum flight times from average flight times for all flights for a specific airport pair. Total delays associated with a specific flight were estimated by multiplying estimated average airborne delay per flight by the number of flights made under that flight number of the month.

- Delays associated with specific flight numbers were allocated to the hour for which that flight was scheduled to arrive, as determined from the Official Airline Guide.

- Average delay for an hour was estimated by dividing total delay for all flights taking place during an hour by the number of operations associated with these flights.

Additional adjustments were made to correct for two problems with outputs of this analysis. A number of flights were reported through the CAB Service Segment tapes but did not appear on the Official Airline Guide records. The delays associated with this group of flights were distributed across the day in proportion to the hourly distribution of flights as reported by the Official Airline Guide. A second difficulty involved with the output of this analysis was the existence of scheduled operations for which no delay data were available from CAB records. These operations include flights by foreign flag carriers and commuter air carriers. (These classes of carriers do not report flight times to the CAB.) Operations by these carriers were assumed to have the same delay as the air carrier operations occurring in the same scheduled hour.

Comparison of PANYNJ and CAB Data

Tables 7.1-1 through 7.1-3 shown the historical hourly landing delays estimated from the analysis of CAB Service Segment data and from reports to the PANYNJ for operations at JFK, LGA, and EWR. The tables contrast arrival delay estimates from the CAB Service Segment data evaluation performed for this study with the delay data reported by participating carriers to PANYNJ.

The different assumptions and definitions embedded in the two data sources result in interesting differences in average delay estimates for the three airports for May of 1972. In all cases, delay estimates from analysis of CAB data analysis exceed similar estimates from PANYNJ data analysis. The disparity is most pronounced for JFK. CAB analysis yields an average arrival delay estimate of slightly over 18 minutes for the month whereas estimates from PANYNJ reports yield an estimate of only 3.2 minutes. A brief examination of the hourly delay entries for JFK points up five hours in which "negative delays" occurred, or in other words, actual block times were systematically less than scheduled block times. This illustrates the difficulties inherent in delay analysis based on scheduled block times. PANYNJ data should be treated as a lower bound on arrival delays because of this. Delay estimates for arrivals at LGA from the two sources were closer

TABLE 7.1-1. ARRIVAL DELAYS AT JFK MAY 1972

| HOUR ENDING | Estimated from CAB Data: Number of Arrivals | Total Delay (Minutes) | Average Delay (Minutes) | Reported to PANYNJ: Number of Arrivals | Total Delay (Minutes) | Average Delay (Minutes) |
|---|---|---|---|---|---|---|
| 1 AM | 590 | 9371 | 15.88 | 228 | 866 | 3.7 |
| 2 | 173 | 1892 | 11.00 | 105 | 742 | 7.0 |
| 3 | 232 | 2738 | 11.80 | 45 | -355 | -7.8 |
| 4 | 308 | 3477 | 11.29 | 52 | 218 | 4.1 |
| 5 | 146 | 2240 | 15.34 | 11 | 67 | 6.0 |
| 6 | 112 | 1364 | 12.18 | 22 | -97 | -4.4 |
| 7 | 359 | 8661 | 24.13 | 66 | 532 | 8.0 |
| 8 | 375 | 6079 | 16.21 | 85 | 46 | 0.5 |
| 9 | 654 | 4414 | 6.75 | 155 | -28 | -0.1 |
| 10 | 253 | 3295 | 13.02 | 62 | 140 | 2.2 |
| 11 | 369 | 3637 | 9.86 | 147 | 101 | 0.6 |
| 12 NOON | 357 | 5707 | 15.99 | 65 | 121 | 1.8 |
| 1 PM | 692 | 5120 | 7.40 | 146 | 18 | 0.6 |
| 2 | 411 | 4959 | 12.07 | 126 | -500 | -3.9 |
| 3 | 610 | 7916 | 12.98 | 197 | -461 | -2.3 |
| 4 | 1316 | 24610 | 18.70 | 253 | 19 | 0.0 |
| 5 | 1423 | 34668 | 24.36 | 293 | 348 | 1.1 |
| 6 | 1566 | 43804 | 27.97 | 397 | 2221 | 5.5 |
| 7 | 820 | 18692 | 22.80 | 237 | 3170 | 13.3 |
| 8 | 1006 | 26429 | 26.27 | 216 | 977 | 4.5 |
| 9 | 960 | 19303 | 20.11 | 301 | 789 | 2.6 |
| 10 | 701 | 11644 | 16.61 | 217 | 1214 | 5.5 |
| 11 | 531 | 6181 | 11.64 | 179 | 1244 | 6.9 |
| 12 MID-NIGHT | 333 | 3229 | 9.70 | 87 | 507 | 5.8 |
| TOTAL | 14296 | 259430 | 18.15 | 3692 | 11979 | 3.2 |

TABLE 7.1-2. ARRIVAL DELAYS AT LGA MAY 1972

| | Estimated from CAB Data | | | Reported to PANYNJ | | |
|---|---|---|---|---|---|---|
| HOUR ENDING | Number of Arrivals | Total Delay (Minutes) | Average Delay (Minutes) | Number of Arrivals | Total Delay (Minutes) | Average Delay (Minutes) |
| 1 AM | 0 | 0 | 0 | 2 | 9 | 4.5 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 46 | 261 | 5.67 | 0 | 0 | 0 |
| 8 | 458 | 1934 | 4.22 | 56 | 1 | 0 |
| 9 | 628 | 5218 | 8.31 | 147 | 599 | 4.0 |
| 10 | 767 | 8966 | 11.69 | 268 | 1891 | 7.0 |
| 11 | 815 | 9118 | 11.19 | 213 | 2481 | 11.6 |
| 12 NOON | 730 | 6606 | 9.05 | 193 | 912 | 4.7 |
| 1 PM | 679 | 6132 | 9.03 | 250 | 1607 | 6.4 |
| 2 | 798 | 5811 | 7.28 | 218 | 1027 | 4.7 |
| 3 | 729 | 4784 | 6.56 | 203 | 580 | 2.8 |
| 4 | 857 | 6938 | 8.10 | 197 | 668 | 3.3 |
| 5 | 1018 | 9281 | 9.12 | 222 | 1793 | 8.0 |
| 6 | 808 | 6802 | 8.42 | 177 | 1277 | 7.2 |
| 7 | 892 | 7610 | 8.53 | 301 | 939 | 3.1 |
| 8 | 820 | 7195 | 8.77 | 252 | 1414 | 5.6 |
| 9 | 1006 | 9205 | 9.15 | 225 | 1504 | 6.6 |
| 10 | 908 | 8247 | 9.08 | 177 | 1575 | 8.8 |
| 11 | 446 | 2923 | 6.55 | 128 | 682 | 5.3 |
| 12 MID-NIGHT | 218 | 1544 | 7.08 | 77 | 499 | 6.4 |
| TOTAL | 12623 | 108575 | 8.6 | 3306 | 19458 | 5.8 |

TABLE 7.1-3. ARRIVAL DELAYS AT EWR MAY 1972

| | Estimated from CAB Data | | | Reported to PANYNJ | | |
|---|---|---|---|---|---|---|
| HOUR ENDING | Number of Arrivals | Total Delay (Minutes) | Average Delay (Minutes) | Number of Arrivals | Total Delay (Minutes) | Average Delay (Minutes) |
| 1 AM | 189 | 1294 | 6.85 | 34 | 34 | 1.0 |
| 2 | 78 | 314 | 4.03 | 22 | -24 | -1.0 |
| 3 | 127 | 741 | 5.83 | 0 | 0 | 0.0 |
| 4 | 75 | 707 | 9.43 | 0 | 0 | 0.0 |
| 5 | 125 | 628 | 5.02 | 0 | 0 | 0.0 |
| 6 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 7 | 94 | 1169 | 12.41 | 0 | 0 | 0.0 |
| 8 | 214 | 1735 | 8.11 | 29 | 94 | 3.2 |
| 9 | 446 | 2815 | 6.31 | 0 | 0 | 0.0 |
| 10 | 470 | 4181 | 8.90 | 15 | 186 | 5.7 |
| 11 | 531 | 3742 | 7.05 | 42 | 161 | 3.8 |
| 12 NOON | 270 | 1928 | 7.14 | 20 | 188 | 9.4 |
| 1 PM | 224 | 1677 | 7.49 | 14 | -22 | -1.5 |
| 2 | 357 | 2062 | 5.78 | 44 | -104 | -2.3 |
| 3 | 415 | 3590 | 8.65 | 27 | 202 | 7.4 |
| 4 | 543 | 3458 | 6.37 | 32 | 168 | 5.2 |
| 5 | 434 | 2712 | 6.25 | 25 | 21 | 0.8 |
| 6 | 726 | 7763 | 10.69 | 49 | 494 | 10.0 |
| 7 | 485 | 3201 | 6.60 | 13 | 234 | 18.0 |
| 8 | 635 | 5458 | 8.60 | 44 | 245 | 5.5 |
| 9 | 609 | 4520 | 7.42 | 62 | 2001 | 32.2 |
| 10 | 452 | 4704 | 10.41 | 47 | 296 | 6.2 |
| 11 | 360 | 3389 | 9.41 | 38 | 238 | 6.2 |
| 12 MID-NIGHT | 253 | 1749 | 6.91 | 42 | 126 | 3.0 |
| TOTAL | 8112 | 63537 | 7.83 | 559 | 4434 | 7.4 |

together than was the case for JFK. Estimates based on CAB data analysis revealed an average arrival delay of 8.6 minutes, and the estimate from PANYNJ data was 5.8 minutes average arrival delay. Arrival delay estimates from EWR were quite similar for both sources, ranging from 7.8 minutes from CAB data analysis to 7.4 minutes for estimates based on PANYNJ data.

Departure delays during May of 1972 were estimated from PANYNJ data above, since no equivalent alternative data source could be identified. The total ground times and estimated excess ground times for the three airports appear in Tables 7.1-4 through 7.1-6. The average departure delay estimated for the three airports ranged between 4.5 and 5.5 minutes for May 1972.

## 7.2 SIMULATING HISTORICAL AIRPORT OPERATIONS

A data source available only at the PANYNJ airports was used to develop a detailed description of activity at EWR, LGA and JFK for the month of May, 1972. The CATER data were used to develop an historical profile of weather conditions, runway use, and the distribution of general aviation operations through the day. When used in conjunction with air traffic control data for EWR, LGA and JFK, and fleet mix information from the May 1972 Official Airline Guide, the hourly processing rate for aircraft can be determined from runway configuration and weather conditions given by CATER data.

The procedure for determining the processing rate for EWR, LGA or JFK using the CATER data is based on several steps. CATER data includes information on the runway used for individual arrivals and departures throughout the day. From this information the

TABLE 7.1-4. DEPARTURE DELAYS AT JFK MAY 1972

| HOUR ENDING | Number of Departures | Reported to PANYNJ Total Ground Time (Minutes) | Reported to PANYNJ Average Ground Time (Minutes) | Average Excess Ground Time (Minutes) | Total Excess Ground Time (Minutes) |
|---|---|---|---|---|---|
| 1 AM | 37 | 877 | 23.7 | 12.4 | 458.8 |
| 2 | 39 | 603 | 15.4 | 4.0 | 156.0 |
| 3 | 59 | 936 | 15.8 | 4.4 | 259.6 |
| 4 | 19 | 287 | 15.1 | 3.7 | 70.3 |
| 5 | 3 | 40 | 13.3 | 1.9 | 5.7 |
| 6 | 23 | 322 | 14.0 | 2.6 | 59.8 |
| 7 | 108 | 1499 | 13.8 | 2.4 | 259.2 |
| 8 | 215 | 2993 | 13.9 | 2.5 | 537.5 |
| 9 | 187 | 2835 | 15.1 | 3.7 | 691.9 |
| 10 | 437 | 7250 | 16.5 | 5.1 | 2228.7 |
| 11 | 248 | 4502 | 18.1 | 6.7 | 1661.6 |
| 12 NOON | 259 | 4314 | 16.6 | 5.2 | 1346.8 |
| 1 PM | 252 | 3817 | 15.1 | 3.7 | 932.4 |
| 2 | 154 | 1814 | 11.7 | 0.3 | 46.2 |
| 3 | 121 | 1551 | 12.8 | 1.4 | 169.4 |
| 4 | 96 | 1095 | 11.4 | 0.0 | 0.0 |
| 5 | 134 | 2046 | 15.2 | 3.8 | 509.2 |
| 6 | 126 | 1836 | 14.5 | 3.1 | 390.6 |
| 7 | 300 | 5448 | 18.1 | 6.7 | 2010.0 |
| 8 | 318 | 6535 | 20.5 | 9.1 | 2893.8 |
| 9 | 164 | 3497 | 21.3 | 9.8 | 1607.2 |
| 10 | 173 | 3374 | 19.5 | 8.1 | 1401.3 |
| 11 | 173 | 3888 | 22.0 | 10.6 | 1865.6 |
| 12 MIDNIGHT | 154 | 2979 | 19.3 | 7.9 | 1216.6 |
| TOTAL | 3802 | 64338 | 16.9 | 5.5 | 20778.2 |

TABLE 7.1-5. DEPARTURE DELAYS AT LGA MAY 1972

| HOUR ENDING | Number of Departures | Reported to PANYNJ Total Ground Time (Minutes) | Reported to PANYNJ Average Ground Time (Minutes) | Average Excess Ground Time (Minutes) | Total Excess Ground Time (Minutes) |
|---|---|---|---|---|---|
| 1 AM | 22 | 201 | 9.1 | 0.0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 |
| 8 | 269 | 3449 | 12.9 | 3.8 | 1014.6 |
| 9 | 178 | 3013 | 16.9 | 7.8 | 1388.4 |
| 10 | 211 | 3266 | 15.4 | 6.3 | 1329.3 |
| 11 | 235 | 3241 | 13.7 | 4.6 | 1081.0 |
| 12 NOON | 229 | 2852 | 12.4 | 3.3 | 755.7 |
| 1 PM | 163 | 2200 | 13.4 | 4.3 | 700.9 |
| 2 | 307 | 4351 | 14.1 | 5.0 | 1535.0 |
| 3 | 215 | 2606 | 12.1 | 3.0 | 645.0 |
| 4 | 208 | 2529 | 12.1 | 3.0 | 624.0 |
| 5 | 174 | 2826 | 16.2 | 7.1 | 1235.4 |
| 6 | 230 | 4238 | 18.4 | 9.3 | 2139.0 |
| 7 | 220 | 4118 | 18.7 | 9.6 | 2112.0 |
| 8 | 279 | 4568 | 16.3 | 7.2 | 2008.8 |
| 9 | 196 | 2667 | 13.6 | 4.5 | 882.0 |
| 10 | 165 | 2250 | 13.6 | 4.5 | 742.5 |
| 11 | 27 | 317 | 11.7 | 2.6 | 70.2 |
| 12 MIDNIGHT | 3 | 19 | 6.3 | 0.0 | 0.0 |
| TOTAL | 3329 | 48711 | 14.6 | 5.5 | 18263.8 |

TABLE 7.1-6. DEPARTURE DELAYS AT EWR MAY 1972

Reported to PANYNJ

| ENDING | Number of Departures | Total Ground Time (Minutes) | Average Ground Time (Minutes) | Average Excess Ground Time (Minutes) | Total Excess Ground Time (Minutes) |
|---|---|---|---|---|---|
| 1 AM | 21 | 265 | 12.6 | 5.2 | 109.2 |
| 2 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| 3 | 21 | 266 | 12.6 | 5.2 | 109.2 |
| 4 | 1 | 10 | 10.0 | 2.6 | 2.6 |
| 5 | 12 | 154 | 12.8 | 5.4 | 64.8 |
| 6 | 2 | 29 | 14.5 | 7.1 | 14.2 |
| 7 | 10 | 74 | 7.4 | 0.0 | 0.0 |
| 8 | 43 | 489 | 11.3 | 3.9 | 167.7 |
| 9 | 28 | 346 | 12.3 | 4.9 | 137.2 |
| 10 | 105 | 1654 | 15.7 | 8.3 | 871.5 |
| 11 | 29 | 342 | 11.7 | 4.3 | 124.7 |
| 12 NOON | 45 | 425 | 9.4 | 2.0 | 90.0 |
| 1 PM | 14 | 194 | 13.8 | 5.4 | 75.6 |
| 2 | 32 | 284 | 8.8 | 1.4 | 44.8 |
| 3 | 29 | 262 | 9.0 | 1.6 | 46.4 |
| 4 | 33 | 362 | 10.9 | 3.5 | 115.5 |
| 5 | 29 | 366 | 13.5 | 6.1 | 164.7 |
| 6 | 46 | 499 | 10.8 | 3.4 | 156.4 |
| 7 | 33 | 433 | 13.1 | 5.7 | 188.1 |
| 8 | 26 | 277 | 10.6 | 3.2 | 83.2 |
| 9 | 22 | 235 | 10.6 | 3.2 | 70.4 |
| 10 | 33 | 296 | 12.0 | 4.6 | 151.8 |
| 11 | 2 | 19 | 9.5 | 2.1 | 4.2 |
| 12 MIDNIGHT | 8 | 63 | 7.4 | 0.0 | 0.0 |
| TOTAL | 622 | 7444 | 11.9 | 4.5 | 2792.2 |

runway configuration can be determined. A recent study[1] documented hourly VFR and IFR processing rates for a number of U.S. airports, including EWR, LGA and JFK, for different runway configurations. The runway configurations previously analyzed include most of the most frequent orientations used by the three PANYNJ airports, and the study results (referred to as Engineered Performance Standards) were used as the basis for processing rate inputs for the model validation. The CATER files include weather observations (in terms of ceiling and visibility) and inspection of these records indicates whether IFR or VFR conditions are in effect. Based on all this information, the appropriate processing rate can be selected for each hour of each day in May 1972.

The Engineered Performance Standards reflect operations with aircraft in use at the selected airports during the 1974-1975 periods. The fleet mix at LGA, EWR and JFK during the period chosen for model validation, May 1972, differed slightly from the mix in 1974-1975, and the Engineered Performance Standards were adjusted to reflect the effect of this fleet mix change on processing rates for the validation. This adjustment was performed using the relationship between changes in fleet mix and resulting changes in processing rate which is within the model framework. The impact of this adjustment was small.

The volume of daily traffic for the validation runs was taken from the daily tower activity data for the three airports. Traffic was separated for air carrier and air taxi, and general aviation

[1] Performance Measurement System for Major Airports, prepared by U.S. Department of Transportation, Federal Aviation Administration, Office of Air Traffic Service, Operations Research Branch, Nov., 1975.

and military. These groupings were used because the distribution of both air carrier and air taxi operations can be observed in the Official Airline Guide for May of 1972, and the distribution of general aviation and military operations throughout the day must be determined by some other source. The CATER data reveal the pattern of actual arrivals and departures for EWR, LGA, and JFK, and a characteristic distribution function was derived from CATER for use in the validation process. The distribution functions were derived by determining the percentage of total general aviation and military operations for the month of May 1972 to take place in each 30 minute period. A separate distribution function was derived for EWR, JFK and LGA, and the appropriate distribution function was used for general aviation and military air traffic for each of the 31 days in the month of May.

## 7.3 RESULTS OF THE VALIDATION EXERCISES

The data described above were input to the Airport Performance Model and the activity at EWR, LGA and JFK for May 1972 was simulated by running the model for each of the 31 days in the month. For each daily run, the model altered the processing rate (based on Engineered Performance Standards) to reflect the runway configurations and weather conditions actually in effect (taken from CATER records). The arrival and departure aircraft demand reflected the demand for that day in terms of volume of operations (taken from the airport tower records) and distribution (based on the Official Airline Guide) for air carriers and air taxi and on the history of activity (recorded by CATER) for military and general aviation traffic.

airport has a processing rate capability of 64 to 68 operations hourly where operations take place on the two intersecting runways, and the processing rate is 48 operations hourly when operations take place on a single runway. The CATER data has an actual record of actual operations which took place in May 1972, and this source strongly indicates that the Engineered Performance Standards underestimate actual airport capacity. Operations records from CATER were aggregated into 30 minute totals. Operations made by aircraft not using the runways (principally motorcraft) were not included in these totals. According to the Engineered Performance Standards, the aircraft processing rate for single runway operations should be 24 per 30 minute period, but 142 half hour periods in the CATER for May (during which single runway operations were in effect) had more than 24 operations. More than sixty half-hour periods had more than 30 operations while operating at single runway configuration. Similarly, the actual operations recorded when the airport was using the intersecting runway configuration frequently exceeded the maximum processing rate of 34 operations per half-hour projected by the Engineered Performance Standards. For May 1972, 65 half-hours (during which the intersecting runway configuration was in use) had greater than 34 operations including helicopter operations according to CATER, and 9 half hours had 40 or more recorded operations.

The processing rate input to the model is quite important in developing good delay estimates. The LGA activity simulation resulted in very large delay outputs because the record of demand for airport activity frequently had several consecutive hours in which the demand for service was considerably greater than the maximum service rate. In the belief that the service rate values originally input were unrealistically low, the simulation for LGA was run again with a processing rate of 60 operations per hour during single runway operations and 78 hourly operations during operating periods in which both intersecting runways were in use. These figures are somewhat arbitrary, but there are many instances documented in the CATER when these processing rates were exceeded.[1] In any case, these processing rates do not appear to be unrealistically high. The results of the second simulation of LGA activity for May 1972 with revised airport processing rate estimates appear in Table 7.3-2. These results indicate that the base case simulation approximates the estimated delay estimated developed from CAB and PANYNJ activity data.

It must be remembered that considerable error may exist in the estimated delay levels developed from historical activity records. A number of assumptions were required before the figures could be developed. If the historical delay estimates do approximate actual delays, however, it must be stated that the simulation of the airport activity for May of 1972 resulted in reasonable estimates of airport delays. A second clear lesson of the validation exercises is that the interoperation times and

[1] A similar review of CATER data revealed only 15 half hours at JFK when the maximum airport processing rate from E.P.S. was exceeded in May 1972. No half hours were found at EWR when the maximum airport processing rate from EPS was exceeded. Thus, the Engineered Performance Standards for airport processing rates for JFK and EWR were considered realistic and were not altered for model validation purposes.

TABLE 7.3-2. COMPARISON OF HISTORICAL AND SIMULATED AIRPORT AVERAGE DELAY ESTIMATES FOR LGA - MAY 1972 (MINUTES)

| OPERATION | HISTORICAL ESTIMATES | SIMULATED ESTIMATES: BASE CASE | SIMULATED ESTIMATES: SENSITIVITY ANALYSIS RUNS (1) | SIMULATED ESTIMATES: SENSITIVITY ANALYSIS RUNS (2) |
|---|---|---|---|---|
| DEPARTURE | 5.5 | 10.3 | 2.5 | 25.6 |
| ARRIVAL | 8.6 | 14.2 | 3.6 | 43.5 |
| AVERAGE (ALL OPERATIONS) | 7.0 | 12.2 | 3.0 | 34.5 |

processing rates input to the model are particularly important in developing good delay estimates. Slight discrepancies in either direction can result in very large savings in estimated delays, particularly at an airport such as LGA in which the airport operates at or near its capacity for protracted periods of time on a regular basis.

## CHAPTER 7. REFERENCES

7.-1. Performance Measurement System for Major Airports prepared for Federal Aviation Administration, November, 1975.

# 8. MODEL APPLICATION

The Airport Performance Model was applied to three actual airport investment problems to demonstrate its use in practical investment decision making. The investments analyzed were parallel runway construction projects at Detroit Metro Wayne (DTW) Charlotte Douglas Municipal (CLT) and Honolulu International (HNL) airports. These projects are expected to increase the processing rate at their airports and reduce airport congestion and delays in future years. The APM application was designed to estimate airport delays and costs in future years using airport traffic forecasts for the currrent processing rates. Subsequently, there statistics were calculated again after airport processing rates had been increased reflecting the addition of the parallel runways. In this manner the airport delay and cost savings were calculated with and without the addition of the airport investment, and the operating cost savings resulting from the runway construction were estimated. The time stream of cost reduction benefits over a ten year period were discounted to current dollars and compared to the costs of the airport capacity expansion project. The resulting information can be the basis of investment allocation decisions by using benefit cost ratios, internal rate of return, net present value ranking or some other project selection framework.

by the Operations Research Branch of the Office of Air Traffic Service, Federal Aviation Administration. The processing rate changes estimated from these sources are shown in Table 8-2. The processing rate increase for DTW under IFR conditions assumes the new runway is instrumented. The IFR processing rate at CLT would be increased to roughly 90 operations hourly with instrumentation of the new runway. The capacity improvement analyzed here for CLT includes only the benefits from the runway itself and does not include the benefits and costs of instrumenting the runway.

The assumptions on airport traffic demand growth and hourly aircraft processing rate were input to the Airport Performance Model together with the airport characteristics data file for CLT, HNL, and DTW. This data file includes information on airport fleet mix, demand distribution, weather characteristics and other factors. Annual airport activity levels for years not shown in Table 8-1 were generated by linear interpolation. The model was excercised repeatedly to estimate annual aircraft and passenger delay costs for the airport without increasing hourly aircraft processing rates. Subsequently, the cost of aircraft and passenger delays at the airports assuming the runway construction projects were made, and hourly processing rates were increased as shown in Table 8-2.

The impact of capacity improvement on average delay per operation is shown in Table 8-3 for CLT, HNL and DTW. In each

TABLE 8-2. PROCESSING RATE INCREASES FOR SELECTED AIRPORT CAPACITY INVESTMENTS (AIRCRAFT OPERATIONS PER HOUR)

| AIRPORT | WEATHER CONDITIONS | |
|---|---|---|
| | VFR | IFR |
| DTW | | |
| EXISTING CAPACITY | 105 | 66 |
| WITH ADDITION OF 3R/21 L | 112 | 100 |
| CLT | | |
| EXISTING CAPACITY | 75 | 57 |
| WITH ADDITION OF 8R/36 L | 135 | 66 |
| HNL | | |
| EXISTING CAPACITY | 82 | * |
| WITH ADDITION OF 8R/26 L | 119 | * |

*VFR conditions are in effect over 99% of the time at HNL

Source: See Discussion in Text

TABLE 8-5. ESTIMATES OF COST AND USER BENEFITS FOR SELECTED AIRPORT INVESTMENTS

| AIRPORT INVESTMENT / INVESTMENT EVALUATION MEASURE | DTW | CLT | HNL |
|---|---|---|---|
| INVESTMENT | RUNWAY 3R/21 L AND INSTRUMENTATION | RUNWAY 18R/36 L | RUNWAY 8R/26 L |
| INVESTMENT COST (1976 $'s x$10^6$) | 16.483* | 6.927 | 10.388 |
| USER DELAY REDUCTION BENEFITS (1976 $'s x$10^6$) | 49.0 | 30.7 | 55.8 |
| NET PRESENT VALUE OF BENEFITS (1976 $'s x$10^6$) | 32.5 | 23.8 | 45.4 |
| BENEFIT COST RATIO | 2.97 | 4.43 | 5.37 |
| INTERNAL RATE OR RETURN (%) | 30-35 | 40-45 | 55-60 |

*Includes $841,000 for installation, operation and maintenance of CAT I ILS for 1976-1986.

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