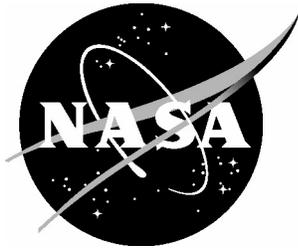


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Future Air Traffic Growth and Schedule Model User's Guide

*Jeremy C. Smith and Samuel M. Dollyhigh
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May 2004

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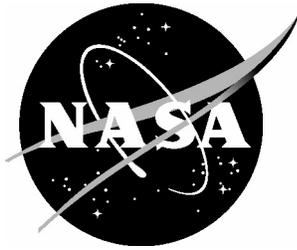
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Abstract

The Future Air Traffic Growth and Schedule Model was developed as an implementation of the Fratar algorithm to project future traffic flow between airports in a system and of then scheduling the additional flights to reflect current passenger time-of-travel preferences. The methodology produces an unconstrained future schedule from a current (or baseline) schedule and the airport operations growth rates. As an example of the use of the model, future schedules are projected for 2010 and 2022 for all flights arriving at, departing from, or flying between all continental United States airports that had commercial scheduled service for May 17, 2002. Inter-continental US traffic and airports are included and the traffic is also grown with the Fratar methodology to account for their arrivals and departures to the continental US airports. Input data sets derived from the Official Airline Guide (OAG) data and FAA Terminal Area Forecast (TAF) are included in the examples of the computer code execution.

The Future Air Traffic Growth and Schedule Model is available on CD-Rom as NASA/CR-2004-213027/SUPPLEMENT and can be obtained from:

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Introduction

The capacity of the nation's transportation system has not kept pace with the growth in demand. Thus costs in terms of lost time and extra fuel consumed, whether it is automobiles or air traffic, continue to grow rapidly for society and business (Ref. 1 and 2). One of NASA's Aerospace Technology Enterprise's aeronautics objectives is to increase capacity and mobility. The theme's performance goals include maximizing airport capacity in all metrological conditions, expanding throughput at the nation's small airports, effectively managing high density traffic flows, and designing new vehicle concepts, such as aircraft that can operate on short runways (Ref. 3). A central issue to conducting system level studies to assess the impact of technologies under consideration to increase the capacity of the air traffic system is to accurately predict future air traffic demands. Any set of technologies to increase capacity will tend to have a wider application and substantially higher payoff when applied to future demand scenarios than when the benefits are measured in the less constrained system of today. Ideally, the unrestricted operational flow demand would be met. References 4 through 7 present a number of approaches to the projection of future traffic flow, including approaches to mitigate the effects of congestion (Ref. 6). A popular growth model, the Fratar algorithm, can be used with readily available databases to project future traffic patterns and schedules. The Fratar algorithm is a trip distribution technique that applies an iterative process to scale a baseline set of origin/destination traffic based on the forecast year growth factors of the individual airports. Commonly used data sources are the current OAG schedule or actual traffic data from the Enhanced Traffic System (ETMS) (Ref. 8) for baseline O&D traffic and the FAA's Terminal Area Forecast (Ref. 9) for the airport traffic growth rates. The additional daily flights between the future year growth schedule and the baseline schedule are then assigned departure times to maintain the cumulative departure time of day pattern of the current schedule.

This report presents an implementation of the Fratar algorithm to predict the additional flights between airports within the system and to spread the additional flights into time slots between existing flights so as to match the established demand patterns for the airports. Although the Fratar method has been commonly used to grow future traffic based on today's traffic and projected growth rates, the implementation code has not been readily available, thus, one purpose of this report is to make the implementation code available to academia, government, and industry researchers. The current implementation is intended to predict an unconstrained future schedule based on projected demand and the time of day patterns from the current schedule. Note that there is an implicit assumption that on the whole the current time of day travel patterns reflect traveler's preferences and thus, a future system will tend to preserve these patterns unless otherwise constrained. The growth model including inputs, output, program options, utility subroutines, installing and executing the code are detailed in the report. A brief description of the baseline air traffic schedule and the airport growth rate data that are contained in the program files is in Appendix A.

AIR TRAFFIC GROWTH MODEL

Description

The Growth Model generates a future air traffic schedule based only on a current schedule and the predicted growth factors for each airport of interest for a future year.

An implementation of the Fratar algorithm is used to create a future daily total number of flights between each origin and destination airport pair of the current schedule. The Fratar algorithm is a simple mathematical expression that is used to allocate future flights between origin and destination airports as a function of the product of the current flights between the origin and destination pairs and the growth factors for each airport. Details of the implementation are given in Fratar Algorithm Implementation section.

The Fratar algorithm is used to create a future daily total of flights between each origin and destination; it is not used to create a schedule. For this reason a separate function was developed to generate the new schedule. This function generates the new schedule based on the current schedule and optionally spreads the additional flights in time slots between the existing flights. Details of this flight spacing algorithm are given in Future Schedule Generation section.

In addition to the main program, a utility program: Airport Operations; is provided that extracts an epoch-by-epoch departure/ arrival schedule from the Growth Model generated schedule for any specified airport. Details of this program are given in Airport Operations Post Processing section.

Installation and Execution

The Growth Model and Airport Operations utility are written in C++ using Microsoft Visual Studio 6.0. A visual studio project file (.dsw) for both the Growth Model and the Airport Operations utility are provided to allow building or modification of the programs. The complete package is available on CD.

The directory structure is as follows:

/GROWTHMODEL/

Contains the source code and the Microsoft project files.

/GROWTHMODEL/data/

Contains the input files.

/GROWTHMODEL/data/example

Contains example input files.

/GROWTHMODEL/data/output/
Contains the output files.

/GROWTHMODEL/data/output/example
Contains example output files.

/GROWTHMODEL/debug
Contains the Microsoft project debug version of the program executable for development.

/GROWTHMODEL/release
Contains the Microsoft project release version of the program executable optimized for speed without debug symbols. Also contains example batch files.

/GROWTHMODEL/doc
Contains the documentation.

Clicking on the “growthModel.bat” icon in the /release directory executes the Growth Model. The batch file can be edited with a text editor. Alternately the Growth Model can be started from Windows by double clicking the “growthModel.exe” icon or from the command line by typing “growthModel”.

The Airport Operations post-processing program can also be run in the same way using the “airportOps.bat” file or directly using the “airportOps.exe” image.

Running the executables directly requires that the input files be collocated with the executable file unless the locations are specified as command line parameters.

Inputs and Outputs

The required input files are: a program control file, a current schedule file and an airport growth factor file. The output files are: a summary of the current schedule, a future schedule and optionally a log file.

Command Line Parameters

The name and location of the program control file can be specified:
e.g. c:\growthStudy\growthModelInput2010.txt

Program Control File

The Program Control File is by default named growthModelInput.txt and must be in the same directory as the executable. The name and location can be changed from the default by specification on the command line as an input parameter.

The Program Control File allows the names and locations of the input and output files and some control parameters to be specified:

inputScheduleFile - The current schedule.

inputGrowthFile -	The growth factors for each airport in the current schedule.
outputCurrentScheduleFile -	The current schedule in the same format as the future schedule.
outputFutureScheduleFile -	The future schedule.
outputLogFile -	Optional debugging/ performance monitoring data (leave blank if not required).

The following control parameters can be specified:

NUM_EPOCHS=	Schedule can be generated in 15 minute (96 epochs) or 1 hr (24) epochs.
NUM_FRATER_ITS=	Number of iterations of the Fratar algorithm. (Any value can be input but 10 -1000 is reasonable).
SPREAD_SCHEDULE=	Space the new flights in time between current scheduled flights (TRUE/ FALSE). If FALSE new flights will be generated at the same departure/ arrival epochs as the current schedule
REFINE_GROWTH_FACTORS=	Adjust Fratar generated growth factors at each iteration to give better convergence of Fratar generated total flights towards required total daily flights between airport pairs.

Comments are denoted using “//”.

Example Program Control File

```
// input file for 2010
inputScheduleFile=c:\asac\growthmodel\data\oagschedule.txt
inputGrowthFile=c:\asac\growthmodel\data\growthfactor_2010.txt
outputCurrentScheduleFile=c:\asac\growthmodel\data\output\oagscheduleCurrent.txt
outputFutureScheduleFile=c:\asac\growthmodel\data\output\oagscheduleFuture_2010.txt
outputLogFile=c:\asac\growthmodel\data\output\growthModelLog_2010.txt
NUM_EPOCHS=96
NUM_FRATER_ITS=1000
SPREAD_SCHEDULE=TRUE
REFINE_GROWTH_FACTORS=TRUE
```

Input Schedule File

The input schedule file contains the current schedule in the following format:

Dep. Airport	Dep. Time	Arr. Airport	Arr. Time	Aircraft Type
3 or 4 chars	hours minutes	3 or 4 chars	hours minutes	string

Example Input Schedule File (part)

```
ABE 655 ATL 859 CRJ
ABE 1255 ATL 1459 CRJ
ABE 1855 ATL 2059 CRJ
ABE 730 BOS 905 DH8
ABE 1850 BOS 2022 DH8
```

The aircraft type is optional.

Note that each airport in the schedule must have a growth factor defined in the Input Growth File (even if zero growth is required).

Input Growth File

The input growth file contains the growth factors for each airport in the following format:

Airport Number	Airport Id	Growth Factor %
unique integer	3 or 4 characters	floating point %

Note that even for airports with zero growth, an entry (0 or 0.0) must be specified.

Example Input Growth File (part)

```
1 ABE 39.98183234
2 ABI 22.7232729
3 ABQ 74.31581146
4 ACV 0
```

Output Current Schedule File

The output current schedule file contains a summary of the input schedule allocated to epochs in the following format:

Departure Airport Id	Departure Epoch	Arrival Airport Id	Arrival Epoch	Number of Flights	Aircraft Type
3 or 4 chars	0 to 23/ 95	3 or 4 chars	0 to 23/ 95	integer	string

The epoch number corresponds to either the hour or 15-minute interval depending on the input control parameter number of epochs. The aircraft type is only output if included in the input schedule file and if present, an aircraft type will be listed for each flight.

Example Current Schedule File (part)

```
ABE 27    ATL 35    01    CRJ
ABE 51    ATL 59    01    CRJ
ABE 75    ATL 83    01    CRJ
ABE 30    BOS 36    01    DH8
ABE 75    BOS 81    01    DH8
```

Output Future Schedule File

The output future schedule file contains the future schedule allocated to epochs in the same format as the output current schedule (see above).

Output Log File

The output log file contains data that can be used to check the results achieved by the Frater algorithm in the following format:

AirportId CurrentFlights ReqdFlights ActualFlights Discrepancy ReqdGrowth % ActualGrowth %

ReqdFlights is the product of current flights and input growth factor, ActualFlights is the Frater computed result and Discrepancy is the difference. ReqdGrowth and ActualGrowth are the input values and Frater computed result respectively.

Summary data are given at the end of the file. The maximum flights discrepancy and the corresponding airport id are logged. The total square discrepancy can be used as a measure of the overall performance of the Frater algorithm and can be used to investigate the effect of changing the number of iterations or use of the **REFINE_GROWTH_FACTORS** flag.

Example Output Log File (part)

```
AirportId CurrentFlights ReqdFlights ActualFlights Discrepancy ReqdGrowth% ActualGrowth%
ABE 41    57    57    0    39.982 39.024
ABI 11    13    13    0    22.723 18.182
ABQ 167   291   289   -2    74.316 73.054
```

```
airport: ABQ max flights discrepancy: 2 total square discrepancy: 44
number of airports: 643
current flights: 30853 future flights: 47991
percentage total growth: 55.547
```

Fratat Algorithm Implementation

The Mathematical formulation of the Fratar algorithm is:

$$F'_{ij} = (F_i * G_i) * \frac{(F_{ij} * G_j)}{\sum_n F_{in} * G_n}$$

where

F'_{ij} - next estimate of flights from airport i to airport j

F_{ij} - current estimate of flights from i to j

F_i - total flights from i

G_n - growth factor for airport n

Setting the current estimate of flights to the current schedule value and the growth factors to the required growth factors initializes the algorithm. Subsequent iterations re-compute the growth factors as the ratio of the current estimate to the required number of flights. The Fratar growth factors therefore tend towards unity as the estimate converges towards the required number of flights. After each iteration the new estimate of flights from i to j and from j to i are equalized by taking the average.

The Growth Model implements the Fratar algorithm using whole numbers of flights. Not allowing fractional flights can lead to small discrepancies between the Fratar computed values and the desired number of flights. For this reason a modification was made to allow the growth factors to be varied slightly from the Fratar computed values to give a closer convergence between the required number of flights and the Fratar computed values. Setting a flag in the input file enables this optional refinement.

Future Schedule Generation

The Fratar algorithm is used to generate a daily total number of flights between each origin and destination pair. It is not used to generate an epoch to epoch total since the algorithm does not work well with small numbers of flights. It is therefore necessary to

generate a new schedule by apportioning the future daily total flights to each time epoch in the day. This is done by maintaining the original schedule and then scheduling the additional flights to match the current cumulative departure schedule. The flights can then optionally be spaced in time according to the following rules:

- Schedule the additional flights evenly between the previous departure epoch and next departure epoch for the same destination where these flights exist.
- Schedule the additional flights evenly between the current time epoch and the next departure when only a later departure exists.
- Schedule the additional flights evenly between the current time epoch and the previous departure epoch when only an earlier departure exists.
- Schedule the additional flights at hourly intervals, subsequent to the current time for morning flights and prior to the current time for evening flights when only one flight exists in the current schedule.

This scheme causes some spreading of the existing arrival/ departure patterns but in practice produces a plausible schedule that preserves much of the existing structure of the banks of arrivals and departures at hub airports. Not spacing the flights allocates new flights in the same departure/ arrival epochs as current flights and may represent a less realistic scheduling policy. Since spacing the flights is optional the user can decide which is the most appropriate scheduling policy for the study being undertaken. Some example output is given in Example Results section.

Airport Operations Post Processing

The Airport Operations program is a utility that can be used to post-process the current or future schedule output file generated by the Growth Model. It extracts an epoch-by-epoch departure/ arrival schedule from the generated schedule for any specified airport contained within the schedule. The program takes the input file path name, the output file path name, the airport of interest and the number of epochs in a day (must match the value used to generate Growth Model schedules) as command line options.

e.g. `airportOps.exe C:\ASAC\GROWTHMODEL\data\output\oagscheduleCurrent.txt C:\ASAC\GROWTHMODEL\data\output\ATL_airportOpsCurrent.txt ATL 96`

The program can be controlled via a batch file to process a list of airports. An example batch file “airportOps.bat” is provided.

The output is in the following format:

Epoch	Departures	Arrivals
0 to 23/ 95	integer	-ve integer

Example Output Airport Operations File (part)

Departures and Arrivals for ATL

Epoch	Departures	Arrivals
0	3	-3
1	1	-3
2	0	-2
3	0	-1
4	0	-3
5	0	0
6	0	-2
7	0	-3
8	0	-1

Example Results

Some example results are contained in the /GROWTHMODEL/data/output/example directory, obtained using the input files in /GROWTHMODEL/data/example directory.

The log files are:

- growthModel_2010.txt and growthModel_2022.txt

with corresponding output files:

- oagscheduleCurrent.txt, oagscheduleFuture_2010.txt and oagscheduleFuture_2022.txt.

The Airport Operations utility program was used to extract schedule data for several airports.

Some examples of the results obtained for 2022 are shown in the Microsoft Excel charts below.

Figure 1 compares the current and Growth Model generated 2022 daily departures and arrivals at 15-minute intervals for Atlanta (ATL). The flight spacing option was used to space the additional flights between the current scheduled flights. The chart shows that the arrival/ departure banking characteristics at Atlanta are still clearly present in the Growth Model generated 2022 data.

Figure 2 shows the effect of not using the flight spacing option. In this case the generated 2022 banking characteristics exactly match the current schedule, but the schedule may represent a less plausible future schedule.

Figure 3 shows the results for Chicago (ORD) using the flight spacing option.

Figure 4 shows the results for Chicago (ORD) without the flight spacing option.

Figure 5 shows the results for Boston (BOS) using the flight spacing option.

Figure 6 shows the results for Boston (BOS) without the flight spacing option.

ATL Departures and Arrivals

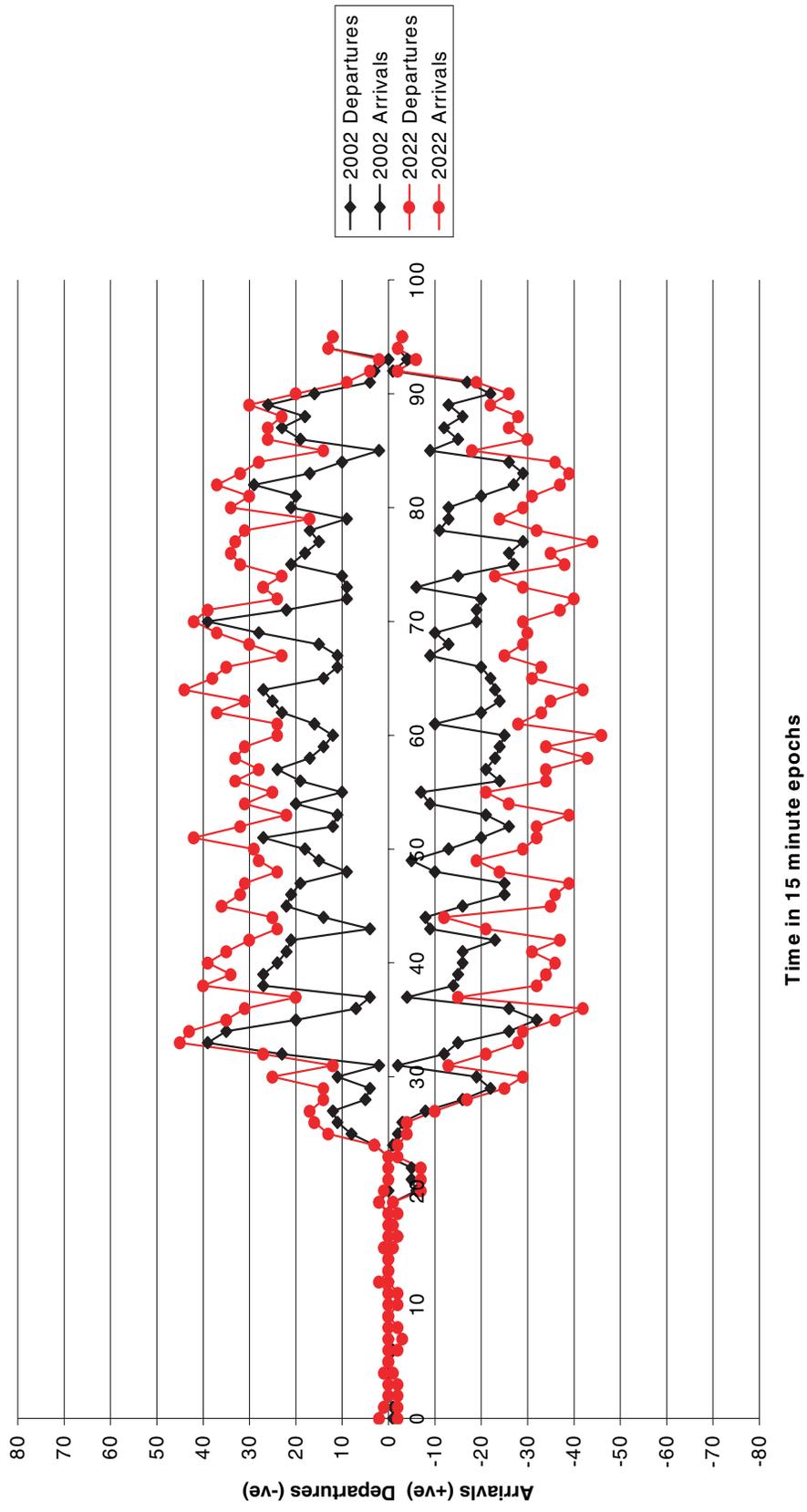


Figure 1 Atlanta schedule with additional flights spaced between current flights

ATL Departures and Arrivals

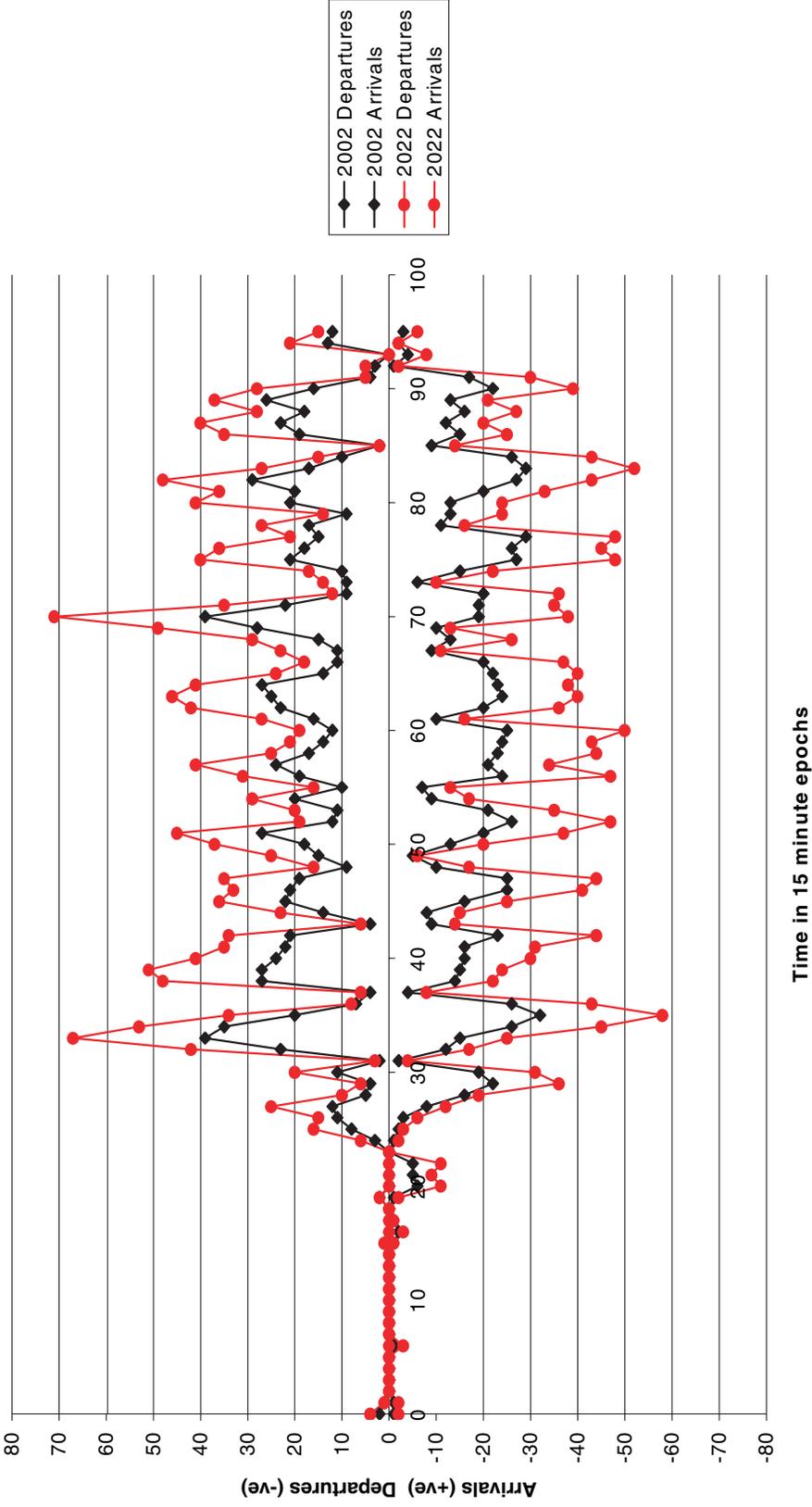


Figure 2 Atlanta schedule with additional flights at same epoch as current flights

ORD Departures and Arrivals

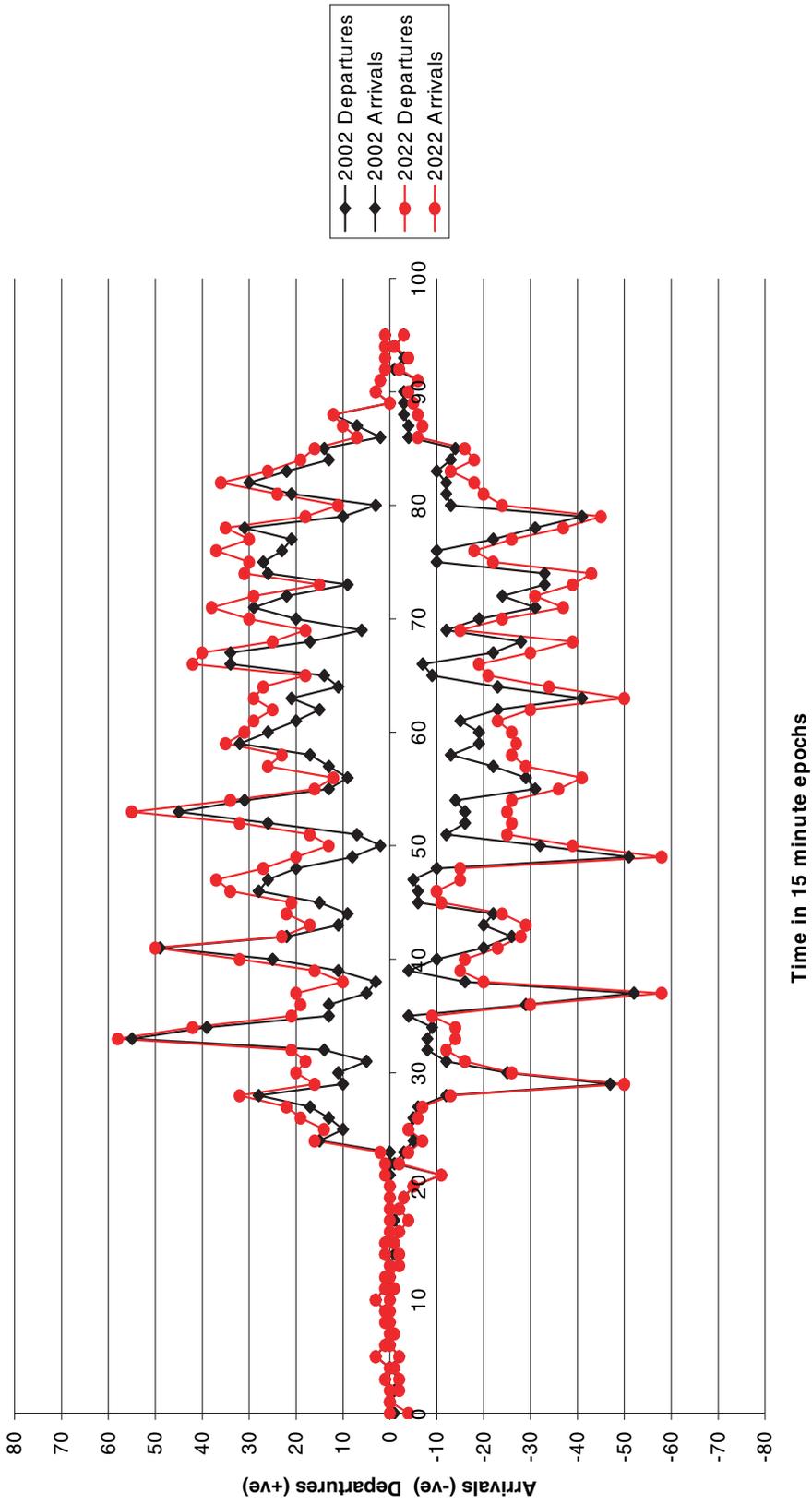


Figure 3 Chicago schedule with additional flights spaced between current flights

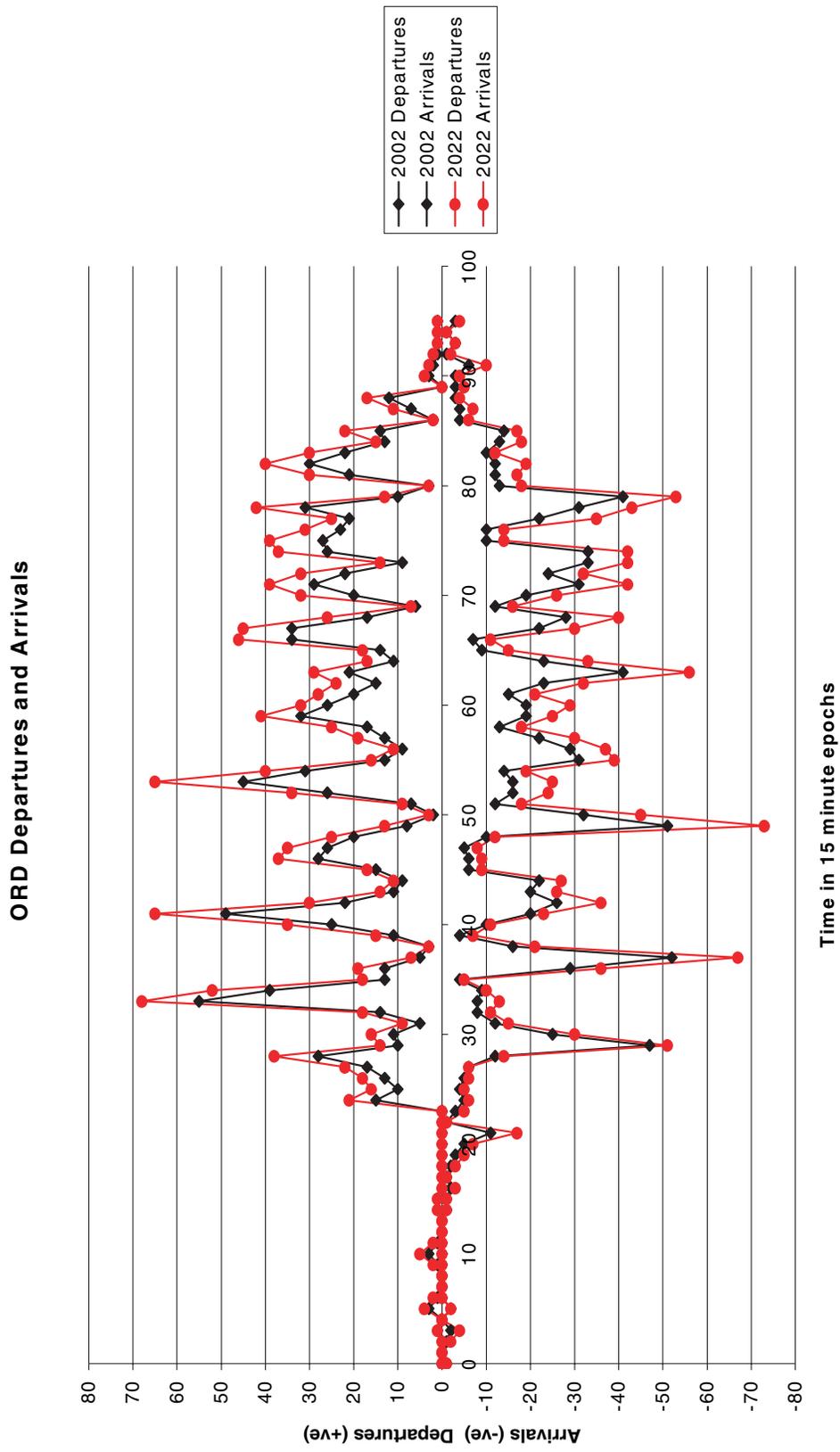


Figure 4 Chicago schedule with additional flights at same epoch as current flights

BOS Departures and Arrivals

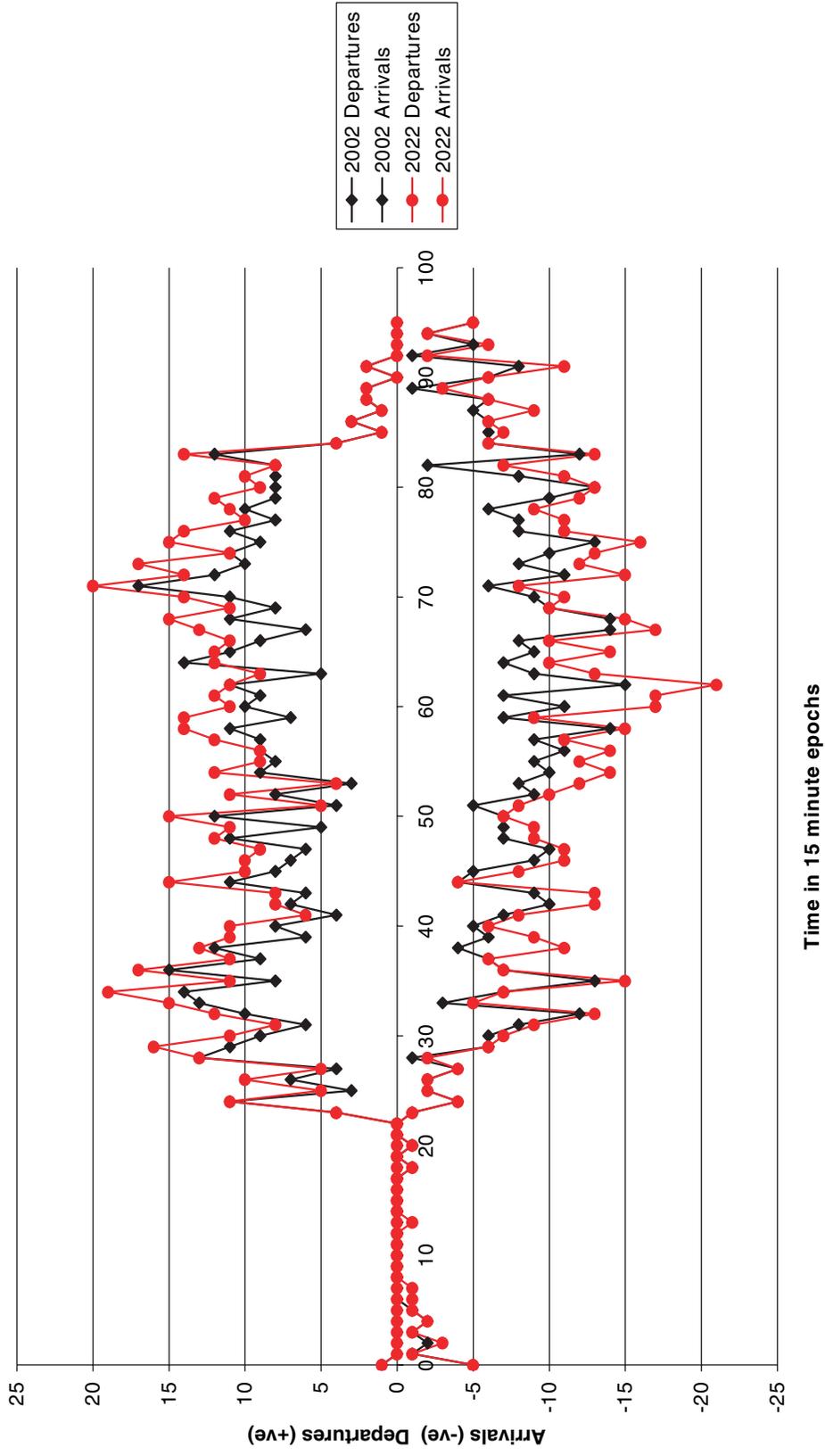


Figure 5 Boston schedule with additional flights spaced between current flights

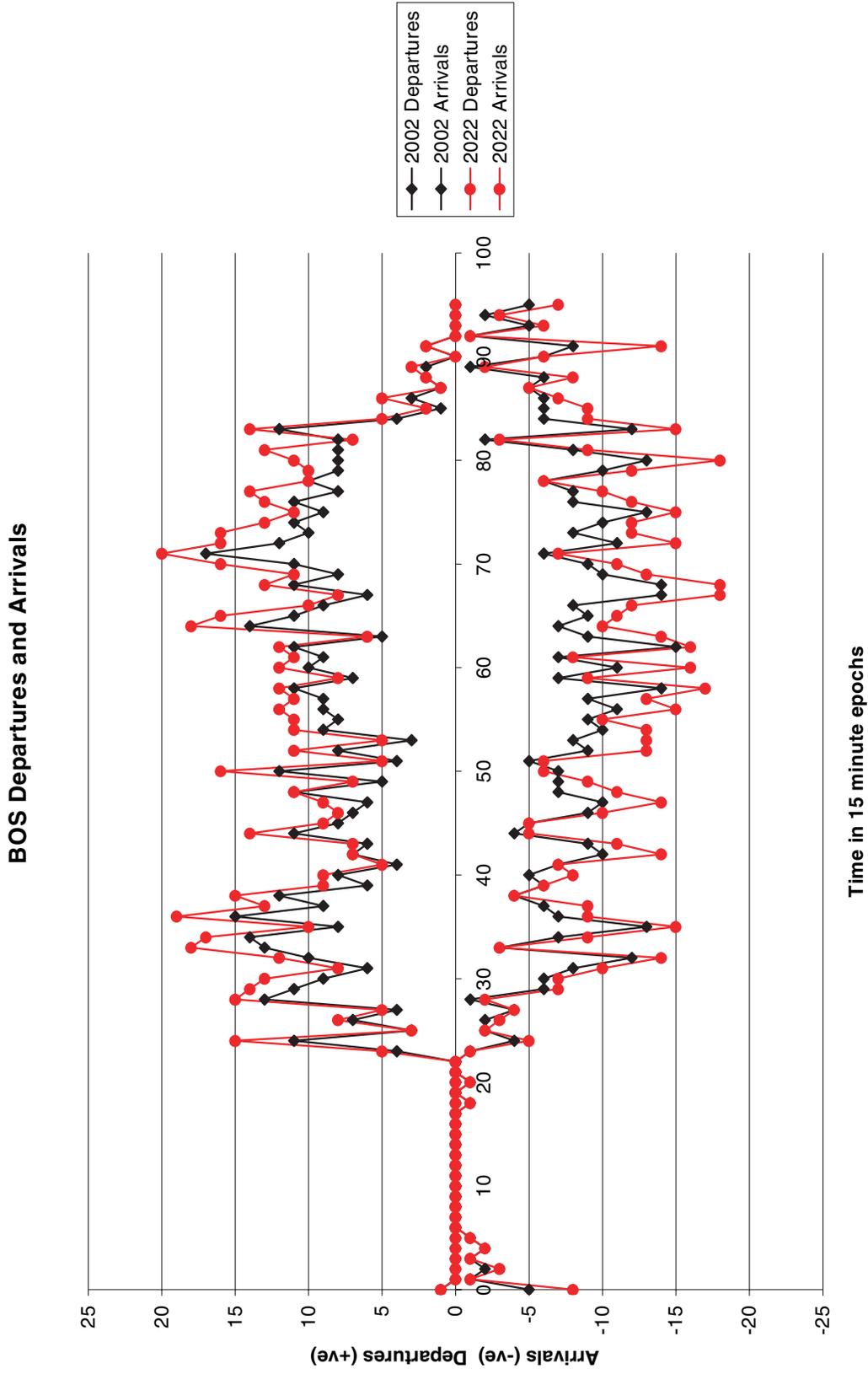


Figure 6 Boston schedule with additional flights at same epoch as current flights

Computer System Requirements

The program was built and tested on a PC running Windows 2000 with a 2.66 GHz Pentium 4 processor and 1 GB of RAM. The Growth Model executes in about 3 minutes with 640 airports and 1000 iterations on this system and should give satisfactory execution speed on far less powerful systems. The number of airports is limited only by the memory capacity of the machine since memory is dynamically allocated as required.

Concluding Remarks

The Future Air Traffic Growth and Schedule Model was developed as an implementation of the Fratar algorithm to project future traffic flow between airports in a system and of then scheduling the additional flights to reflect current passenger time-of-travel preferences. The methodology produces an unconstrained future schedule from a current (or baseline) schedule and the airport operations growth rates. As an example of the use of the model, future schedules are projected for 2010 and 2022 for all flights arriving at, departing from, or flying between all continental United States airports that had commercial scheduled service for May 17, 2002. Inter-continental US traffic and airports are included and the traffic is also grown with the Fratar methodology to account for their arrivals and departures to the continental US airports. Input data sets derived from the Official Airline Guide (OAG) data and FAA Terminal Area Forecast (TAF) are included in the examples of the computer code execution.

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Appendix A – OAG and Airport Growth Data

The baseline OAG data set was extracted from the international OAG data for 2002. Worldwide yearly flight schedules are for sale by OAG (www.oag.com), which was formerly known as the Official Airline Guide. The data are for May 17, 2002 for all scheduled flights into, from, and between airports in the continental United States. Flights arriving and/or departing a total of 643 airports were scheduled for the baseline day. Of these airports, 458 are located in the continental US and the remaining 185 are either foreign or located in Alaska or Hawaii and have flight arriving from or departing to one or more of the 458 continental US airports.

The airport growth data is from two sources. The US airport growth data is from the FAA terminal Area Forecast (TAF). This FAA forecast is produced annually and for larger airports is developed using historical relationships between airport passenger demand and/or activity measures and local and national factors that influence aviation activity (Ref. 9). The TAF assumes an unconstrained demand for aviation services based on local and national economic conditions, as well as, conditions within the aviation industry as a whole. However, if an airport has historically functioned under constrained conditions, the forecast may reflect those constraints since they are embedded in the historical data. Large hub airport forecasts not only consider local economic variables, but also the growth of both originating and connecting traffic and load factors for aircraft operating from the hub airports. In addition to the 474 airports receiving FAA and contract tower services, the TAF databases also includes projections for 2895 other airports in the National Plan of Integrated Airport Systems (NPIAS). Airport air traffic growth data for the non-US airports was derived from data in the FAA Aerospace Forecast (Ref. 10). The projections for international revenue passenger miles (RPM's) were adjusted for the projected changes in average aircraft size (number of seats), trip length, and the average load factor to arrive at a projected growth rate in terms of aircraft operations. All non-US airports were assigned this growth rate. Note that these foreign airport numbers could have been further refined by obtaining International Civil Aviation Organization (ICAO) data for the international aircraft movements for the last five years at major international airports (Ref. 11) and adjusting the growth rate to reflect the current trends at each airport. However it is not anticipated that this latter step would substantially change the projected arrivals and departures from continental US airports, but is offered as a further refinement on the analysis. Also note that there are other private sources of aviation growth data that may not exactly match the FAA growth rates and in general tend to be more conservative than the FAA numbers.

The baseline OAG schedules and the growth rate tables for 2010 and 2022 are included in the program files. The output files using this data to produce projected schedules for 2010 and 2022 are also included.

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14. ABSTRACT The Future Air Traffic Growth and Schedule Model was developed as an implementation of the Fratar algorithm to project future traffic flow between airports in a system and of then scheduling the additional flights to reflect current passenger time-of-travel preferences. The methodology produces an unconstrained future schedule from a current (or baseline) schedule and the airport operations growth rates. As an example of the use of the model, future schedules are projected for 2010 and 2022 for all flights arriving at, departing from, or flying between all continental United States airports that had commercial scheduled service for May 17, 2002. Inter-continental US traffic and airports are included and the traffic is also grown with the Fratar methodology to account for their arrivals and departures to the continental US airports. Input data sets derived from the Official Airline Guide (OAG) data and FAA Terminal Area Forecast (TAF) are included in the examples of the computer code execution. The Future Air Traffic Growth and Schedule Model is available on CD-ROM as NASA/CR-2004-213027/SUPPLEMENT.					
15. SUBJECT TERMS Fratar Algorithm; Air Traffic Growth; Air Traffic Demand; Air Traffic Schedules					
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