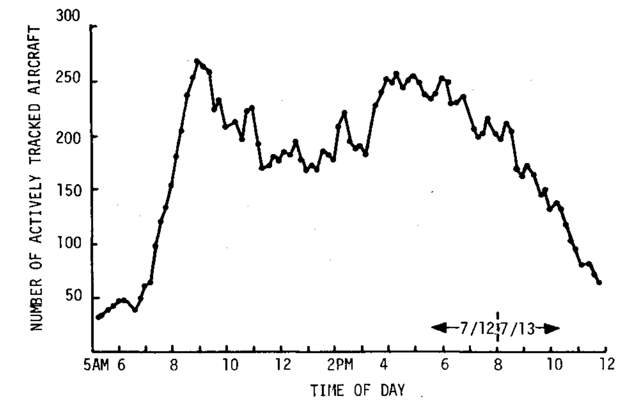

Fig. 1 Number of actively tracked aircraft in Cleveland ARTCC vs time of day, July 12, 1979.

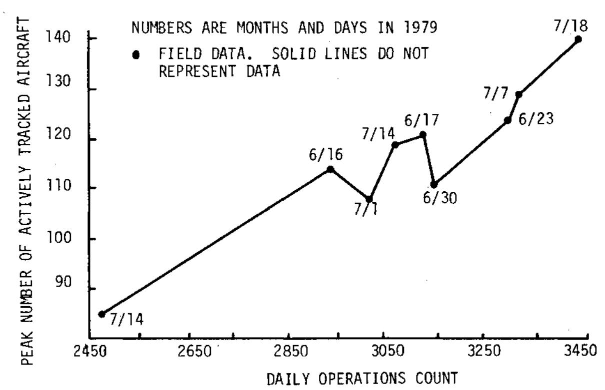

Fig. 2 Peak number of actively tracked aircraft in Houston ARTCC vs number of operations.

Interpretation of Principal Results

In the last section, linear regression was used to derive a relationship between peak IAC and operations data. This section derives the same relationship theoretically. Approximate all air activity by one constant pulse with a 12-h window (see Fig. 1). The average number of operations per hour is $X/12 = (0.083)X$, where X is the total number of daily operations. There are two terminal operations per in-flight aircraft, i.e., for every arrival there is a departure. This relationship is approximately true during busy times, for a busy airport within the ARTCC cannot allow for long a significant excess between arrivals and departures. The number of overflights (for a terminal ARTCC) during periods of peak morning activity are relatively small. The peak count is therefore $(1/2)(0.083)X = (0.042)X$. The estimated slope, 0.042, agrees very well with the actual slope, 0.037.

Houston (an enroute ARTCC) is likely to have a significant number of morning overflights. There are two terminal operations per in-flight aircraft, but one overflight operation per in-flight aircraft. There are therefore an average of three operations for every two in-flight aircraft. The peak IAC is $(2/3)(0.08)X = (0.05633)X$. The slope 0.056 agrees closely with the slope of the regression curve, $A = 0.053$.

The foregoing physical interpretations are simplistic, but they do suggest that regression models describing terminal and enroute centers are possible.

Conclusions

Analysis of preliminary data (Table 1) suggests that a regression of peak number of actively controlled aircraft on total daily operations is a feasible way to economically estimate the peak IAC over various ARTCCs. The method is attractive because operations data are easy to acquire. It is possible to have one general regression model for the entire continental U.S. or separate models for each ARTCC. The "noise" in the former (i.e., the standard error of estimate) would depend on the "noise" in the latter models. For example, the standard error of estimate for the overall model was $\hat{\sigma} = 34.7$, whereas for the individual Houston model, $\hat{\sigma} = 5.1$.

Peak models for terminal and enroute centers appear possible, and improved estimates of peak IAC might be possible by regressing not on total daily operations but, instead, on their component operations, which consist of arrivals, departures, and overflights. An important question might be answered: Are individual model parameters required for each ARTCC, or can models be devised that are applicable to two or more centers as a group?

A more comprehensive sampling and analysis plan to obtain new data from all ARTCCs will be used to validate these results. Daily, weekly, and possible seasonal effects will also be analyzed. The original regression model, which regressed on only one variable, may eventually be replaced by an improved model that regresses on several variables. However, it is unknown if there will be a significant improvement in model accuracy. Finally, the limited number of samples (Table 1) probably means that the tolerances in Table 2 may not be very accurate. However, preliminary engineering planning does not require precise accuracy in peaks or tolerances.[5]

Acknowledgment

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Air Traffic Control Computer Performance in the National Airspace System

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Introduction

THE Federal Aviation Administration operates a nationwide enroute air traffic control system which is supported by several dedicated computers. This equipment

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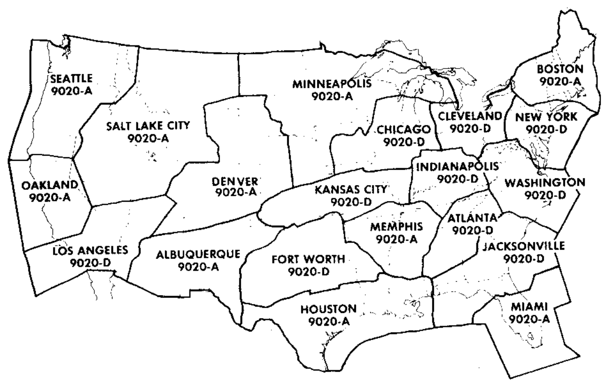

Fig. 1 Geographical coverage of the NAS enroute centers.

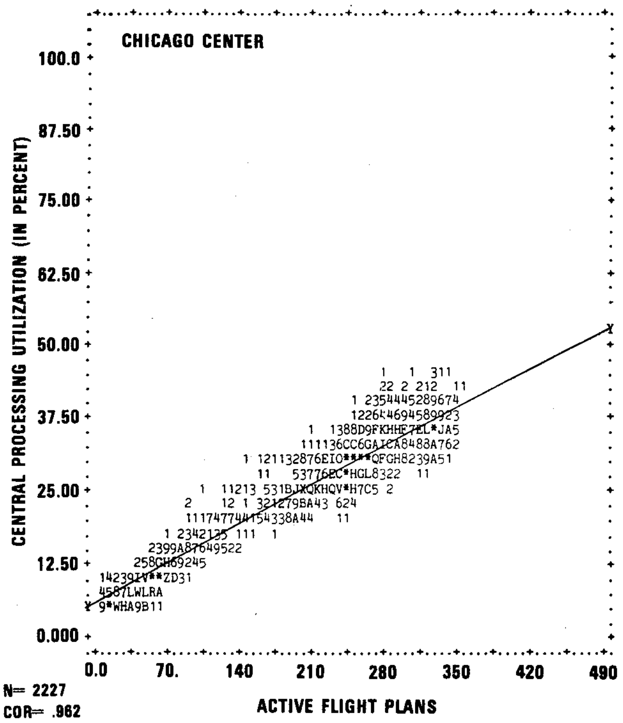

Fig. 2 Scatter diagram for Chicago Center.

sustains traffic loads which continue to increase over the years. Consequently, the computers will eventually reach their designed processing limit. Plans are now in effect to replace them by the late 1980s with more powerful computers which will handle the growth in air traffic through the coming decades. In the meantime, it is important to determine the performance of the current computers in processing traffic loads expected in the immediate future. The study described in this Note addresses this problem and represents an assessment of the equipment's capability to handle traffic until a replacement system is available. A mathematical analysis based on linear regression has been completed in order to quantify computer performance, characterized in this study as central processing utilization (a key measure of computer work) expressed as a function of air traffic loads. Using a statistical tool,[1] the analysis examined data recorded minute-by-minute for several days at all enroute centers in the National Airspace System (NAS) during air traffic operations.

System Overview

The airspace over the continental United States is divided into 20 geographical areas, each falling under the jurisdiction

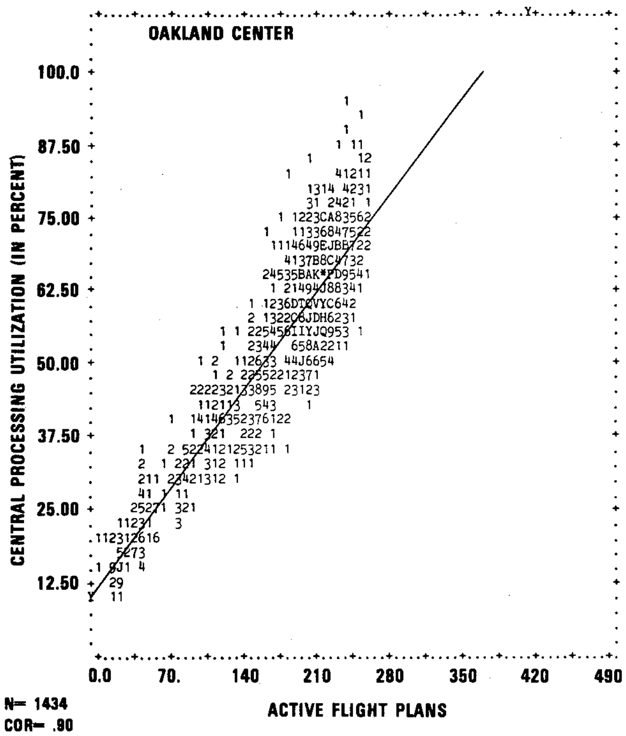

Fig. 3 Scatter diagram for Oakland Center.

of a traffic control center as described in Fig. 1. At each center, a computer, essentially based on the IBM 360 family and designated as the 9020 Central Computer Complex, provides automation support to air traffic controllers by performing simultaneously several processing functions related to safe handling and separation of aircraft.[2] Ten of the busiest centers have 9020D equipment, while the remaining ten sites have the slower 9020A computers (see Fig. 1). A 9020D processes data about 2.5 times faster than the 9020A.

Analysis

A main goal of this study was to identify critical performance and workload measures for the central computer complex and then relate them to each other in a linear regression model. Toward this end, central processing utilization, a parameter expressing the percentage of time that the arithmetic nucleus spends in processing data, was selected as a key performance measure. It reflects computer work and varies during the day as air traffic demand for computer services climbs and decays over time at each facility. Although other factors can possibly limit computer performance (such as excessive response times, for example), processing utilization was chosen because it is the most accurate indicator of overall hardware use in the case of the 9020 experience.

In the process of defining a proper workload measure, it was determined that diverse air traffic conditions and a variety of controller requests for data constitute the load on the computer. The inclusion of all these factors in a model results in a complex expression. A complex model, in turn, becomes difficult to calibrate and to apply in practice. As a result, the selection was narrowed down to one important workload factor: the number of active flight plans processed by the computer. The study assumes that this value substantially reflects the total load on the system. This generalization holds because, although air traffic requires a multitude of services from the computer complex, its two essential functions are to process and to track almost all flight plans. The latter is therefore an ultimate representation of total workload.

Table 1 Regression equations for all air traffic control centers

Center[a]	IBM system[b]	Equation of percent utilization as a function of flight plans	Fit[c]	Standard error[d]	Sample size
Albuquerque (ABQ) 2.9	A	utilz[e] = 10.61 + 0.224flight plans	0.893	6.18	3617
Boston (BOS) 2.9	A	utilz = 7.982 + 0.234flight plans	0.815	6.50	3184
Denver (DEN) 2.10	A	utilz = 13.67 + 0.212flight plans	0.904	5.44	1580
Houston (HOU) 2.9	A	utilz = 8.460 + 0.236flight plans	0.950	5.12	4281
Memphis (MEM) 2.9	A	utilz = 9.219 + 0.195flight plans	0.935	4.72	4168
Miami (MIA) 2.9	A	utilz = 8.412 + 0.231flight plans	0.867	5.16	3138
Minneapolis (MSP) 2.9	A	utilz = 10.72 + 0.236flight plans	0.895	5.51	2990
Oakland (OAK) 2.10	A	utilz = 11.46 + 0.239flight plans	0.810	6.90	1434
Seattle (SEA) 2.10	A	utilz = 9.387 + 0.233flight plans	0.892	4.03	1967
Salt Lake City (SLC) 2.9	A	utilz = 11.72 + 0.205flight plans	0.860	5.06	2200
Atlanta (ATL) 2.9	D	utilz = 5.218 + 0.082flight plans	0.835	3.36	2644
Chicago (CHI) 2.10	D	utilz = 4.532 + 0.098flight plans	0.925	2.90	2227
Cleveland (CLE) 2.9	D	utilz = 3.904 + 0.096flight plans	0.916	3.42	3035
Washington (DCA) 2.9	D	utilz = 4.387 + 0.096flight plans	0.837	3.97	3400
Fort Worth (FTW) 2.10	D	utilz = 4.544 + 0.101flight plans	0.812	4.58	3231
Indianapolis (IND) 2.9	D	utilz = 2.576 + 0.102flight plans	0.931	2.59	4155
Jacksonville (JAX) 2.9	D	utilz = 5.979 + 0.076flight plans	0.824	3.05	2218
Los Angeles (LAX) 2.9	D	utilz = 1.797 + 0.126flight plans	0.931	2.54	561
Kansas City (MKC) 2.9	D	utilz = 4.818 + 0.104flight plans	0.890	2.18	3128
New York (NYC) 2.9	D	utilz = 5.129 + 0.132flight plans	0.830	5.14	3449

[a] 2.9 or 2.10 next to each center name corresponds to the A3d2.9 or A3d2.10 software version, respectively. [b] The IBM system column refers to the center's computer version. [c] The Fit column contains the coefficient of determination which when close to 1.0 indicates a close fit to the data. [d] The standard error column contains the standard error of estimate which is a measure of the standard deviation of the data points around the regression line. [e] "Utiliz" is an abbreviation for central processing utilization.

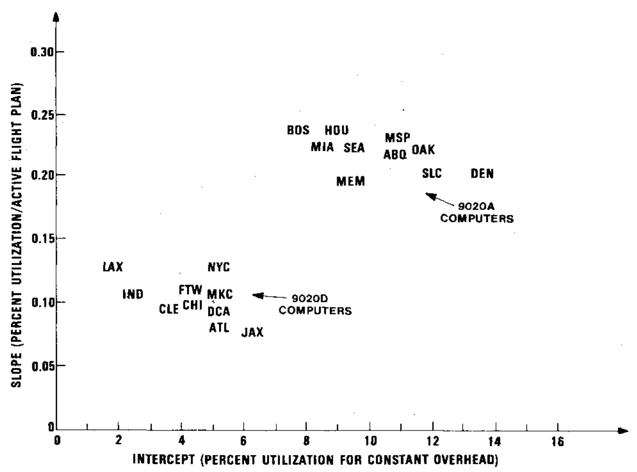

Fig. 4 Plot of sites according to the slope and intercept values of their respective equations in Table 1.

Results

Scatter diagrams have been prepared to visualize the collected data for each site. Those in Figs. 2 and 3, for example, are plots of central processing utilization (shown as a percentage of the total available capacity along the y axis) and the corresponding active flight plan count (shown along the x axis) for Chicago and Oakland data, respectively. Digits in the graphs denote single or repeated observations taken at different times. A 2 indicates two identical observations, a 3 denotes three observations, and so on. For counts greater than nine, the letter A denotes ten observations, B is for 11 observations, and so on. An asterisk is used for 36 or more observations. The straight line shown in each plot corresponds to the calculated least-squares first-order equation which best fits the data. The N near the bottom left indicates the sample size while the COR represents the coefficient of correlation between the vertical and horizontal variables. Chicago has a 9020D system which is faster than Oakland's 9020A. This difference is seen in Fig. 2, which shows a lower utilization at Chicago despite heavier traffic loads. Otherwise, the utilization and active flight plan scatter in both figures follows a linear trend which suggests that the straight-line regression equation is an appropriate way to describe the data. Equivalent plots have been prepared for each of the remaining facilities and the linear scatter shape prevails throughout the site data. The derived regression equations for the 20 sites appear in Table 1. The intercept and slope components of each equation have been plotted in Fig. 4 to observe any difference between sites. Two clusters are apparent in that figure: the fast 9020D sites in the lower left corner of the plot and the slower 9020A sites in opposite direction. The smaller differences within each cluster are assumed to be due to local traffic and environment conditions. The intercept term in the equations accounts for cyclic processing created by periodic programs. It is present even under no traffic load. These programs, like the program element dispatcher and the beacon/primary radar data processor, are scheduled to work in continuous cycles or at specific intervals (ranging from 1 to a few seconds) regardless of traffic load. As a last step, the accuracy of the equations has been verified by using a cross-validation technique.[3]

Conclusions

Flight plan count correlates well with central processing utilization for all sites. These two parameters are therefore consistent in relating utilization to workload. Furthermore, the relationship between utilization and flight plans follows generally a straight-line equation for all centers. Although unpredictable factors may possibly limit performance prior to processing saturation, the quantitative approach described in this Note has been shown to be effective for all sites and can be used in future studies to rapidly evaluate computer usage.

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