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CONTROLLER PRODUCTIVITY IN THE UPGRADED THIRD GENERATION AIR TR--ETC(U)

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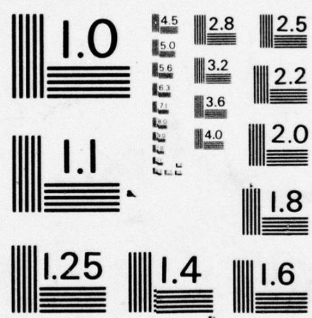

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Controller Productivity in the Upgraded Third Generation Air Traffic Control System

Part I: Automation in the Pre-Data Link Era

JULY 1976

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Systems Engineering Management
Washington, D.C. 20591

NOTICE

APPROVED BY: Neal A. Blake

Acting Director, Office of Systems Engineering Management
Federal Aviation Administration
Department of Transportation

Technical Report Documentation Page

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16. Abstract

This document is one of two reports which were prepared to provide the latest estimates of the expected increase in productivity of enroute and terminal area air traffic controllers, due to the implementation of the Upgraded Third Generation control system. Part I addresses the automation improvements in the pre-data link era. A new methodology for projecting staffing requirements is provided which makes it possible to assess the impact of varying degrees of improvements in different types of facilities. The benefits due to the implementation of these automation programs are discussed in detail and transformed into dollar savings.

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EXECUTIVE SUMMARY

The number of air traffic control personnel employed during 1975 by the En Route and Terminal facilities was 21,645 (end of year employment) corresponding to an annual salary cost of $532 million. The latest FAA forecasts indicate that airport operations and IFR aircraft handled are expected to double by 1987. It is shown in this report that if this traffic growth is not matched by an increase in controller productivity, the number of controllers employed by both en route and terminal systems would increase by 1987 to 35,000 people at an annual cost of $861 million (constant 1975 dollars).

In 1971, the FAA published its first report on the increase in controller productivity which might be expected as a result of implementing the Upgraded Third Generation (UG3RD)* program which is designed to enhance air traffic control operations through automation. At that time the UG3RD program was still in the concept formulation stage. As a result, that report was based on generalized descriptions of those features of the UG3RD which were expected to increase controller productivity. In the fall of 1974, the Department of Transportation, in its staff study of the UG3RD,** asked the FAA to reassess the expected benefits of the UG3RD including its impact on controller productivity.

This document is one of two reports which have been prepared to provide the latest estimates of the expected increase in productivity of en route and terminal area air traffic controllers due to the UG3RD program and to be responsive to the DOT request of 1974. This report (Part I) addresses the increased productivity expected to be achieved as a result of those UG3RD programs which are scheduled to be available in the pre data link era (1976-1985). The second report*** addresses those improvements expected to be achieved when the data link is available as a result of the Discrete Address Beacon System (DABS)

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*Rucker, R. A., "Controller Productivity Study", The MITRE Corporation, MTR-6110, November 1971.

**"Review of the UG3RD ATC System Development", Department of Transportation Staff Study, August 1974.

***Keblawi, F. S., "Controller Productivity in the Upgraded Third Generation Air Traffic Control System, Part II: Automation in the Data Link Era," The MITRE Corporation, March 1976.

program and when advanced automation has been developed for the automatic generation of ATC messages. Both reports assess the benefits beginning with the implementation of the improvement programs to the year 2000.

Approach for Projecting Staffing Requirements

The approach used in this report for obtaining the projected staffing requirements was based on the FAA mathematical models for facility staffing whenever possible. However, since staffing requirements in different size terminal facilities will differ depending upon the improvement programs implemented in those facilities, it was necessary to develop a staffing model that provides separate staffing projections for the different types of terminals that comprise the terminal ATC system. The approach used in this model was to derive a relationship between the traffic activity and the terminal staff for the different types of terminal facilities. To this end, data was obtained from Air Traffic Service (AAT-130), which provided a listing of all the FAA Terminal facilities by name, type and regional jurisdiction as well as the 1974 staffing and air traffic activity for each terminal facility. The data was then analyzed to obtain such relationship using Aircraft Operations (AO) and Instrument Operations (IO) as measures of traffic activity. This relationship was then used to determine the staffing of an average facility.

Controller Productivity

In both the en route and terminal systems, the measure of productivity which was used was the number of aircraft handled per hour. As a measure of the effectiveness of an automation system, the concept of controller productivity gain was used and was defined as:

$$P = \frac{\text{Controller Productivity in Improved System}}{\text{Controller Productivity in Present System}}$$

Terminal Automation

In the pre-data link era (1976-1985), the two improvement programs expected to have a significant controller productivity impact are as follows:

- Automated Flight Data Handling and Distribution. This program involves the development of a tabular display of flight data with automatic dissemination of information from centralized data bases and to provide the controller with accurate and timely information on traffic expected in his airspace. The expected productivity impact due to the implementation of this program is shown in this report to be about 20% for ARTS-III facilities. Some of the smaller facilities will be impacted by as much as 20% but some will not be impacted at all.

- Metering and Spacing - This program addresses the development of automation techniques to aid the controller in sequencing, metering and spacing of terminal traffic arriving at high capacity airports. In this study, it was assumed that only the top 32 terminal facilities would have Metering and Spacing automation. It is shown in the body of this report that the productivity gain at these facilities is expected to be between 1.13 and 1.25. Since the medium size facilities would not have Metering and Spacing in the pre-data link era, the range of controller productivity gain in ARTS-III facilities would be between 1 and 1.25.

Other improvement programs (Conflict Alert, Radar Tracking, Minimum Safe Altitude Warning, Area Navigation, and En Route Metering) that are components of the UG3RD pre-data link era will have a decided impact in the areas of safety and capacity, but are not expected to have a significant impact on controller productivity.

Because of the natural division of the terminal facilities into two categories, ARTS-III and non-ARTS-III terminals, it was easier to deal with productivity gain values that were applicable to these two categories instead of dealing with a range of values, or different values for each of the many different types of terminal facilities. It is shown in this report that the average productivity gain weighted over the whole ARTS-III terminal system, due to both enhancement programs, Automated Flight Data Handling and Metering and Spacing, is approximately 1.32. Similarly the average productivity gain of the non-ARTS-III facilities is about 1.05. The reason for the low value for the non-ARTS-III terminals is because of the numerous number of facilities such as VFR Towers and Non Radar Approach Control Towers that will not be impacted by improvements.

Average controller productivity gain values for terminal control facilities are shown in Table 1.

TABLE 1
IMPACT OF IMPROVEMENT PROGRAMS ON CONTROLLER PRODUCTIVITY IN TERMINAL SYSTEM

TERMINAL SYSTEM	UG3RD IMPROVEMENT PROGRAM	CONTROLLER PRODUCTIVITY GAIN
ARTS-III	• AUTOMATED FLIGHT DATA HANDLING/TABULAR DISPLAY	1.2 - 1.22
	• METERING AND SPACING	1.0 - 1.25
	AVERAGE "WEIGHTED" PRODUCTIVITY OF ARTS-III TERMINALS	1.32
NON ARTS-III	• AUTOMATED FLIGHT DATA HANDLING/TABULAR DISPLAY	1.0 - 1.2
	AVERAGE "WEIGHTED" PRODUCTIVITY OF NON ARTS-III TERMINALS	1.05

En Route Automation

In the pre-data link era, the only automation program that is expected to have a significant impact on controller productivity is the Control Sector Redesign and its associated Tabular Display and Flight Data Handling. The proposed system will provide the en route sector controllers with an electronic tabular display of flight data, thereby replacing the flight strip printers. It would also provide controllers with efficient means for communicating with the flight data base by using simplified data updating and data entry procedures/devices. The expected impact of this program on controller productivity gain is 1.35 obtained as follows:

- Productivity gain due to elimination of flight strips and "A" man position is $\frac{2.5}{2.0} = 1.25$.
- Productivity gain due to elimination of "Duplicate" updating of flight strips = 1.08.
- Combined productivity gain = 1.25 x 1.08 = 1.35.

Other UG3RD automation programs (Conflict Alert, Flight Plan Conflict Probe, Central Flow Control, Local Flow Control, and Area Navigation) in the pre-data link era are not expected to have a significant impact on the controller productivity although they would positively impact the safety and capacity of the ATC system.

Schedule of Implementation

The estimated schedule of implementation of the enhancement programs is shown in Figure 1. For better perspective, both data link and pre-data link era's are shown. Experience shows that two years are required after the implementation of the last site in order for the full potential of an enhancement to be realizable throughout the ATC system. This is also shown in the figure. A linear increase in productivity from the baseline value of unity to the full value was assumed to take place between the years 1980 and 1985, for both the en route and terminal facilities.

Staffing Costs

Figure 2 shows the potential savings in O&M costs in the terminal facilities over a 25 year period due to implementation

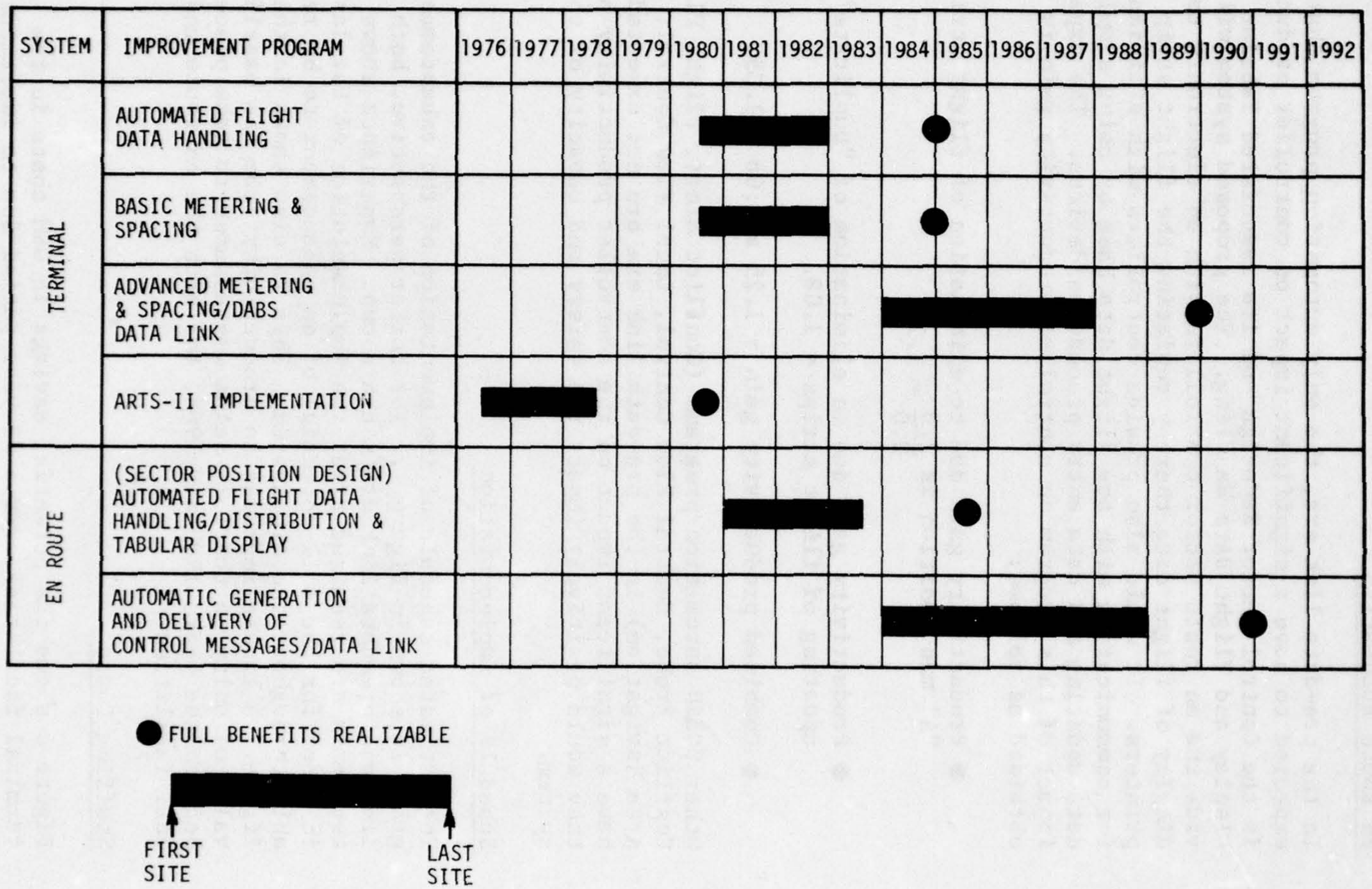
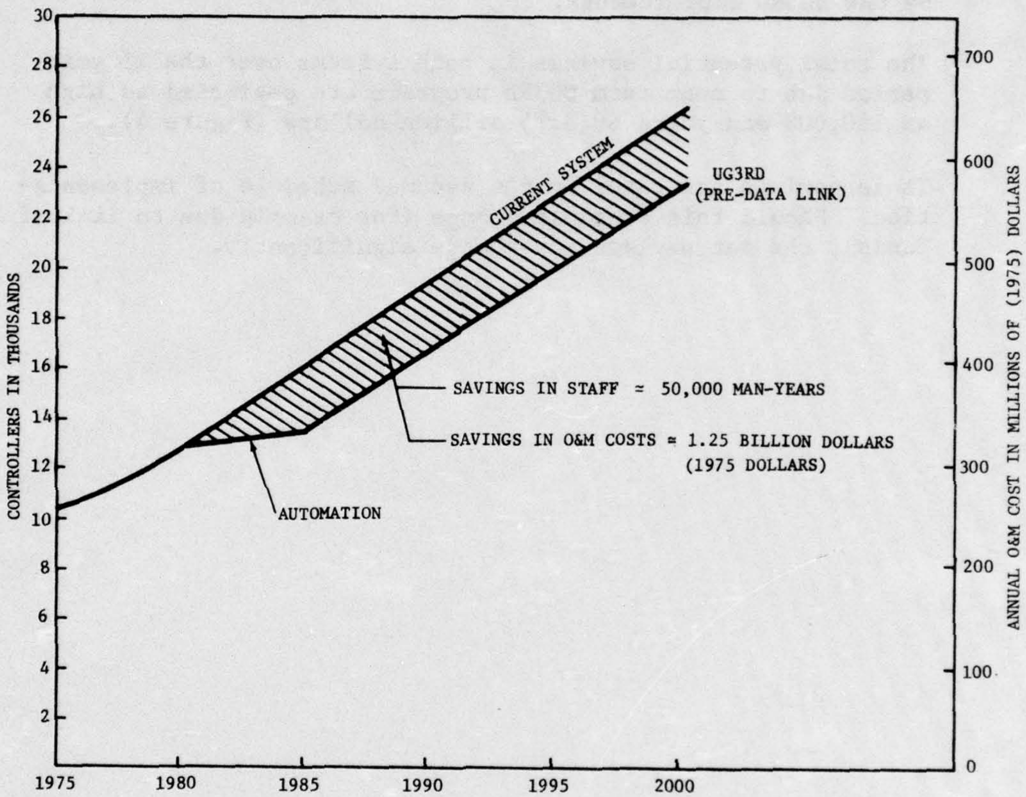


FIGURE 1
ESTIMATED SCHEDULE OF UG3RD IMPROVEMENT PROGRAMS THAT IMPACT PRODUCTIVITY



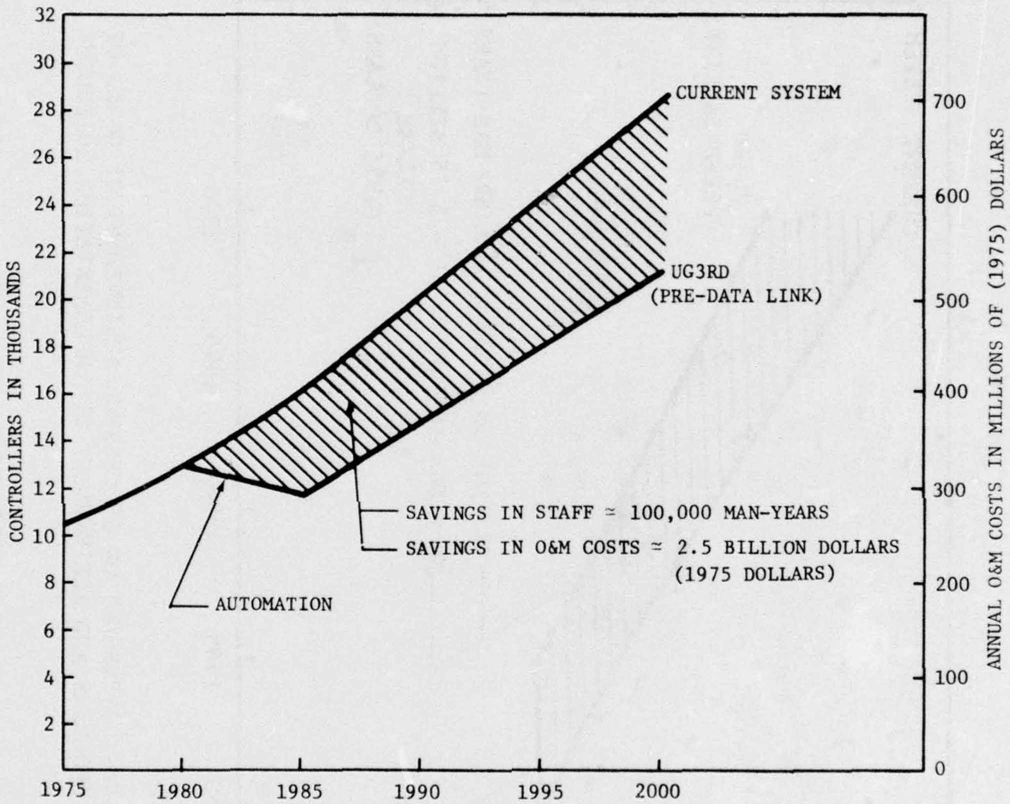
NOTE: SAVINGS CONTINGENT ON SUCCESSFUL ACHIEVEMENT OF GOALS OF E&D PROGRAMS AND ACHIEVEMENT OF IMPLEMENTATION SCHEDULES

FIGURE 2
POTENTIAL SAVINGS IN TERMINAL SYSTEM O&M COSTS DUE TO UG3RD IMPROVEMENTS

of near term UG3RD improvements amounts to approximately 50,000 man-years. This corresponds to a (1975) dollar savings of about 1.25 billion dollars. Figure 3 shows that the corresponding potential savings in the en route system to be about 100,00 man-years or 2.5 billion of 1975 dollars. The reason for this difference between the two systems is that the staffing requirements of the non-ARTS-III terminals (which is more than half the total terminal system staffing requirements) are hardly affected by the UG3RD improvements.

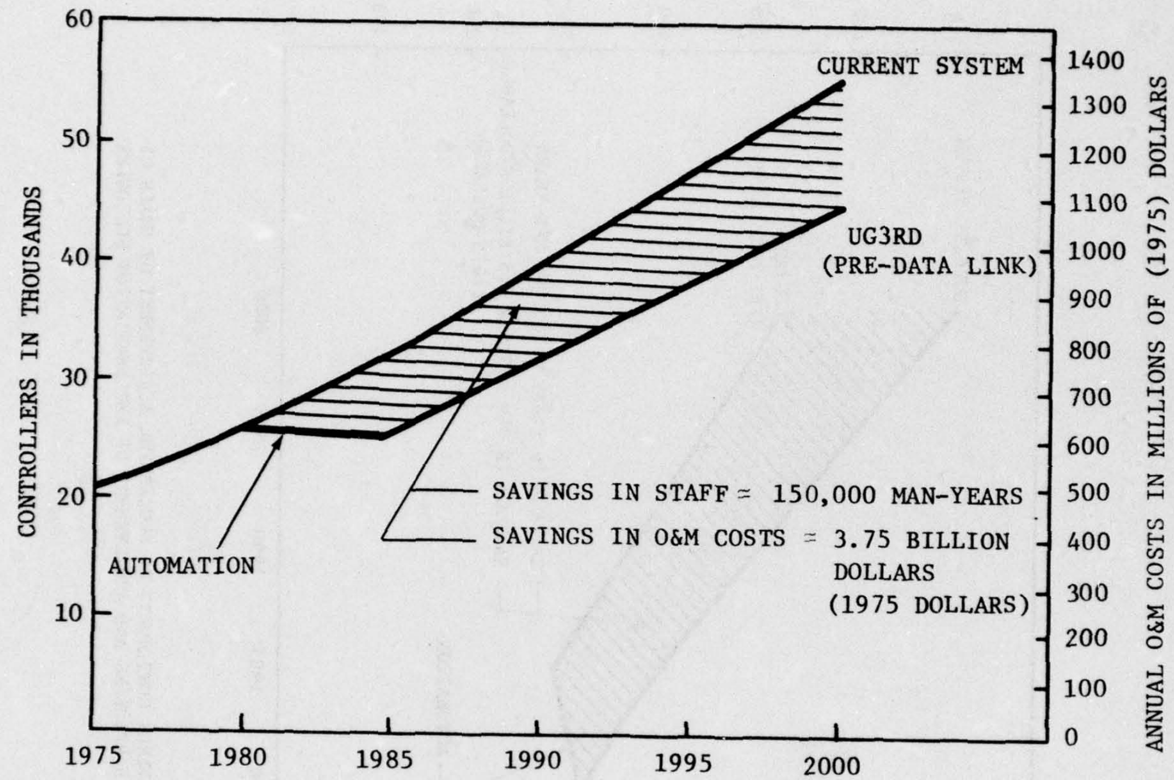
The total potential savings in both systems over the 25 year period due to near term UG3RD programs are estimated as high as 150,000 man-years or 3.75 billion dollars (Figure 4).

These savings are based on the assumed schedule of implementation. Should this schedule change (for example due to lack of funds), the net savings may change significantly.



NOTE: SAVINGS CONTINGENT ON SUCCESSFUL ACHIEVEMENT OF GOALS OF E&D PROGRAMS AND ACHIEVEMENT OF IMPLEMENTATION SCHEDULES

FIGURE 3
POTENTIAL SAVINGS IN EN ROUTE SYSTEM O&M COSTS DUE TO UG3RD IMPROVEMENTS



NOTE: SAVINGS CONTINGENT ON SUCCESSFUL ACHIEVEMENT OF GOALS OF E&D PROGRAMS AND ACHIEVEMENT OF IMPLEMENTATION SCHEDULES

FIGURE 4
TOTAL POTENTIAL SAVINGS IN EN ROUTE AND TERMINAL SYSTEMS

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1. INTRODUCTION

1.1 Background

In 1975, there were 21,645 (end of year employment) civil air traffic controllers employed by the terminal and en route facilities of the United States. Of these, about 11,800 were employed in 140 Terminal Radar Approach Control (TRACON) Facilities and in nearly 400 airport control towers. Another 10,800 were employed in the Air Route Traffic Control Centers (ARTCC's). The ARTCC's provide control of all (en route) IFR flights to and from terminal areas and airports, both in the Continental United States (CONUS) and elsewhere. According to the FAA Air Traffic Service, the direct salary and benefits costs for terminal and en route controllers average $24,600 per man-year for a total of $532 million in 1975.

According to the latest Federal Aviation Administration (FAA) forecasts[1,2], aircraft operations at controlled airports and Instrument Flight Rules (IFR) Handles are expected to double by 1987. If they do, and if the Air Traffic Control facility ratios of flights served to controller staffs needed are not significantly increased, staff sizes would rise to 35,000 controllers in the en route and terminal systems. The annual cost would increase to $861 million in 1987 (in terms of constant 1975 dollars).

This excessive cost increase can be reduced by increasing the productivity of the air traffic controllers.

In 1971, the FAA published its first report[3] on the increase in controller productivity which might be expected as a result of the upgraded third (UG3RD) generation ATC system improvement program. At that time, the UG3RD program was still in the concept formulation stage. As a result, that report was based on generalized descriptions of those features of the UG3RD which were expected to increase controller productivity. In the fall of 1974, the Department of Transportation in its staff study[4] of the UG3RD asked the FAA to reassess the expected benefits of the UG3RD including its impact on controller productivity. The MITRE Corporation was then tasked by the FAA Office of Systems Engineering Management (OSEM) with updating that study. The study results and the work performed are documented in this report.

1.2 Scope

The basic guidelines established by the FAA's Office of Systems Engineering Management (OSEM) for this study/update were as follows:

- Review all the pertinent literature published to date on controller productivity.
- Review those parts of the UG3RD development program aimed at improving controller productivity in the en route and terminal area ATC facilities and make an assessment as to the increased productivity which appears to be realizable.
- Calculate future en route and terminal area ATC facility staffing and O&M costs both with and without the implementation of the UG3RD productivity improvement programs.

1.3 Literature Review

The following is a listing of the publications that were reviewed and of the organizations that issued them. The literature was used in this report whenever applicable, and the studies were referenced as appropriate.

STANFORD RESEARCH INSTITUTE (SRI)

- "Capacity and Productivity Implications of En Route ATC Automation" by G. J. Couluris et al, FAA Report Number FAA-RD-74-196, dated December 1974.
- "Case Study of the UG3RD Generation En Route ATC System Staffing Estimates for the Los Angeles Center" by G. J. Couluris. A draft report number FAA-AVP-75-5, dated June 1975.
- "An Evaluation and Design Criteria for ATC En Route Sector Configurations" FAA-RD-74-216 by Schmidt et al. dated December 1974.
- "The Air Traffic Controller's Contribution To ATC System Capacity in Manual and Automated Environments Vol. II, and Vol. III" FAA-RD-72-63, by Ratner et al, dated June 1972.

The METIS Corporation

- "ARTS-III Enhancements Costs and Benefits" A draft report number FAA-AVP-75-3 prepared by the METIS Corp. and dated August 1975.

AIR TRAFFIC SERVICE/OFFICE OF MANAGEMENT SYSTEMS (AAT/AMS)

- "A Staffing Standard Study of ARTS-III Facilities" An FAA Study conducted by Air Traffic Service and Office of Management System, dated April 1975.

TRW

- "Automation Applications in An Advanced Air Traffic Management System" report number DOT-TSC-OST-74-14, dated August 1974.

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER (NAFEC)

- "Preliminary Two-Dimensional Area Navigation Terminal Simulation" An FAA report number FAA-RD-74-209, dated 23 July 1975.

- "A Pilot Study of En Route Controller Workload" by Allen Busch, et al. A draft report dated March 1975.

1.4 Organization of the Report

The results of the controller productivity study is being published in two parts. This document, Part I, deals with the impact of the UG3RD programs which will be implemented in the near term (1976-1985). Part II, to be published separately, will deal with the impact of those UG3RD improvements to be achieved when the data link is available as a result of the Discrete Address Beacon (DABS) program and when advanced automation has been developed for the automatic generation of ATC messages.

This document is organized as follows: In Section 2, historical trends and expected future trends in air traffic activity and corresponding staffing requirements are examined assuming no increase in controller productivity. Section 3 presents a brief description of the methodology used in the study for the productivity and staffing calculations. In Section 4, the methods used for estimating staffing requirements are explained in detail. Measures of controller productivity and the relationship between workload and productivity are discussed in Section 5. Section 6 presents discussions of terminal automation and the expected impact of the UG3RD pre-data link programs on controller productivity. Section 7 presents a similar analysis of the pre-data link en route automation programs. The last section (Section 8) converts the productivity assessments of Sections 6 and 7 into calculations of the associated staffing requirements and presents a comparison between those staffing requirements and the staffing requirements which would be needed if there was no increase in productivity.

2. TRENDS IN STAFFING REQUIREMENTS

In this section, the history of traffic growth and the associated controller staffing requirements in the past decade is presented. Unless specified otherwise, the term "controller staff" as used in this report generally refers to the actual air traffic controllers plus the necessary administrative and clerical personnel that support them.

2.1 Trends in the Terminal System

The number of Terminal Area Instrument operations have grown from 12 million in 1967 to about 25 million in 1975. To handle this increased traffic the Air Traffic Control staffing requirements of the terminal system grew from about 6,000 to 11,000 controllers. It is currently estimated that the number of instruments operations will again double by the end of the coming decade. To handle this growth, the number of controller staff personnel would have to increase substantially (50 percent) unless controller productivity is increased.

The history of traffic and terminal staffing growth is shown in Figure 2-1. Figure 2-2 shows the future trends of traffic in Terminal facilities as measured by aircraft operations and instrument operations. Figure 2-3 shows the trend in staffing requirements in the terminal system assuming present day controller productivity. Traffic forecasts are based on Office of Aviation Policy (AVP-120) publications[1] and estimations. Forecasts of the number of people needed to staff the en route and terminal area ATC facilities were based on:

- The latest (1975) terminal staffing equations used by Air Traffic Service for budgeting purposes.

- The facility growth rate per the FAA's Ten Year Plan up to 1985.

- An assumed tower growth rate[5] of ten per year for the era beyond 1985.

It is evident from Figure 2-3, that, without increased productivity, the O&M cost of terminal operations would double by 1990 and nearly triple by the year 2000.

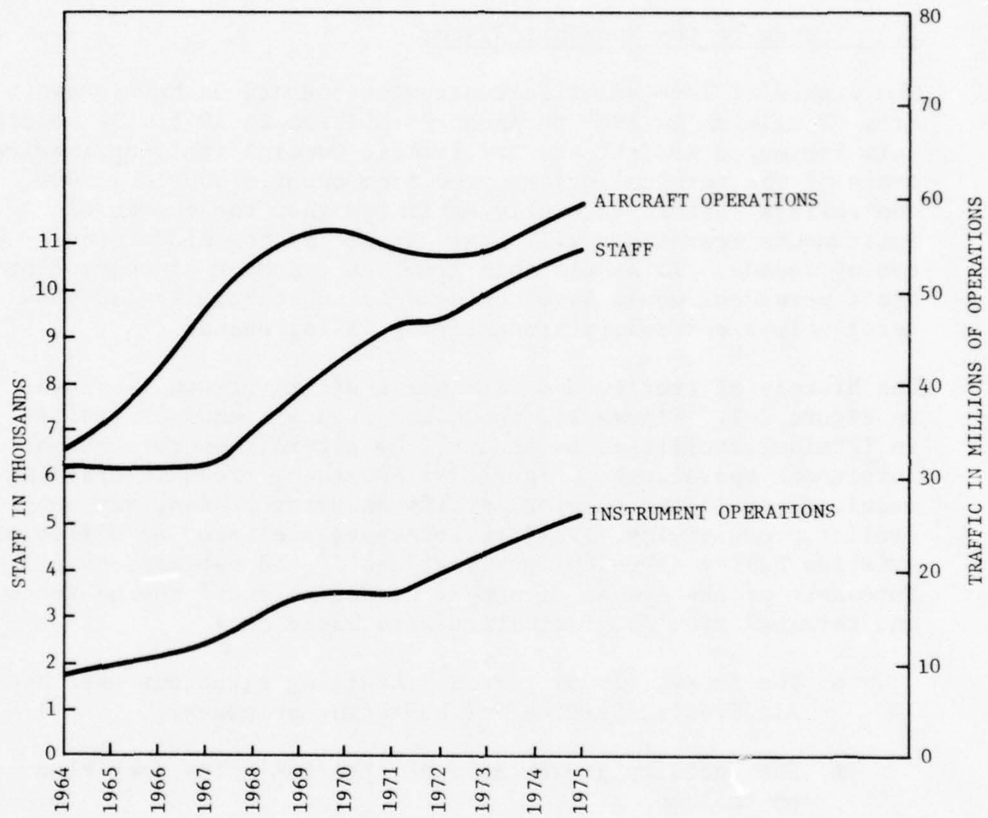

FIGURE 2-1
PAST TRENDS IN TERMINAL STAFFING AND TRAFFIC

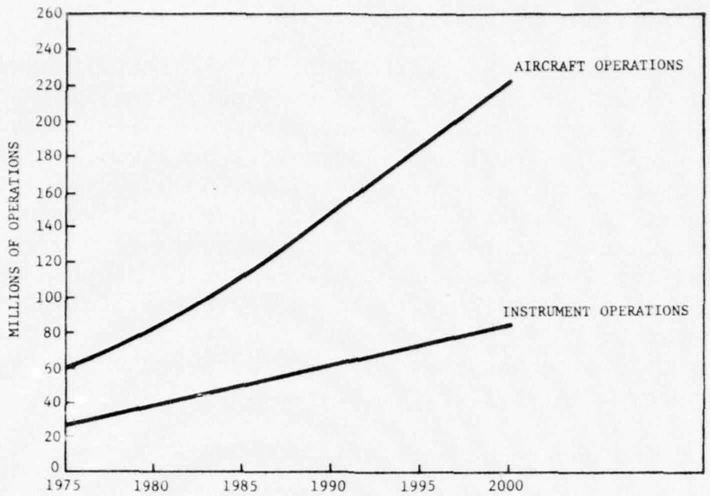

FIGURE 2-2
FORECAST TERMINAL OPERATIONS

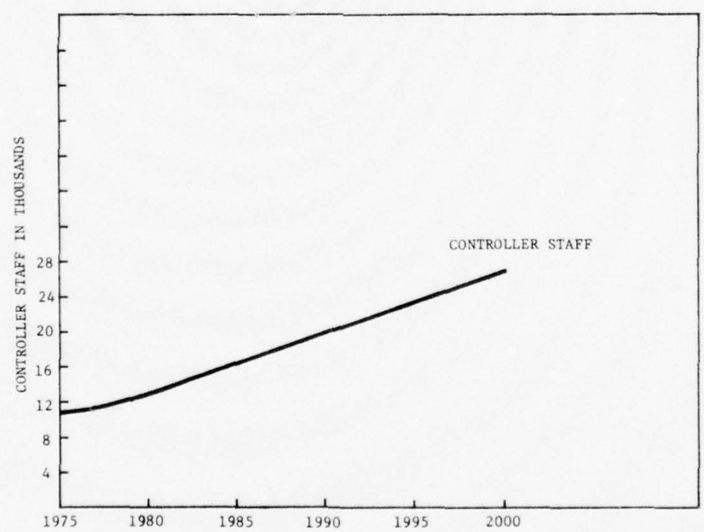

FIGURE 2-3
FORECAST TERMINAL CONTROLLER STAFF ASSUMING NO PRODUCTIVITY INCREASES

2.2 Trends in the En Route System

The number of Instrument Flight Rule (IFR) aircraft handled has increased from 15 million in 1967 to about 24 million in 1975, an increase of about 70%. The enroute system staff associated with air traffic control has increased from 7,000 people to 11,000 people an increase of about 57%. Assuming the present day productivity, and the FAA traffic forecasts[2], the staffing requirements of the en route system would double by 1990 and almost triple by the end of the century. Figures 2-4 and 2-5 show the historical growth in en route traffic and staffing respectively. Figure 2-6 shows the forecast[1,2] traffic growth from 1975 to the year 2000. Figure 2-7 shows the expected growth in staffing requirements.

2.3 Total (En Route and Terminal) O&M Costs

The costs to the FAA of operating the terminal and the en route systems are at present 532 million dollars paid as salaries to about 21,600 people. Figure 2-8 shows that if there was no increase in controller productivity, the total staffing requirements would grow to about 55,000 people by the end of the century and that the associated O&M cost would grow to about 1.4 billion dollars (in terms of 1975 dollars).

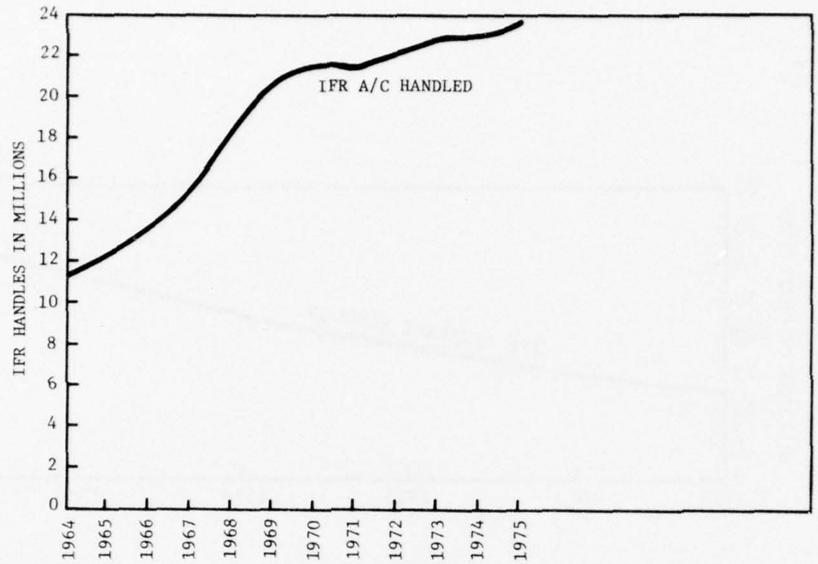

FIGURE 2-4
PAST TRENDS IN EN ROUTE SYSTEM TRAFFIC

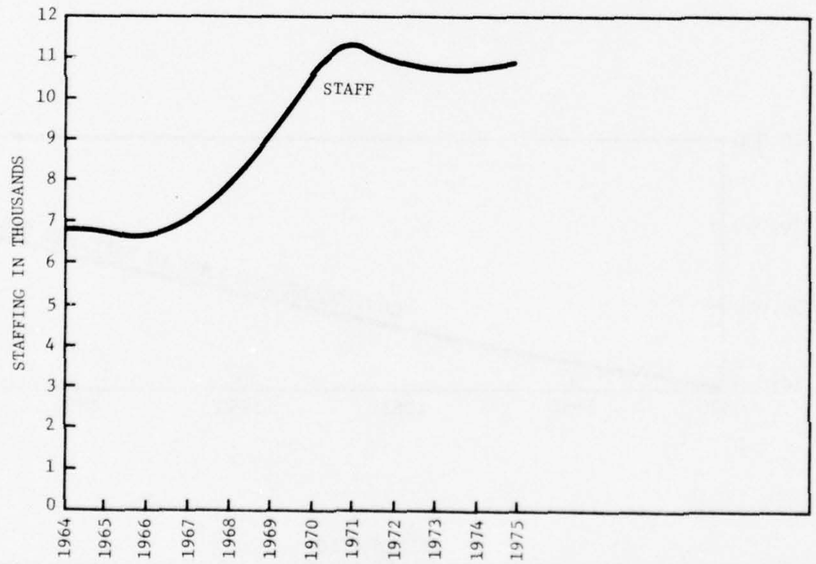

FIGURE 2-5
PAST TRENDS IN EN ROUTE SYSTEM STAFFING

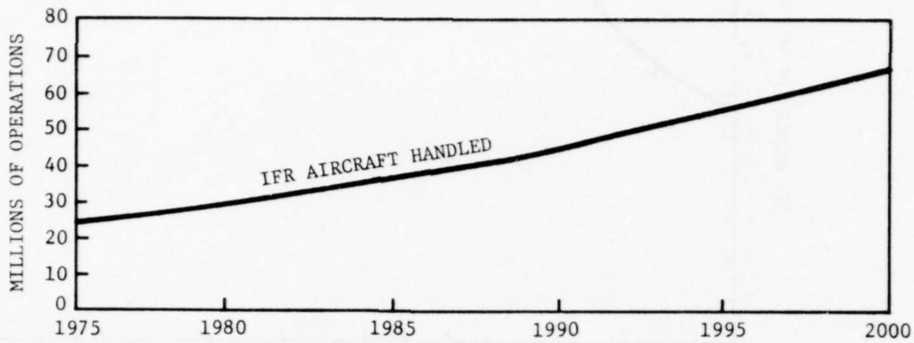

FIGURE 2-6
FORECAST EN ROUTE OPERATIONS

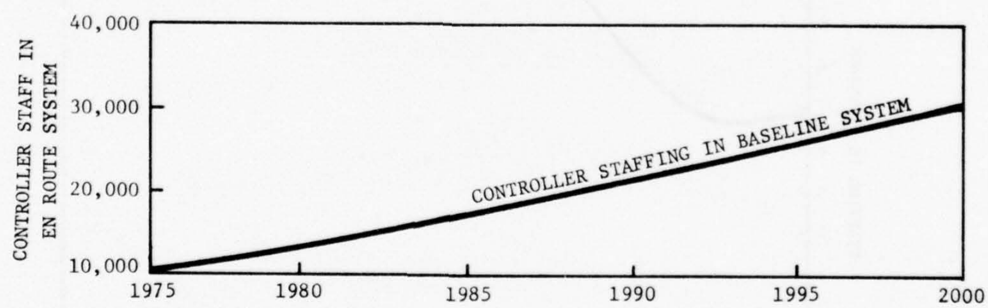

FIGURE 2-7
FORECAST EN ROUTE CONTROLLER STAFF ASSUMING NO PRODUCTIVITY INCREASES

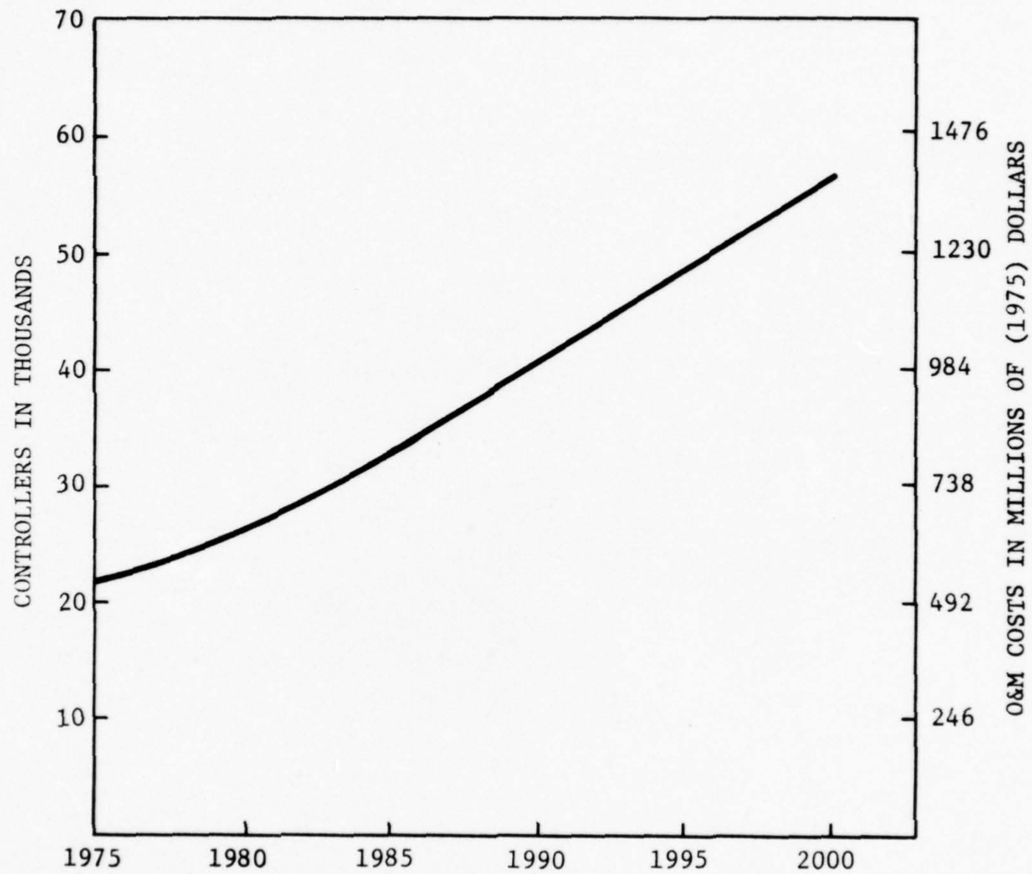

FIGURE 2-8
GROWTH IN STAFFING AND O&M COST IN THE EN ROUTE AND TERMINAL SYSTEMS WITHOUT AN INCREASE IN CONTROLLER PRODUCTIVITY

3. GENERAL APPROACH

The first step in the approach was to calculate the staffing projections based on the latest FAA air traffic forecast and assuming no increases in productivity. In the case of the en route facilities, it was sufficient to use the FAA staffing equations since the UG3RD improvement programs would be implemented uniformly across the different en route centers. The FAA staffing equation for the terminal system was also used to obtain the aggregate staff of the whole terminal system assuming no productivity improvements. However, since the future staffing requirements in different size terminal facilities will differ depending upon the improvement programs implemented in those facilities, it was necessary to develop a new methodology for estimating future terminal staffing requirements. The staffing projections obtained by the use of this methodology were compared against the projections obtained by the use of the FAA terminal system staffing equation to ascertain that the difference between the two methods was insignificant. In both the staffing equation and the new methodology, the staffing projections are a function of the number of facilities as well as the traffic activity as measured by the number of aircraft operations and instrument operations handled in the terminal area.

In order to obtain a better understanding of the type and sizes of facilities, their operating procedures, and staffing practices, visits were organized to the following facilities:

- New York Common IFR Room
- Kennedy International Airport
- Washington National Airport
- Lancaster Tower
- Reading Tower
- Erie International Airport

During those trips, discussion of the functions of the different controllers were undertaken in order to better assess the impact of the UG3RD programs. Additionally, a visit was undertaken to Leesburg ARTCC to obtain a better understanding of the interactions and interfaces between the centers and the terminal areas.

As a result of these visits and discussions, and after a review of the FAA Air Traffic control staffing standard(6) which provides the basis of staffing allocations in each and every facility, it was decided to use a statistical approach in estimating the staffing requirements by facility type. For this purpose, data was obtained from Air Traffic Service (AAT-130), which provided a listing of all the FAA terminal facilities by name, type and region as well as the 1974 staffing and air traffic acitivty for each facility. A relationship was found between the air traffic activity and the annual staffing required for each type and size of the terminal facilities. This relationship was then used for projecting the future staffing requirements using the FAA traffic forecasts.

The second step in the approach was to derive a peak shift team size and structure so that all the control functions are manned. In deriving the peak shift strategy from the annual facility staffing requirement, use was made extensively of the rules provided in the FAA staffing standard(6). In obtaining an average team structure per facility consultations were conducted with Office of Management System, Air Traffic Service and some of the visited facilities. In addition, use was made of a series of reports by the National Aviation Facilities Experimental Center (NAFEC), which document the peak shift team structure for airports of various sizes.

The third step in the approach consisted of reviewing the applicable documentation of the UG3RD improvement programs (both en route and terminal) and assessing their impact (when implemented) on each type of facility. Interviews were then held with many MITRE & FAA personnel who are involved in different programs and who have familiarity with the operational concepts behind those programs. Several interactions were sometimes necessary before the impact of a particular program was adequately sized. As a result, an assessment was made of the productivity value of all upgraded third programs on the following types of facilities: en route facilities, ARTS-III terminal facilities, and Non-ARTS-III terminal facilities.

Finally, the productivity impact was translated into a staffing projection taking into consideration an FAA schedule of implementation of the UG3RD programs. The projections were extended from the initial implementation phase (1980) to the end of the century. Productivity impacted staffing projections and O&M costs of both the en route and terminal facilities were then compared to the projections and costs of the current system (with no increase in productivity). The potential cost savings due to the UG3RD programs were then calculated. These savings are based on the assumed schedule of implementation, should this schedule change (for example due to lack of funds) the net savings may change significantly.

It should be stated here that the productivity analysis is based on the current view of the controller assignments, and on how those assignments are impacted by the UG3RD improvements. Ultimately, however, this is an FAA management problem that may be resolved differently by using alternate restructuring of the assignments and procedures.

4. METHODS FOR CALCULATING STAFFING REQUIREMENTS

In this section, a discussion is provided of the methodology used in estimating staffing requirements for both the en route and terminal systems.

4.1 Terminal System Staffing

The term terminal system refers to a set of facilities of various types either directly or indirectly associated with airports. Table 4-1 lists the different types of terminal facilities according to the FAA staffing standard.[6] These facilities have different sizes and levels of equipment sophistication. For example, the Type 5 facilities (IFR room plus Tower Cab) can be broken down into three different sizes: Large, Medium and Small; the large and medium facilities have an operational ARTS-III system while the smaller facilities are scheduled to get an ARTS-II system in the near future. The larger facilities are expected to have certain UG3RD improvement programs implemented in them that would not be implemented in the smaller facilities. Some, but not all of the improvements to be implemented in the large facilities, would also be implemented in the medium facilities; similarly for other types of facilities.

The approach used in this report, to obtain the staffing requirements for these facilities, consists simply of relating the traffic activity to the terminal staff, not only by considering the aggregate traffic activity and staff in the terminal system as a whole, but also by considering the average staff requirements and the average air traffic activity of the different types of terminal facilities shown. To this end, data was obtained from Air Traffic Service (AAT-130), which provided a listing of all the FAA terminal facilities by name, type and regional jurisdiction as well as the 1974 staffing and air traffic activity for each terminal facility. The data was then analyzed to obtain a relationship between the required staff and the traffic activity as measured by aircraft

TABLE 4-1
TYPES OF TERMINAL FACILITIES

FROM STAFFING STANDARD			
TYPE	NAME	FACILITY MAKEUP	ARTS PARTICIPATION
5	RADAR APPROACH CONTROL TERMINAL	IFR ROOM AND CAB	LARGE AND MEDIUM - ARTS-III SOME SMALL - ARTS-II*
9	RADAR APPROACH CONTROL FACILITY (e.g., NEW YORK IFRR)	IFR ROOM NO CAB	LARGE - ARTS-III MOST SMALL - ARTS-II*
7	LIMITED RADAR APPROACH CONTROL TOWER (e.g., JFK)	CAB ONLY	ASSOCIATED WITH ARTS-III FACILITIES
8	RADAR APPROACH CONTROL TOWER	TRACAB	SOME ARTS-II*
3,4	NON RADAR APPROACH CONTROL TOWER	CAB ONLY	NONE
1,2	VFR TOWER	CAB ONLY	NONE

*TO BE IMPLEMENTED.

operations* (AO) and instrument operations** (IO) in the terminal areas. This relationship was then used to determine the staffing of an average facility. To compute the average AO's and IO's per facility for any future year, the 1974 distribution of traffic among the terminal types was assumed to hold in future years except for a minor adjustment to allow for the upgrading of facilities as assumed by the Ten Year Plan.(7)

The average staff per terminal facility of a certain type was then multiplied by the number of facilities of that type. The total terminal system staff was then found by summing over all types of facilities. Similarly, in the UG3RD system, with productivity ratios for certain types of terminals greater than unity (ARTS-III facilities for instance), the future staffing estimates can be found by first computing the required staff per terminal type, dividing by the productivity gain and then summing over all the types of facilities in the terminal system.

4.1.1 Relationship Between Traffic and Staffing Requirements

Figure 4-1 illustrates the 1974 distribution of the number of facilities, the traffic activity and the staff, or the terminal system among the various types of terminals. For example, the Type 5 (TRACON and CAB) terminals account for 25 percent of all terminal facilities while they service in excess of 50 percent of all annual instrument operations and 30 percent of all annual aircraft operations in the terminal system; the service being provided by about 50 percent of the total terminal system staff.

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*An aircraft operation is defined by the FAA as an aircraft arrival at or a departure from an airport with FAA traffic control service. A local operation is performed by an aircraft that operates in the local traffic pattern or within sight of the tower; is known to be departing for or arriving from flight in local practice areas; or executes simulated instrument approaches or low passes at the airport. All aircraft arrivals and departures other than local are classified as itinerant operations.

**An instrument operation is defined as the handling by an FAA terminal traffic control facility of the arrival, departure, or over at an airport of an aircraft on the IFR flight plan or the provision of IFR separation to other aircraft by an FAA terminal traffic control facility. Non-IFR instument counts at Terminal Control Area (TCA) facilities and Stage III of expanded area radar service are included.

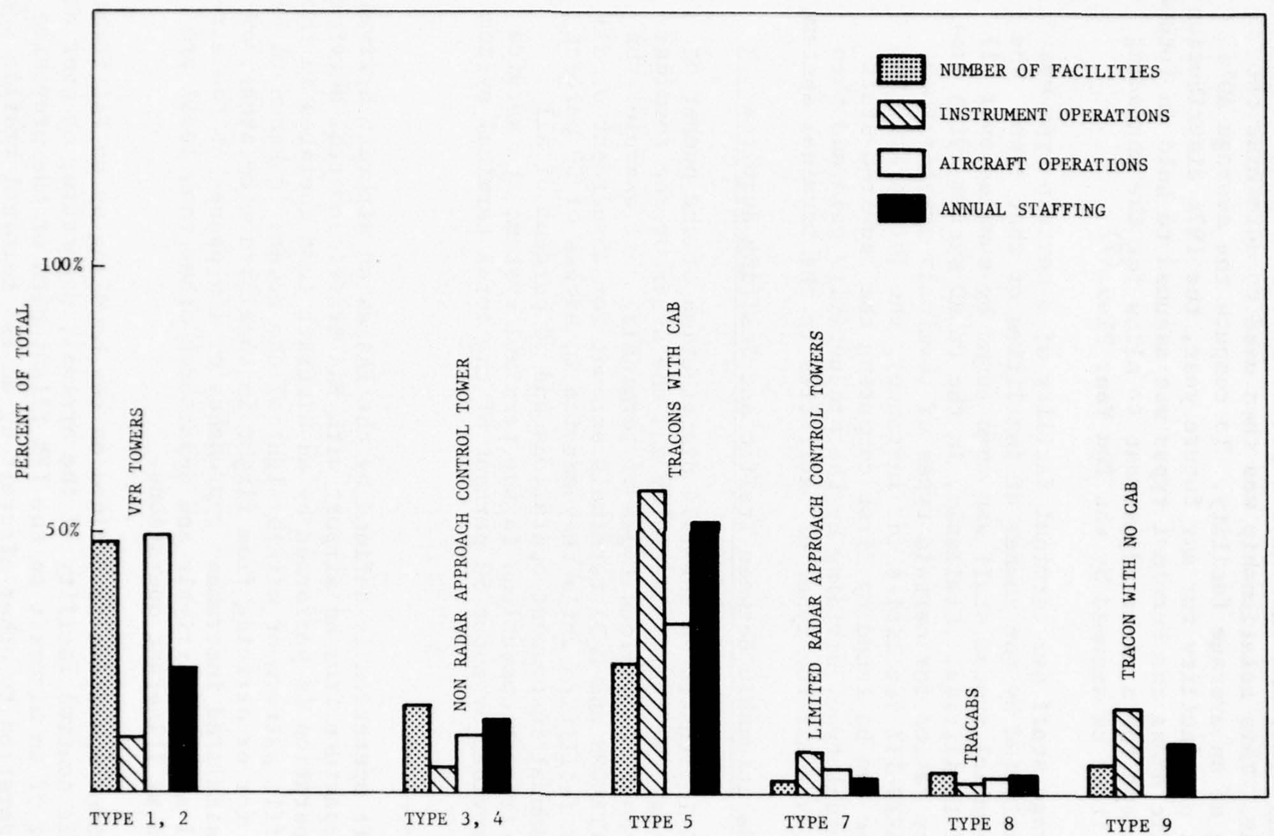


FIGURE 4-1
ANALYSIS OF TERMINAL FACILITY OPERATIONS (FY74)

The annual staffing and traffic activity for each individual facility are plotted for the different terminal types. As an example, Figure 4-2 shows the staffing for facilities of Type 9 (TRACONS With No CAB) as a function of annual instrument operations.

Based on the average expected traffic per facility, of the TRACON/No CAB type, Figure 4-2 makes it possible to evaluate the staffing for an average facility of that type. Thus, a facility having an annual traffic of 100,000 instrument operations is expected to need, on the average, an annual staff of 26 people in order to appropriately staff it. Similarly, relationships between staffing and traffic activity were found and plotted for all other types of terminals. Appendix A shows a complete set of these relationships.

4.1.2 Traffic Distribution

Table 4-2 shows the air traffic distribution across the terminal system as well as the staffing required during 1974 to service this traffic. The table shows a further breakdown of the TRACONs according to their sizes. The TRACONS with a tower CAB were broken down into three categories, small, medium and large; the large and the medium size facilities have an ARTS-III computer and display system and are planned to have the associated improvements. The TRACONS with no Tower CAB were broken down into large and small only, since the larger ones have an ARTS-III facility and the smaller ones do not.

Table 4-2 shows for example that of the total 28.8 million instrument operations recorded in 1974 in all the terminal system, 3.259 million were in VFR towers, 1.430 million were in non radar approach control towers, 4.538 million were in small TRACONS with tower CABS, and so on. This distribution of instrument operations and aircraft operations was used as a basis for deriving the traffic distribution of 1985. Thus, since in 1974 the large TRACONS with CABs had 6.833 million instrument operations or $\frac{6.833}{28.857}$ = 23.7% of the total instrument operations in the system, it was assumed that in 1985 that type of facility would also have 23.7% of the instrument operations forecast for 1985.

An adjustment was made, however, to allow for the facility upgrading per the FAA Ten Year Plan (see Table 4-3). In this upgrading, it was assumed (based on discussions with Air Traffic Service and Office of Aviation Systems Plans) that 90 percent

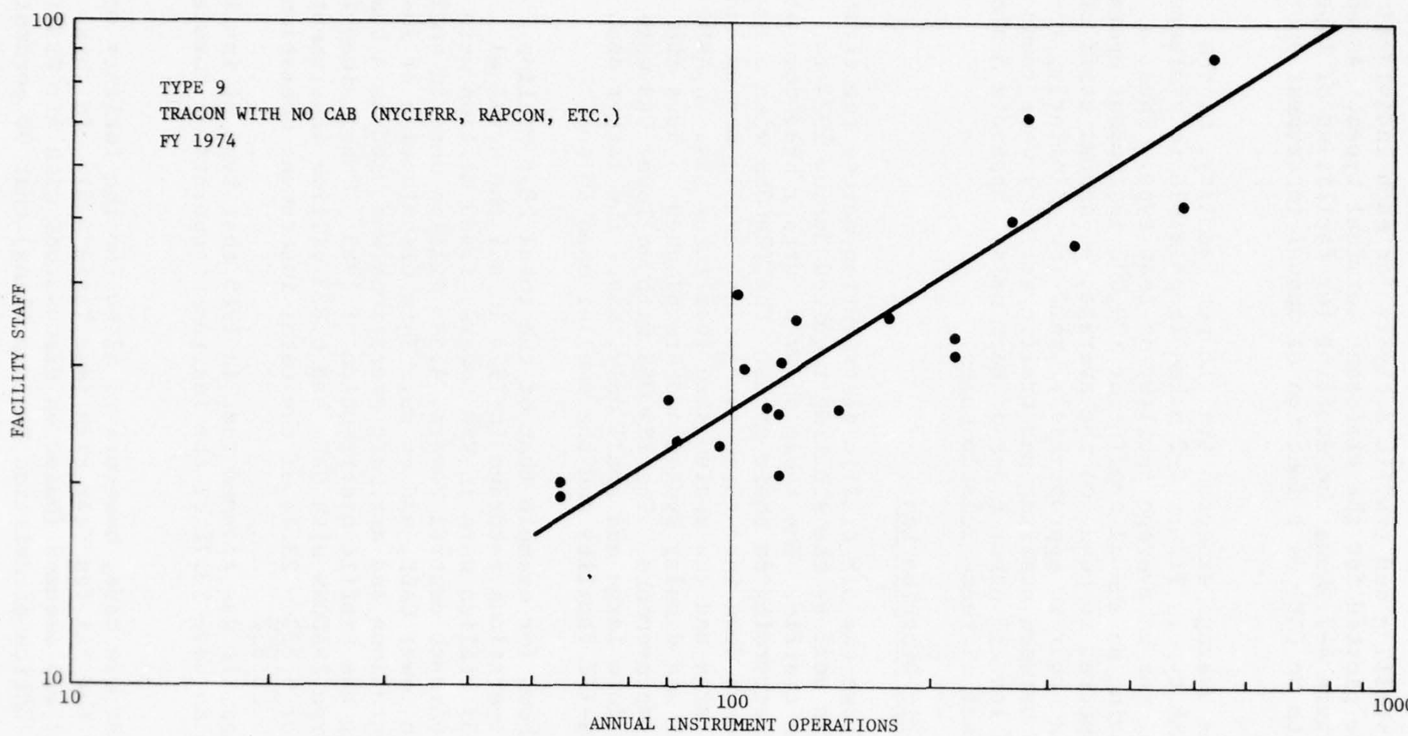


FIGURE A-1
TRAFFIC VERSUS STAFF FOR TRACONS WITH NO CAB

TABLE 4-2
ANNUAL TERMINAL STAFFING* AND AIR TRAFFIC ACTIVITY IN 1974
(BASED ON TODAY'S STAFFING STANDARDS)

YEAR		VFR TOWERS	NON RADAR APPROACH CONTROL TOWERS	TRACON (IFR ROOM + CAB)			LIMITED RADAR APPROACH CONTROL	TRACAB	TRACON NO CAB		TOTAL
				SMALL	MEDIUM	LARGE			LARGE	SMALL	
1974	NUMBER OF TERMINALS	198	67	51	(31)	(19)	(9)	17	(13)	11	416
	IO (000's)	3,259	1,439	4,538	5,122	6,833	2,301	591	3,795	979	28,857
	AO (000's)	27,987	6,382	7,418	5,464	5,548	2,849	1,739	0	162	57,549
	AVERAGE STAFF/ TERMINAL	11.4	13.9	34	54	80	30	18.6	50.9	25	
	ANNUAL STAFF	2,269	932	1,751	1,684	1,523	270	317	662	270.0	9,686
PERCENT OF TOTAL 1974 STAFFING		23.4	9.6	18.1	17.4	15.7	2.8	3.3	6.9	2.8	100

*DATA OBTAINED FROM AAT-130

( ) AN ARTS-III OR ASSOCIATED FACILITY

TABLE 4-3
MAJOR TERMINAL AREA CONTROL FACILITIES/EQUIPMENT

FACILITY/EQUIPMENT	PRESENT SYSTEM		FUTURE SYSTEM	
	COMMISSIONED DEC. 31, 1974	APPROVED NOT COMMISSIONED	IN PLAN 1976-85	TOTAL 1985
TOWERS	403	18	14	435
AIRPORT SURVEILLANCE RADAR	156	26	18	200

of the new radar facilities would be upgraded into the TRACAB configuration and the other 10 percent into a TRACON configuration. The traffic of the upgraded facilities was then counted in the type of terminals to which those facilities were upgraded to (either TRACABS or TRACONS). (It was assumed that the upgraded facilities would be selected from the population of VFR towers and Non-Radar Approach Control Towers.) The resulting traffic distribution for the different terminal types is as shown in Table 4-4.

4.1.3 Staffing Projection

In computing the 1985 staffing, the traffic distribution shown in Table 4-4 was used. Prior to applying this distribution, however, to the forecast instrument operations, a slight adjustment in the latter was required. This adjustment was needed because the official FAA forecasts were based on a counting procedure that eliminates the double counting of the IO in the primary and the secondary airports. However, this double counting corresponds to a realistic workload since the same instrument operation aircraft has to be serviced by both airports. For example, the official FAA aviation forecasts identified the IO traffic count for 1974 as 24.1 million. The gross count by air traffic service (that does not discount for double counting) is 28.8 million. An upward adjustment of 19.2 percent should therefore be applied to the 1974 official FAA count. Air traffic service budgeting procedures account for this by modifying the coefficients of the staffing equation so that the equation could be used with the official FAA forecasts.

Using the official FAA forecast and adjusting the IO forecast for double counting, distributing the traffic as in Table 4-4, computing the average IO and AO per terminal, and using the charts of Appendix A, the expected staffing projection per terminal could be obtained. Such a projection was obtained for the year 1985 and is shown in Table 4-5. The average staff per terminal was then multiplied by the number of terminals to obtain the annual staff for each terminal type. The sum of the staff required for all terminals was 15,084. This is a 56 percent increase in staffing above the 1974 requirement corresponding to a doubling of traffic.

4.1.4 Comparison to the FAA Staffing Equation Projections

As a validation of the methodology illustrated in the preceeding sections, a comparison between the aggregate staffing estimates obtained by the use of that methodology and the FAA

TABLE 4-4
ESTIMATED TRAFFIC DISTRIBUTION IN TERMINAL SYSTEM IN 1985

FACILITY	TRAFFIC (PERCENT OF TOTAL)	
	INSTRUMENT OPERATIONS	AIRCRAFT OPERATIONS
VFR TOWERS	9.9	43.2
NON RADAR APPROACH CONTROL TOWERS	3.3	8.6
TRACON & CAB		
LARGE	23.9	9.7
MEDIUM	17.7	9.3
SMALL	16	14.1
LIMITED RADAR APPROACH CONTROL TOWERS	8	4.9
TRACAB	4.7	9.9
TRACON/NO CAB		
LARGE	13.1	0
SMALL	3.4	0.3
TOTAL	100	100

TABLE 4-5

EXPECTED ANNUAL TERMINAL STAFFING AND AIR TRAFFIC IN 1985

(BASED ON TODAY'S STAFFING STANDARDS)

YEAR		VFR TOWERS	NON RADAR APPROACH CONTROL	TRACON (IFR ROOM + CAB)			LIMITED RADAR APPROACH CONTROL	TRACAB	TRACON NO CAB		TOTAL
				SMALL	MEDIUM	LARGE			LARGE	SMALL	
1985	NUMBER OF TERMINALS	205	48	55	(31)	(19)	(9)	56	(13)	11	447
	IO	5,500	1,806	8,838	9,790	13,090	4,400	2,611	7,260	1,870	~ 55,000
	AO	47,619	9,534	15,517	10,212	10,656	5,439	11,024	0	333	~110,000
	AVERAGE STAFF/ TERMINAL	13	24	54	82	133	45	25	79	36	
	ANNUAL STAFF	2,665	1,152	2,970	2,542	2,527	405	1,400	1,027	396	15,084

() = AN ARTS-III OR ASSOCIATED FACILITY

staffing equation for the terminal system could be made. The FAA staffing equation (adjusted for the double counting) is as follows:

$$S_T = 9.6 \times N + 0.0202\ AO + 0.195\ IO \qquad (4\text{-}1)$$

where

S_T = Total terminal system staff

N = Total number of terminals

AO = Total aircraft operations in 1000's

and

IO = Total instrument operations in 1000's

This equation is the result of a regression analysis applied to the whole terminal system. The equation shows that the terminal system staffing has three components. The first component is a function of the number of facilities, while the other two are a function of the traffic. The factor, which is independent of traffic, suggests that a minimum number of people are required regardless of traffic. The other two factors suggest that the higher the traffic the higher the staffing required for controlling them. Equation 4-1 yields a total terminal staff requirement of 15,526 while the model devised in the preceeding sections yields 15,084. The difference is less than three percent. For all practical purposes, then, the two methods are equivalent vis-a-vis the gross staffing estimate. The additional advantage inherent in the detailed model is that it breaks down the staffing in a manner which enables different productivity estimates for different terminal types to be factored into the staffing estimates.

4.1.5 Staffing for the Peak Shift

In this section, the process of deriving the staffing model is continued to the level of detail necessary for the proper derivation of the controller productivity values. The ultimate objective was to derive an average control team for each facility type. For that, the average peak shift staffing was needed, and it is developed in this section.

The average facility staffing of the peak shift could be obtained from the average annual staff per facility by the use of the staffing standard in reverse, starting with average annual staff. This is illustrated in Tables 4-6 and 4-7. For example, of the staff of 80 people required by an average large TRACON with a tower CAB, about 17 are supervisory and four are Data System Specialists (DSS). (Four DSS's was assumed as an average; although it was recognized that a facility requires either 3 or 5 DSS's depending on whether it was an area support facility or not.) Thus, the annual controller staffing requirement for the facility was computed to be 59. Dividing this by 1.6 yields the daily staffing requirement.

There are two equivalently staffed peak shifts of the day (EVE and DAY), with the MID (Midnight to Morning) shift requiring one or two controllers, depending on justification. It was assumed here, after consultation with Air Traffic Service (AAT-130) and Office of Management System (AMS-560), that the MID shift would require ten percent of the total daily staff, and the remainder was evenly divided between the DAY and EVE shifts. This results in a peak shift staffing requirement for an "average" large TRACON of 17 controllers. In a similar manner, peak shift staffing for other facilities was found. Table 4-6 shows the peak shift staffing requirement and how it was obtained for average ARTS-III facilities of different types. Table 4-7 shows the peak shift staffing requirements for smaller facilities.

4.1.6 Structure of the Control Team

Having estimated the peak shift staffing as was shown in the previous section, it was then possible to postulate a distribution of the controller staff among the different functions performed in a terminal facility. This was based on observations of operations in typical facilities visited, on consultations with Air Traffic Service (AAT-130), and Office of Management Systems (AMS-560), and on examining a series of airport survey documents prepared by NAFEC.[8] It should be noted that in some cases different terminal facilities use different nomenclature for describing some of the functions they perform. In this report, common usage is conformed to and the exceptional is avoided. Table 4-8 shows the structure of the control team in a hypothetical average ARTS-III facility during the peak shift. Table 4-9 illustrates this structure for smaller facilities.

TABLE 4-6
1974 PEAK SHIFT STAFFING OF AN AVERAGE ARTS-III FACILITY

	TRACON & CAB		TRACON NO CAB (LARGE)	LIMITED RADAR APPROACH CONTROL TOWER
	LARGE	MEDIUM		
AVERAGE ANNUAL STAFF	80	54	50.9	30
SUPERVISORY (FROM STAFFING STANDARD)	-17	-9	-10	-7
DSS STAFF 4/ARTS-III FACILITY	-4	-4	-4	-
NUMBER OF CONTROLLERS PER FACILITY	59	41	36.9	23
DIVIDE BY 1.6	36.9	25.6	23.1	14
EVE, DAY SHIFTS = 0.45 TOTAL	17	12	11	6

TABLE 4-7
1974 PEAK SHIFT STAFFING OF AN AVERAGE SMALL FACILITY

	SOME OF THESE ARE PLANNED TO BE EQUIPPED WITH ARTS-II				
	TRACON & CAB (SMALL)	TRACON NO CAB (SMALL)	TRACAB	NON RADAR APPROACH CONTROL TOWER	VFR TOWER
AVERAGE ANNUAL STAFF	34	25	18.6	13.9	11.4
SUPERVISORY (FROM STAFFING STANDARD)	-7	-4.5	-4.5	-3.5	-3.5
NUMBER OF CONTROLLERS	27	20.5	14.1	10.4	7.9
DIVIDE BY 1.6	16.9	12.8	8.8	6.5	4.9
EVE, DAY SHIFTS = 0.45 TOTAL	8	6	4	3	2.2*

*70% OR MORE OF TOWERS HAVE NO NIGHT SHIFT.

TABLE 4-8
STRUCTURE OF CONTROL TEAM IN ARTS-III FACILITIES
(AVERAGE FACILITY-1974)

LOCATION	CONTROLLERS	TRACON & CAB		TRACON/NO CAB	LIMITED RADAR APPROACH CONTROL TOWER
		LARGE	MEDIUM	LARGE	
IFR ROOM	FINAL APPROACH	2	1	2	
	ARRIVAL	3	3	3	
	DEPARTURE	3	2	3	
	COORDINATOR/HANDOFF	3	1	2	
	FLIGHT DATA	1	1	1	
	TOTAL IFR ROOM	12	8	11	
TOWER CAB	LOCAL	1	1		1
	ASSISTANT LOCAL	1	-		1
	GROUND	1	1		1
	CLEARANCE DELIVERY	1	1		1
	FLIGHT DATA	1	1		2
	TOTAL TOWER CAB	5	4		6
FACILITY	TOTAL CONTROLLER STAFF	17	12	11	6

TABLE 4-9
STRUCTURE OF CONTROL TEAM IN SMALL FACILITIES
(AVERAGE FACILITY-1974)

LOCATION	CONTROLLERS	TRACON* & CAB	TRACON* NO CAB	TRACAB*	NON RADAR APPROACH CONTROL TOWER	VFR TOWER
IFR ROOM	ARRIVAL	1	2			
	DEPARTURE	1	2			
	COORDINATOR/HANDOFF	1	1			
	FLIGHT DATA	1	1			
	TOTAL IFR ROOM	4	6			
TOWER CAB	LOCAL	1		1AC+1LC	1 AC/LC	1
	GROUND	1		1	1 GC/CD	1 GC/CD
	CLEARANCE DELIVERY	1		1		
	FLIGHT DATA	1			1	0.2
	TOTAL TOWER CAB	4		4	3	2.2
FACILITY	TOTAL CONTROLLER STAFF	8	6	4	3	2.2

*SOME OF THESE ARE ARTS-II.

AC = APPROACH CONTROLLER
LC = LOCAL CONTROLLER
GC = GROUND CONTROLLER
CD = CLEARANCE DELIVERY

A comparison between the staffing requirement, as determined by this analysis of an "average" large TRACON with a Tower CAB and four actual large facilities, is shown in Table 4-10. Those facilities are: Tampa, Houston, New Orleans, and Washington/ National. In comparing the structure of the control team of the "average" facility with that of National Airport, it can be noted that one of the main differences is in the number of hand-off/coordinator positions: National has six such positions while the hypothetical "average" facility has three. Other differences are: National requires two flight data men intead of one, and it has a need for one helicopter position. Since there are only a handful of helicopter positions throughout the country, it was not necessary to include it in the model.

The utilization by National of more staff than the "average" size facility is explained by the fact that National has a highly complex airspace due to numerous air traffic restrictions in a relatively small airspace, and that the traffic activity at National is on the high end of the spectrum of air traffic activity in large facilities in general.

Table 4-10 also illustrates the different ways in which facilities operate. As expected each facility operates to facilitate the expeditions and safe flow of traffic within the local unique set of constraints that are dictated by its own airspace, its organization and its restrictions. Therefore, it is safe to say that an "average" facility is an abstract entity which facilitates computations and analysis as applied to aggregates of facilities and should not be compared to staffing at actual facilities. An actual survey of all the facilities involved would provide better data than the use of the "average" facility as derived herein, but such activity does not seem warranted at this time.

4.2 En Route System Staffing

The En Route System is basically different from the terminal system in that it has fewer types of control positions than the terminal system. In the en route system, the basic air traffic control staffing unit is the sector, whose structure is more or less the same throughout the whole system. The control positions used in the en route system are the following:

TABLE 4-10
STAFFING COMPARISON BETWEEN ACTUAL FACILITIES AND AN AVERAGE FACILITY

<table>
<tr><th></th><th>CONTROLLERS</th><th>AVERAGE LARGE ARTS-III</th><th>TAMPA</th><th>HOUSTON</th><th>NEW ORLEANS</th><th>WASHINGTON NATIONAL AIRPORT</th></tr>
<tr><td rowspan="6">IFR ROOM</td><td>FINAL APPROACH</td><td>2</td><td>1</td><td>2</td><td></td><td>2</td></tr>
<tr><td>ARRIVAL</td><td>3</td><td>4</td><td rowspan="2">3</td><td>2</td><td>3</td></tr>
<tr><td>DEPARTURE</td><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>COORDINATOR/HANDOFF</td><td>3</td><td>3</td><td>3</td><td></td><td>6</td></tr>
<tr><td>FLIGHT DATA</td><td>1</td><td>3</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>TOTAL IFR ROOM</td><td>12</td><td>13</td><td>10</td><td>4</td><td>16</td></tr>
<tr><td rowspan="7">TOWER CAB</td><td>LOCAL</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>ASSISTANT LOCAL</td><td>1</td><td></td><td></td><td></td><td>1</td></tr>
<tr><td>GROUND</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>CLEARANCE DELIVERY</td><td>1</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td><td>1</td></tr>
<tr><td>FLIGHT DATA</td><td>1</td><td>1</td></tr>
<tr><td>HELICOPTER</td><td></td><td></td><td></td><td></td><td>1</td></tr>
<tr><td>TOTAL TOWER CAB</td><td>5</td><td>3</td><td>3</td><td>3</td><td>6</td></tr>
<tr><td>TOTAL</td><td>FACILITY STAFF</td><td>17</td><td>16</td><td>13</td><td>7</td><td>22</td></tr>
</table>

- R-(Radar) Controller Position
- D-(Data) Controller Position
- A-(Assistant) Controller Position

Additionally, a flow controller and a mission coordinator are responsible for traffic coordination for the center. The flow controller coordinates traffic control activities among sectors, areas (groups of sectors), and other ATC facilities. The mission coordinator communicates with military facilities regarding airspace or altitude reservations for planned military missions.

Generally, a typical en route sector is composed of one radar position, one D-position with one A-position shared by two sectors. The R-position is generally the lead position in the sector.

It should be noted, however, that the FAA staffing standard specifies only the total number of positions required to staff a sector without specifying the control position as such. The standard specifies that the number of positions per sector can be anywhere from one to four depending on the type of sector (high, low or transitional), the number of aircraft handled per hour and the sector flight time. The number of aircraft handled used for staffing calculations is measured on a day that approximates the 37th busiest day of the year.

Since the UG3RD improvement programs are expected to be implemented uniformly across all the sectors of the en route system, it is reasonable to use the FAA staffing equation in order to calculate the projected staffing requirements. Thus, no new staffing calculation methodology is required. The staffing equation, which is based on a regression analysis of staffing data obtained from the ARTCC's, is as follows:

$$S_E = 36.2N + 0.413 \times \text{IFR Handles} \qquad (4\text{-}2)$$

where

S_E = En Route System Staff. This refers to air traffic controllers plus administrative and clerical support personnel

N = Number of Air Route Traffic Control Centers (ARTCC's)

and IFR Handles are in thousands.

5. CONTROLLER PRODUCTIVITY MEASURES

In the context of this study, the controller productivity measure to be used has to meet one essential constraint: it should be possible by means of this measure to assess the individual impact of an automation program on the staffing requirement in both the en route and the terminal systems. This constraint, added to the fact that the staffing standard is essentially based on the peak hourly traffic in the three daily shifts, suggests the use of a controller productivity measure defined over a period of an hour. The following definition will therefore be used in the rest of this report.

> Definition - The productivity of the air traffic controller is defined to mean the demand serviced per controller, per hour. The demand serviced can be viewed as the number of aircraft handled per controller.

This is a widely accepted definition in the ATC community. It is, however, important to note the difficulties associated with the productivity concept as a measure of system performance. Any measurement of a control system performance that involves humans directly in the control loop is "elastic." This means that it is difficult to measure the limits on the human's capacity because those limits vary. Thus, the performance of an air traffic controller may vary from day to day, even from hour to hour, depending on many factors that could go under the umbrella of the "psychological conditions." Similarly, the performance of one air traffic controller may be different from that of another controller for the same reasons even though both of them control the same airspace (at different times). This human "elasticity" contributes to a high degree of uncertainty in any measure entertained for the purpose of calibrating productivity or other system parameters. It is, therefore, plausible and quite adequate to use judgement in estimating productivity gains or reductions. That judgement, however, should be based on averages and aggregates rather than on one controller's performance under a variety of conditions.

5.1 Definition of Controller Productivity Gain

In order to quantify the effects of changes in the automated system on controller staffing, the concept of "productivity gain" has been defined(4) as the following ratio:

$$P = \frac{\text{Demand Serviced Per Controller in an Improved System}}{\text{Demand Serviced Per Controller in the Present System}} \quad (5\text{-}1)$$

or

$$P = \frac{\text{Controller Productivity in an Improved System}}{\text{Controller Productivity in the Present System}} \quad (5\text{-}2)$$

For example, P = 2 implies either:

1. Twice the demand can be serviced with the same number of controllers.

2. The same demand can be serviced by half the number of controllers.

In this study, it was assumed that the controller is working on the average at the same "pace" or "strain" level in either system.

5.2 Productivity and Workload Reduction

With the aid of automation, the workload associated with the serviced demand would be reduced. This reduction in workload may or may not result in a productivity gain. In general, the relationship between controller productivity and workload is not a straightforward one. There are cases where reduction in workload could not result in the elimination of control positions, or even combining them. For example, the local controller position would always be required in towers regardless of the activity. However, there are cases where it is reasonable to expect that reduction in workload could eliminate the need for a control position or could make it possible to perform its residual unautomated functions from another control position.

The combined performance of two functions by one control position is not unusual in the terminal system today. For example, the ground control function and the clearance delivery function are combined at some lower activity towers. In certain TRACABS, the local controllers also perform the approach control function in addition to their regular duties. This function is generally performed from the IFR room in other TRACON configurations. In the IFR rooms (or in the en route system) it may be possible, under certain reduced workload conditions to resectorize and combine the airspace so that fewer controllers control the same airspace.

In view of the foregoing discussion, the following statements can therefore be made:

> *For constant traffic, reducing workload could lead to a reduction in number of controllers and therefore increased productivity if:*
>
> - *positions can be eliminated (e.g., flight data or coordinator)*
>
> - *airspace can be reorganized so that controllers can handle more traffic (e.g., approach and departure controllers in terminal system)*

Alternatively, for a higher traffic environment (such as in 1985), today's controllers could possibly handle more traffic with increased automation. The productivity due to increased automation will be discussed with respect to today's traffic.

In applying the controller productivity gain definition to both the en route and terminal systems, controller work assignments will be examined for an assessment of how those assignments will be impacted by the UG3RD automation programs. It should be noted that the derived productivities are thus dependent on the starting point (i.e., the current view of controller assignments). Ultimately, however, this is an FAA management problem which may be resolved differently by using alternate restructuring of the assignments and procedures.

6. TERMINAL AUTOMATION IN PRE-DATA LINK ERA

In the pre-data link era (1976 to 1985), two UG3RD improvement programs are expected to have a significant productivity impact on ARTS-III terminal facilities:

1. Automated Flight Data Handling and Distribution
2. Metering and Spacing

Additionally, it is expected that the Automated Flight Data Handling and Distribution System will leave a measurable impact on the ARTS-II facilities.

The uncertainty associated with the impact of these programs is minimal, as will be shown in the following paragraphs of this section. There are other automation programs however, whose impact on terminal area controller productivity is either uncertain or negligible. These programs are:

- Conflict Prediction
- Radar Tracking
- Minimum Safe Altitude Warning
- Area Navigation
- En Route Metering

6.1 Automated Flight Data Handling and Distribution

The broad goals of the present Automated Flight Data Handling and Distribution program[9] (ADH) are as follows:

1. Development of a Tabular Display to provide flight data in the tower at the local controller, ground controller, clearance delivery and the flight data positions. (A Tabular Display will be available at each of these positions.)
2. Centralized Tower Flight Data Entry at the flight data position.
3. Display of flight data on the TRACON PVD[10] by means of an alternate switch that would enable the controller to view additional data whenever desirable.

This data would disappear whenever the switch is in the normal position.

4. Automatic Dissemination of Terminal Flight Data.

5. Improving system performance through improving timeliness and controller access to current flight data.

6. Providing the interface hardware necessary to extend the enhanced ARTS-III capabilities to remote TRACABS and other installations at satellite airports served by the TRACON.

The Automated Flight Data Handling and Distribution (ADH) System and its associated Tabular Displays, will eliminate the need for the Flight Strip Printers and the flight progress strips handled by the flight data man and other controllers. Many facilities especially the larger ones, employ a flight data man both in the tower and in the IFR room. Because of the heavy activity in them, some of the large TRACONS use two flight data men (in the IFR room) on the busy shifts.

The impact of the ADH system on controller productivity includes:

Reduced voice coordination between large facilities and satellite facilities provided with ADH:

- *Handoff would be performed via tabular display*
- *Full flight plan data would be made available (ID, aircraft type, ... etc...)*

Reduced voice coordination between terminals and ARTCCs

- *In busy periods large queues develop at the Flight Strip Printer. This results in the updates being untimely which necessitates coordination calls either to get data or to forward information.*
- *Coordination is sometimes necessitated because the full flight plan may be desired by the controllers. ARTS has abbreviated flight plan information only (e.g., lacks type of A/C).*
- *Since some terminals do not get arrival strips 20 minutes prior to arrival, coordination is required for obtaining information on arriving traffic.*

6.1.1 Impact on IFR Room Operations

The elimination of much coordination currently performed would eliminate one of the primary functions of the so called coordinator/handoff men in the IFR room. At present, coordinators perform the following functions:

1. They assist controllers in obtaining and delivering information.

2. They feed information on incoming VFR A/C into ARTS system.

It may therefore be practical, desirable, and cost effective to eliminate the coordinator positions in the IFR room if the flight data man in the IFR room could handle the incoming VFR traffic. The question then presents itself: could the flight data man do that in the ADH environment? In order to answer this question, we need to examine the functions he has to perform in that environment.

In the ADH era, the flight data (FD) man in the IFR room no longer needs to handle strips, update them and deliver them to controllers. Walking across the IFR room delivering those strips is one of his main duties. Another duty that the FD man has today is to post and update meteorological data and airport status so that they are visible to the controllers.

It seems feasible therefore to realign the FD man's duty so that he would continue to be responsible for airport status and meteorological information but in addition he could take over the coordinator/handoff man's job of feeding the VFR traffic information into the ARTS-III system.

6.1.2 Impact on Tower Operations

Here, the primary impact is on the flight data man's workload since he no longer needs to handle strips, update them and deliver them to controllers. His reduced workload makes it possible to combine the flight data and the clearance delivery positions at some facilities. In the upgraded ADH environment, the FD man would have access to the data system through a keyboard similar to the ARTS-III keyboard. He would continue to prepare the ATIS tape (NAVAIDS status, weather and runway restrictions).

6.1.3 Summary of ADH Impact

The proposed ADH system would impact not only the ARTS-III terminals, but also the ARTS-II and the satellite facilities that have Flight Strip Printers. However, the prime impact of the ADH system would be on the large facilities and not on the small ones. Even if ADH were implemented in the small non-radar facilities, its impact on these would be minimal since non-radar facilities have limited manpower resources (and needs). The impact of installing ADH in these low level facilities would be on the parent facilities with which coordination is essential.

Table 6-1 summarizes the impact of the ADH system on the controller productivity in ARTS-III facilities. It is expected that the coordinator/handoff positions could be eliminated from the IFR rooms of ARTS-III facilities of all sizes. Additionally, due to the lower level of activity at the medium size ARTS-III facilities, it is expected that the clearance delivery and flight data positions could be combined. It is also expected that the limited radar approach control towers would need one less support position. In Table 6-1, this is accredited as one less FD position. The resulting overall productivity gain of ARTS-III facilities ranges from 1.2 to 1.22.

Table 6-2 sumamrizes the impact of the ADH system on the controller staffing in the smaller ARTS-II facilities. Only the coordinator/handoff positions are expected to be impacted in the IFR rooms of the small TRACONS. The TRACAB operation is already an efficient one and it would not be impacted by the implementation of the ADH system.

Smaller facilities (VFR towers and non-radar approach control towers) would not have an increased productivity as a result of implementing the ADH system, although implementing the system in some of those facilities could positively impact the productivity of the larger facilities.

6.2 Metering and Spacing

This program addresses the development of automation techniques[9] to aid the controller in the sequencing, metering and spacing of terminal traffic arriving at high activity airports. When implemented, it should plan and regulate the rate, order and separation of successive arriving flights. Although the main objective[11] of the program is to utilize runways of

TABLE 6-1
IMPACT OF AUTOMATED FLIGHT DATA HANDLING AND DISTRIBUTION ON ARTS-III FACILITIES STAFFING

LOCATION	CONTROLLERS	TRACON & CAB				TRACON/NO CAB		LIMITED RADAR APPROACH CONTROL TOWER	
		LARGE		MEDIUM		LARGE			
		3RD	3RD & ADH	3RD	3RD & ADH	3RD	3RD & ADH	3RD	3RD & ADH
IFR ROOM	FINAL APPROACH	2	2	1	1	2	2		
	ARRIVAL	3	3	3	3	3	3		
	DEPARTURE	3	3	2	2	3	3		
	COORDINATOR/HANDOFF	3	0	1	0	2	0		
	FLIGHT DATA	1	1	1	1	1	1		
	TOTAL IFR ROOM	12	9	8	7	11	9		
	IFR ROOM PRODUCTIVITY GAIN		1.33		1.14		1.22		
TOWER CAB	LOCAL	1	1	1	1			1	1
	ASSISTANT LOCAL	1	1	-	-			1	1
	GROUND	1	1	1	1			1	1
	CLEARANCE DELIVERY	1	1	1	1			1	1
	FLIGHT DATA	1	1	1				2	1
	TOTAL TOWER CAB	5	5	4	3			6	5
	TOWER CAB PRODUCTIVITY GAIN		1		1.33				1.2
IFR ROOM & TOWER CAB	TOTAL CONTROLLER STAFF	17	14	12	10	11	9	6	5
	FACILITY CONTROLLER PRODUCTIVITY GAIN		1.21		1.2		1.22		1.2

TABLE 6-2
IMPACT OF AUTOMATED FLIGHT DATA HANDLING ON INDIVIDUAL ARTS-II FACILITIES STAFFING

LOCATION	CONTROLLERS	SMALL TRACON & CAB		SMALL TRACON NO CAB		TRACAB (COMBINED IFR ROOM & CAB)	
		3RD	3RD & ADH	3RD	3RD & ADH	3RD	3RD & ADH
IFR ROOM	ARRIVAL	1	1	2	2	1	1
	DEPARTURE	1	1	2	2		
	COORDINATOR/HANDOFF	1	0	1	0		
	FLIGHT DATA	1	1	1	1		
	TOTAL (IFR ROOM)	4	3	6	5		
	IFR ROOM PRODUCTIVITY GAIN		1.33		1.2		
TOWER CAB	LOCAL	1	1	X	X	1	1
	GROUND	1	1	X	X	1	1
	CLEARANCE DELIVERY	1	1	X	X	1	1
	FLIGHT DATA	1	1	X	X		
	TOTAL (TOWER CAB)	4	4	X	X	4	4
	TOWER CAB PRODUCTIVITY GAIN		1	X	X	-	-
IFR ROOM & TOWER CAB	TOTAL FACILITY CONTROLLERS	8	7	6	5	4	4
	FACILITY PRODUCTIVITY GAIN		1.14		1.2		1

a busy airport more efficiently (and thus increase capacity and reduce delays), its impact on controller productivity should be significant.

Currently, the Metering and Spacing (M&S) function is accomplished by both the final approach controller and the other approach controllers that feed into the final approach airspace. In some facilities, a sequencer sequences the traffic one or two sectors removed from final approach. The approach controllers regulate the flow so that it is matched to the rate at which the final approach controller is capable of accepting under the circumstances. The final approach controller gives speed and altitude commands to regulate the flow of traffic for handoff to the local controller at the tower. The local controller works with the final approach controller so that he interleaves his depatures at convenient gaps in the arrival stream, consistent with aircraft characteristics and wake vortex problems.

In the initial phases of Metering and Spacing automation, only the arrival aspect of the control operation would be addressed. Current concepts(12) utilize three levels of control: metering, delay spacing, and precise final spacing to optimize the sequence and interarrival spacing between aircraft landing at the runway. The metering control would be accomplished initially by the en route system adjusting the interarrival spacing and speed of aircraft approaching an arrival fix. This spacing would be requested by the approach controller based on the overall aircraft arrival rate into the terminal area as well as the quantity of traffic coming to the particular fix in question. This data could be displayed to the approach controllers by the M&S system. The delay spacing control would be accomplished on the approach leg between the arrival fix and the downwind leg of the base-leg region by utilizing speed control and, when necessary, vectoring. The precision delivery control in the base-leg region would be used to correct for errors in the aircraft's performance in meeting its M&S scheduled landing time. The difference between the aircraft's estimated time of arrival at the runway and its scheduled landing time would determine the path stretching commands to be given and the speed adjustments to be made in this region. The M&S system would also use dynamic schedule adjustment, and resequencing when necessary to maintain separation.

The application of automated metering and spacing functions would mean that, in high activity airports, the workload associated with the approach control function would be reduced due to reduced voice coordination. Under these conditions, it is reasonable to expect that the total number of approach controllers would be about equal to the number of departure controllers who are not aided by the M&S system. This could be achieved by enlarging the approach sectors airspace boundary, since the capacity of the approach controller would be increased. It is important to remember, though, that the controller would still have to communicate clearances to the pilot by voice.

The availability of the sequencing instructions to all controllers would result in:

- *Reduced voice coordination between two arrival controllers feeding traffic into the airspace of the final controller, or, alternatively eliminating the need for the sequencing controller position.*

- *Reduced voice coordination between the arrival controller and the final controller.*

- *Reduced voice coordination between the local controller or his assistant and the IFR room's final or approach controllers, (depending on the size and mode of operation of the TRACON). With automated M&S, the local controller or his assistant could feed into the system certain gap requirements for departure and the characteristics of the departing aircraft, thus reducing the communications workload on both control positions involved.*

- *Reduced voice coordination between the approach controller and the en route controller, assuming automatic interfacing between the en route metering and M&S systems.*

- *Reduced approach controller workload since this controller no longer performs the metering and spacing function mentally.*

Assuming that restructuring the approach control airspace is feasible, Table 6-3 summarizes the expected impact of the M&S system on controller staffing in ARTS-III facilities. In the large TRACONS, the approach controller positions can be

TABLE 6-3
IMPACT OF BASIC METERING AND SPACING ON ARTS-III FACILITIES STAFFING

	CONTROLLERS	TRACON & CAB				TRACON/NO CAB		LIMITED RADAR APPROACH CONTROL TOWERS (9)	
		LARGE (19)		MEDIUM (31)		LARGE (13)			
		3RD & ADH	3RD & ADH & BMS	3RD & ADH	3RD & ADH	3RD & ADH	3RD & ADH & BMS	3RD & ADH	3RD & ADH & BMS
IFR ROOM	FINAL APPROACH	2	4			2	4		
	ARRIVAL	3				3			
	DEPARTURE	3	3			3	3		
	COORDINATOR/HANDOFF	0	0			0	0		
	FLIGHT DATA	1	1			1	1		
	TOTAL (IFR ROOM)	9	8			9	8		
	IFR RM PRODUCTIVITY GAIN		1.13				1.13		
TOWER CAB	LOCAL	1	1					1	1
	ASSISTANT LOCAL	1	0					1	0
	GROUND	1	1					1	1
	CLEARANCE DELIVERY	1	1					1	1
	FLIGHT DATA	1	1					1	1
	TOTAL TOWER CAB	5	4					5	4
	TOWER PRODUCTIVITY GAIN		1.25						1.25
IFR ROOM & TOWER CAB	TOTAL CONTROLLER STAFF	14	12			9	8	5	4
	FACILITY PRODUCTIVITY GAIN		1.17				1.13		1.25

reduced by one and the assistant controller positions could be eliminated entirely. Since, in the near term, it is expected that the automation of the Metering and Spacing function would be implemented only in the 32 large ARTS-III facilities, (19 TRACONS with CAB and 13 TRACONS without CAB) the latter are the only ones impacted. The productivity gain on impacted facilities ranges from 1.13 to 1.25 depending on the facility type.

6.3 Other Terminal Automation Programs

This section addresses improvement programs that are part of the UG3RD that would aid the controller in the performance of his duties to monitor and manipulate the safe and expeditions flow of traffic, and indirectly contribute to a higher productivity gain. Taken individually, though, they do not have a sufficiently significant increase in productivity to warrant any claims of a major nature. The following paragraphs address these programs.

6.3.1 Conflict Alert[9,13]

This program is oriented towards enhanced safety and not increased productivity. It provides for the design, development and verification of automation techniques to aid in avoiding conflicts in the movement of terminal air traffic at ARTS equipped terminal facilities. The advent of the Terminal Control Area (TCA) and the Expanded Radar Service (ERS) concepts, while enhancing safety in the terminal airspace, have placed an increased burden on the controlling ATC facility in terms of the number of flights whose position and movement must be monitored and instructions/advisories formulated and issued to avoid potential conflicts. The automated Conflict Alert (CA) function will assist the controller in predicting the near future air situation. Controlled flights as well as non-controlled VFR traffic operating in the same airspace are involved. A design and development effort similar to that of the en route Conflict Alert Program[14,15] is currently in progress.

Although the Conflict Alert function alerts the controller either to a situation he missed or to something he had intended to address, the controller is generally relieved of performing some calculations mentally. Conflict Alert algorithms would calculate the current separations, closure rates, closest approach distance and time to closest approach. Thus, some small controller productivity impact could be expected due to the implementation of this program. This program however, has, as its prime objective, the enhancement of safety rather than the reduction in workload. Since it is difficult to predict the frequency of occurrence of events requiring Conflict Alert (CA) and the number of a subset of those events where the controllers workload was actually reduced and by how much, no productivity impact will be assumed due to CA in this report.

6.3.2 Radar Tracking

The objective of this program is to establish the means of automatically providing reliable and accurate tracking data on all detected flights within the sensor coverage and area of jurisdiction of about one half of the TRACONS and towers served by the ARTS-III system. Possible expansion of radar tracking into the ARTS-II system is under consideration as part of the ARTS-II enhancement programs. (Another potential ARTS-II enhancement is the implementation of the beacon tracking into the system.) Automatic tracking of all detected flights rather than just "controlled", transponder equipped, flights is involved in order to support such control automation functions as conflict alert and to facilitate all digital display operations. It is also expected to improve overall reliability of tracking by providing additional data with which to resolve otherwise ambiguous situations encountered in the scan-to-scan correlation process of ATCRBS data when several targets are in close proximity to one another. Initial emphasis[9] will be on providing: (1) tracking of flights not equipped with a transponder or whose transponder is malfunctioning, (2) a secondary source of position data for track updating when beacon responses are not received due to fading or shielding of the aircraft's antenna, and (3) increased azimuthal accuracy in the determination of aircraft position. Other efforts will be directed to accomplishing this function in a multisensor environment, where the sensors are not collocated. This would extend the surveillance coverage and would provide an alternate source of data in the event of a sensor failure.

The radar tracking function would aid the controller in the performance of his surveillance function and would provide support to the Conflict Alert function. Radar tracking could affect controller productivity in negative as well as positive senses. For example, for any one aircraft, the improved tracking reliability would decrease the workload associated with surveillance, (reduced Requests to Ident), but because of the increased number of aircraft being tracked, and therefore monitored by the controller, the workload would increase somewhat. Thus, a strong case cannot be made for a significant impact either on workoad reduction or increase due to the implementation or radar tracking in ARTS facilities.

6.3.3 Minimum Safe Altitude Warning (MSAW)

Development is underway of an automation technique for the basic ARTS-III system to automatically advise controllers when tracked aircraft with Mode C are descending below the minimum safe altitudes in the terminal area.

In controlling aircraft in flight, the basic role of Air Traffic Controllers in the past has been to separate the aircraft leaving the safe navigation of the aircraft to the pilot. This role is undergoing some changes at the present time, since the controllers have the added responsibility of monitoring the aircraft altitude to detect potentially unsafe separation of aircraft from terrain, and providing the pilot with a warning to that effect. The manual performance of this task necessarily increases workload. It is possible that a special controller or a set of controllers would be assigned for the manual performance of that duty. In this analysis, however, no impact would be assumed due to the automation of MSAW.

6.3.4 Area Navigation (RNAV)

Area Navigation (RNAV) is a capability which will give more flexibility to the currently defined VOR airway route structure since it will permit navigation along routes not coincident with existing VOR radials.

Several studies [16,17,18] of Area Navigation have shown that a reduction of controller workload due to RNAV may be possible under certain conditions. A NAFEC study[18] has shown that this reduction could be between 20 and 40 percent. However, there is a capacity/productivity tradeoff to be considered in the terminal area since it has been shown[19] that airport capacity could decrease somewhat due to the implementation of RNAV. Furthermore, it is difficult to make the case that this workload reduction could be translated into controller productivity. For example, while it is true that the approach controller is a high stress and high workload position, it is also true that this controller's philosophy of operation is to separate the aircraft as opposed to navigating them. The application of this philosophy especially in a mixed RNAV and non-RNAV environment implies a continuous interaction with the pilots of the aircraft under the control of this position, thus negating the workload related benefits attributable to RNAV. Additonally, the approach controller prefers the flexibility inherent in the vectoring made possible by the surveillance system. Furthermore, the workload reduction obtained due to the implementation of RNAV at low density airports cannot be translated into a productivity gain because of the low staffing levels at those facilities.

Thus, in summary, although a good case can be made for workload reduction due to RNAV, no controller productivity could be claimed.

6.3.5 En Route Metering

It has been shown[20] by simulation that en route metering can result in a significant reduction in the number of aircraft simultaneously handled in the terminal area. This reduction can be as high as 35 to 40 percent in the case of a terminal area with an airport operating at capacity. Thus, it could be assumed that with en route metering, some large size TRACONS could accomplish their control function using a smaller number of controllers during the peak shift, since it can be assumed that a step decrease in workload can lead to smaller staffing. However, not all airports have a demand level at or close to capacity--a situation where there is productivity potential. Therefore, a 35 to 40 percent reduction in workload could not be directly applied to all large TRACONS.

According to the staffing standard, the staffing in the IFR room is determined by the peaks during the busy shift on the 37th busiest day. Since the advent of en route metering would relieve this peaking by stretching the aircraft flight path into the en route system, the staff required to handle the traffic in very large facilities might be reduced. Assuming that only the ten busiest airports are impacted, it appears that the overall productivity gain impact on the whole terminal system would be about 5 percent to 7 percent.

This productivity gain is, however, obtained at the expense of an equal productivity loss in the en route system because the aircraft would have either been delayed or their path stretched in the en route system. Because of this, no net productivity gain will be assumed in either the terminal or en route systems due to en route metering. It should be noted that the main benefit to the user of En Route Metering is reduced delays via more regulated flow.

6.4 Productivity Summary for the Terminal System

Table 6-4 summarizes the expected impact of automating the individual ARTS-III terminal facilities on the controller productivity gain in those facilities. The combined impact on the large ARTS-III facilities due to implementing Automated Data Handling (ADH) and Metering and Spacing (M&S) is expected to result in a productivity gain between about 40 and 50 percent. The impact of implementing the ADH system on the medium size facilities amounts to about a 20 percent gain in controller productivity. No impact on medium facilities due to M&S is anticipated since in the time frame under consideration, it is expected that the M&S system will be implemented in large facilities only. Similarly Table 6-5 summarizes the impact of the terminal automation on the smaller facilities. The Automated Flight Data Handling system is expected to have an impact on controller productivity gain in the small TRACONS of about 14 to 20 percent.

Although they are derived by considering the controller staffing only, these productivity gains are applicable to all the operations personnel in a facility. This can be seen by examining Table 6-6 which shows overhead as a function of facility size. The table shows that percent overhead is not a very strong function of facility size. For the large ARTS-III facilities the overhead's range of variation is from 23 percent to 28 percent of the total facility staff. For the small TRACONS, overhead ranges from 20 percent to 23 percent. Thus, any refinement of the productivity model to include the effect of overhead is not justified. Therefore, it will be assumed that the productivity gains derived in this section would apply to the total facility staff.

Because of the natural division of the terminal types into ARTS-III terminals and other types, it is of interest and value to compute an average or "weighted" productivity gain that is applicable to one category or the other. This can be defined as follows:

$$\overline{P} = \frac{S}{S_p} \qquad (6-1)$$

TABLE 6-4
SUMMARY OF PRODUCTIVITY GAIN IN THE ARTS-III TERMINAL FACILITIES
(INCLUDING OVERHEAD)

IMPROVEMENT PROGRAM	PRODUCTIVITY GAIN			
	ARTS-III TRACONS AND TOWERS		LARGE ARTS-III TRACONS WITH NO TOWER	LIMITED RADAR APPROACH CONTROL TOWERS
	LARGE	MEDIUM		
● AUTOMATED FLIGHT DATA HANDLING	1.21	1.2	1.22	1.2
● METERING AND SPACING	1.17	1	1.13	1.25
COMBINED PRODUCTIVITY GAIN	1.42	1.2	1.38	1.5
AVERAGE WEIGHTED PRODUCTIVITY GAIN	1.32			

TABLE 6-5

SUMMARY OF PRODUCTIVITY GAIN IN THE SMALLER FACILITIES OF THE TERMINAL SYSTEM

IMPROVEMENT PROGRAM	PRODUCTIVITY GAIN				
	SMALL TRACON & CAB	SMALL TRACON NO CAB	TRACAB	NON RADAR APPROACH CONTROL TOWER	VFR TOWER
• AUTOMATED FLIGHT DATA HANDLING	1.14	1.2	1.0	1.0	1.0
• BASIC METERING & SPACING	1.0	1.0	1.0	1.0	1.0
COMBINED PRODUCTIVITY GAIN	1.14	1.2	1.0	1.0	1.0
AVERAGE "WEIGHTED" PRODUCTIVITY GAIN	1.05				

TABLE 6-6
OVERHEAD AS A FUNCTION OF FACILITY SIZE

FACILITY		SUPERVISORY & DSS / TOTAL FACILITY STAFF
TRACONS + CAB	LARGE	26%
	MEDIUM	25%
	SMALL	23%
TRACON/ NO CAB	LARGE	28%
	SMALL	20%
TOWERS	LIMITED RADAR APPROACH CONTROL	23%
	TRACAB	24%
	NON RADAR APPROACH CONTROL	25%
	VFR	31%

where

$\overline{P}$ = Average or "weighted" productivity gain

S = baseline staff summed over the terminal types considered assuming no automation

S_p = staff summed over terminal types considered assuming automation

Thus for 1985, the staff size with no automation (S) for the ARTS-III facilities is found by summing from Table 4-5 the staff of the following facilities:

- Large TRACON and CAB
- Medium TRACON and CAB
- Large TRACON/No CAB
- Limited Radar Approach Control Tower

The staff size assuming increased productivity (S_p) is then found by dividing the staff of each of the above facilities by the productivity attained by the facility by 1985 (Table 6-4) and then summing the result. The ratio S/S_p is the average or "weighted" productivity and is equal to 1.32 for the ARTS-III facilities (see Table 6-4). The average productivity for all the other terminals combined is found by a similar procedure and the result is 1.05 (see Table 6-5).

7. EN ROUTE AUTOMATION IN PRE-DATA LINK ERA

7.1 Sector Workload

The en route sector workload is distributed among the Radar (R) Controller, Data (D) Controller and the Assistant (A) Controller in the following fashion. The radar controller handles tactically oriented functions. He is responsible for assuring the separation of aircraft, short term (tactical) traffic planning, and voice air/ground (A/G) communications using the NAS plan view display and the associated keyboard entry system. The controller in the D-position handles "strategic" or long term functions associated with planning and sector maintenance. He manages and negotiates transfers of control jurisdiction responsibility for aircraft (handoffs), maintains intersector coordination, and organizes flight strips that are retained in the NAS operation in case of NAS system computer failure. The D-controller also has a keyboard entry set and can communicate with the NAS computer system. Assistant controllers typically support a pair of sectors by servicing the flight data processing equipment that supports the sector operations.

A detailed analysis of the distribution of sector workload among different functions and control positions was performed(21) by Stanford Research Institute. The analysis is based on a time and motion study which measures the times taken to perform certain tasks and the frequency of occurrence of these tasks. Based on the SRI work, Table 7-1 illustrates the distribution of workload among functions and positions. The table shows that the total sector workload is about 70 man-min per hour of which the R-controller's share is about 52 and the D-controller's share is about 18. Thus, the R-controller performs about 74 percent of the sectors workload while the D-controller's share is 26 percent. The distribution of the R-controller's workload among four broad functional categories of workload is shown in the table. These categories are: communications, conflict prediction/resolution, surveillance/monitoring, and manual/console operations. The D-controller's workload is treated as one category: planning and sector maintenance. In performing the sector planning function, the D-controller actually performs conflict prediction and resolution on a long term basis (as compared to the R-controller's tactical role) and performs the necessary coordination with other sectors to ensure the expeditious and safe flow of traffic. The A-controller generally handles the flight strips, removing them from the flight strip printer (FDEP), loading

TABLE 7-1
DISTRIBUTION OF AN EN ROUTE SECTOR WORKLOAD

CONTROLLER	FUNCTION	MAN-MIN./HR*	PERCENT OF TOTAL
RADAR (TACTICAL ORIENTED FUNCTIONS)	COMMUNICATIONS	22.4	32%
	CONFLICT DETECTION/RESOLUTION	8.3	12%
	SURVEILLANCE/MONITORING	10.7	15%
	MANUAL/CONSOLE OPERATIONS**	10.1	15%
D-MAN	PLANNING AND SECTOR MAINTENANCE	18	26%
	TOTAL	69.5	100%
0.5 ASSISTANT CONTROLLER PER SECTOR FOR HANDLING FLIGHT STRIPS			

*FAA-RD-74-196 DATED DECEMBER 1974. A REPORT BY STANFORD RESEARCH INSTITUTE.

**INCLUDING STRIP PROCESSING

the strips individually on loaded plastic holders, and handing them over to the D-controller. The A-controller is also considered to be in training and therefore, he performs some of the D-controller's duties.

The impact of automation programs on these controllers, their functions, and the sector workload will be the subject of the following sections. This impact is in either one of two forms:

1. Eliminating or reducing the workload of support positions or;

2. Permitting the R-controller to control more aircraft.

In the discussions to follow the controllers productivity will be discussed at the current level of traffic activity.

7.2 Control Sector Position Re-Design/Tabular Display

In the near term (1976-1985), the only automation program that is expected to have a significant impact on controller productivity is Control Sector Re-Design and its associated Tabular Display and Flight Data Handling. Currently, non-radar flight data, including flight plan information and meteorological data, is provided to the Air Traffic Control sector teams in the Air Route Traffic Control Centers (ARTCC) primarily by printed flight progress strips at the "A" position and by Computer Readout Display at both the "A" and the "D" positions. Air traffic controller data entries into the system are via keyboards associated with the Computer Update Equipment Subsystem.

The current design of man-machine interface at the en route sector positions is deficient in that it imposes time consuming manual tasks on controllers and requires excessive sector staffing under heavy traffic conditions. A Proposed Tabular Display Subsystem offers a potential for significant system productivity benefits in terms of reduced staffing and increased traffic handling capacity of the controller. The proposed system consists of multiple processing, display and data entry modules which will interface with the Central Computer Complex (CCC) in the ARTCC and provide an electronic display of flight data at the "D" position, thereby replacing the Flight Strip Printers. It will also provide the air traffic controllers with efficient means for communicating with the flight data base by using simplified data updating and data entry procedures/devices, thereby, replacing the computer readout and update equipments. Storage and retrieval of data during various failure modes of operation is to be accommodated in the design of the Tabular Display Subsystem.

More specifically, the Tabular Display Subsystem has the following features:

1. Automatic ordering of flight entries by time under separate fix headers.

2. Automatic updating of flight data, some of which may require controller acknowledgement of the update.

3. The automatically displayed flight data is simplified but the capability is provided for a callup of more detailed flight data.

4. The Tabular Display/Touch input design is interactive allowing the controller to complete most input actions without the use of a keyboard.

5. A limited amount of sector tailoring will be utilized with the Tabular Display. Present design calls for similar interfaces/displays at all sectors. The differences are limited to Menu items such as fixes and altitudes.

The Tabular Display subsystem is expected to impact controller productivity in the following manner:

(a) The basic impact is eliminating the need for the "A" position by eliminating the flight progress strips.

(b) Another small impact is the eliminating of the handling of flight strips by the R-controller. Controllers are required to make dual entries to maintain up-to-date system and sector data bases. Control actions resulting in modifications to flight data require controllers to input updated information to the CCC via sector entry devices and also to hand-annotate flight progress strips. In addition, modification actions cause update messages to be routed to other control sectors requiring controllers at these sectors to manually update flight strips. It was estimated[21] that this processing plus other RDP/FDP NAS-related operations consume about 15 percent of the total workload of a sector. About one half of this is workload[21] related to manual flight strip processing and is performed by the R-controller. The Tabular Display will eliminate the need for this activity.

(c) In addition, the "D" controller's handling of flight strips is also eliminated. Yet no productivity could be claimed in this regard until a substantial reduction in the R-controller workload materializes making it possible to increase the traffic he could handle or leading to the combining of setors, in which case the D-controller could support two sectors.

In assessing the contribution of the Tabular Display to productivity, one has to consider both the FDP workload reduction and the elimination of the A-man position. The latter alone reduces sector staffing requirement from 2.5 to 2.0 controllers. The combined effect is a productivity of 1.35 obtained as follows:

- Productivity due to elimination of flight strips and and "A" man position is $\frac{2.5}{2.0}$ = 1.25.

- Productivity due to elimination of "Duplicate" updating of flight strips (1.08).

- Combined productivity impact = 1.25 x 1.08 = 1.35.

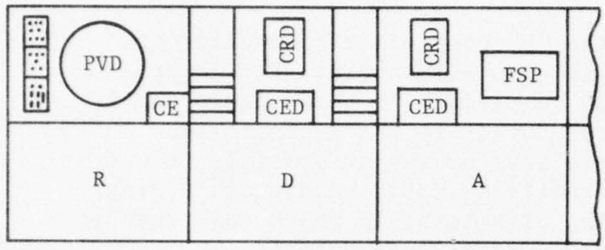
This productivity is expected to affect the number of aircraft handled per control team. However, it is not expected that the D-controller would be capable of supporting two sectors (thus being shared by them) until further automation capabilities are introduced. Figure 7-1 shows pictorially the present and future control sector design, and the man-power associated with it.

7.3 Other En Route Automation Programs

This section addresses automation programs that are part of the UG3RD that will have impact in areas other than productivity. However, the implementation of these programs is expected to positively enhance the controller productivity since the controller will have at his disposal automated aids

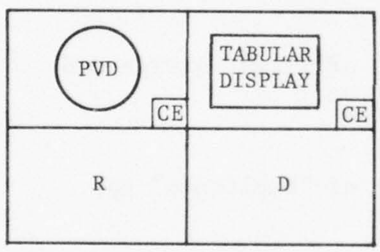
3RD GENERATION (PRESENT SYSTEM (NAS STAGE A, MODEL 3d):

R = 1.0
D = 1.0
A = 0.5
2.5



CRD = COMPUTER READOUT DEVICE
CED = COMPUTER ENTRY DEVICE
FSP = FLIGHT STRIP PRINTER
CE = COMPUTER ENTRY, INCLUDING "QUICK ACTION" KEYS AND TRACKBALL.

UPGRADED 3RD (1980-1985) (REVISED SECTOR DESIGN):



R = 1.0
D = 1.0
2.0

FIGURE 7-1
REDUCING THE AVERAGE NUMBER OF CONTROLLERS PER EN ROUTE SECTOR

in the performance of his duties. The following sections analyze these programs and the uncertainties associated with their impact on productivity. The En Route Metering will not be discussed here, since it was thoroughly discussed in the section on Terminal Automation.

7.3.1 Conflict Alert[14,15]

The automated conflict alert function aids the radar controller in predicting situations where loss of radar separation minimum standards are about to occur. Using information presently available in the 9020 computer from the automatic tracking function and the flight plan data base, the conflict alert function provides the radar controller with an alert on his plan view display of impending situations of separation being less than minimum. The alert is generated a short time before the separation minimums might actually be violated.

This function has been developed for initial application to all tracked aircraft (IFR versus IFR) in high altitude Positive Control Airspace (PCA) where all aircraft are required to be equipped with beacon and altitude reporting capability. Additional conflict alert related developments are in progress in the following areas:

- Extending the design for application in low-altitude airspace.
- Introduction of flight intent (flight plan route) information into the conflict alert logic.
- Extension of conflict alert to aircraft in hold status.
- Extension of conflict alert for non-beacon equipped IFR aircraft in low altitude airspace.

The Conflict Alert (CA) function alerts the controller either to situations he missed or to something he had intended to address; the controller is generally relieved of performing some calculations mentally. CA algorithms calculate the current separations, closure rates, closest approach distance and time to closest approach. Thus, some small controller productivity imapct could be expected due to the implementation of this program. This program, however, has as its prime objective the enhancement of safety rather than the reduction in workload. Since it is difficult to predict the frequency of occurrence of events requiring CA and the number of a subset of those events where the controllers workload was actually reduced and by how much, no productivity impact will be assumed due to CA in the report.

7.3.2 Flight Plan Conflict Probe(22,23)

The objective of the Flight Plan Conflict Probe (FPCP) aid is to provide computer assistance to controllers in planning conflict free flight paths for controlled aircraft. In today's en route environment, controllers do not have information on traffic much beyond that of the individual sector under their control. They are, therefore, unable to plan conflict free flight paths beyond this limited amount of center airspace. As a result, controllers have no way of knowing whether or not the actions they take to avoid potential conflict situations through their sectors will create additional conflict situations in the remainder of the center airspace. The proposed Flight Plan Conflict Probe could provide controllers with a capability to achieve "longer" range planning. Present plans and developmental efforts intend to accomplish this by having the computer use updated flight plans to check (probe) an aircraft's intended flight path (route of flight) to determine if the intended flight path results in a conflict with another flight. The probe is initiated at departure, handoff, after a significant change in flight plan data (e.g., route amendment), or at the controller's request. Possible conflicts are determined based upon: separation threshold, route widths, longitudinal position uncertainty and altitude bounds.

The implementation of the Flight Plan Conflict Probe automation aid may have a bearing on controller productivity by relieving controllers from performing most of their normal planning, and by minimizing the number of potenial conflicts, and thus reducing the workload associated with conflicts. However, since the extent to which there is a productivity impact is difficult to estimate at this time, no productivity gain due to FPCP will be assumed in this report.

7.3.3 Central Flow Control(11,24)

The major flows of traffic are regulated at the national level from the ATC System Command Center in Washington, D.C. The central flow control operations in the center continuously compare the projected traffic data base against the data base that provides weather, airport, and navigation/control system status. Problems such as weather to be avoided or system overloads to be reduced are flagged and solutions developed in coordination with the affected en route and terminal ATC facilities. Notices or advisories, clearance restrictions, or other similar instructions are disseminated to the appropriate facilities and other points of contact with the users. At the present time, the Airport Information Retrieval System provides data processing support for central flow control via time-shared computer terminals, it is expected that a dedicated computer system will be obtained to provide expanded automation support. The Central Flow Control System will be extended to include dynamic updates of the data base for air traffic originating at and destined to the ten major terminals. This will provide improved estimates of air traffic demand for the major terminals and the interconnecting air routes and would be used for rerouting traffic from congested routes/fixes.

The automation of Central Flow Control would definitely have benefits in reducing fuel consumption and delays, but its impact on controller productivity may be questionable since it will affect only a small number of sectors during high congestion situations which occur only occasionally. No productivity gain will be assumed in this report due to this automation.

7.3.4 Local Flow Control

The present concept of local flow control as expressed in recent statements by Air Traffic Service is oriented towards attaining benefits to the user of the ATC system.[25] Air Traffic Service (ATS) envisions the following:

1. Reduction of Departure Delays Through Re-Routing

ATS proposes the use of a plan view display in order to assist the local flow controller in decreasing departure delays. This display of data would enable the local flow controller to quickly assess departure traffic flow and preclude excessive departure delays by judiciously re-routing traffic to avoid certain routes/fixes during severe congestion situations. Congestion of the air routes or fixes is an indication that a particular sector (or sectors) is being worked to capacity. The capacity limitation in the en route system could be either the physical space limitation or the capacity of the controller to handle the demand. In the latter sense there is a workload reduction payoff due to the re-routing resulting from the application of this function. The net effect, though, is smoothing of workload over many sectors rather than overloading one particular sector. But, since the FAA staffing standard is based on the peak hourly activity during any particular shift, this flow control function could have the effect of reducing the staffing requirements for some sectors that are functioning at capacity, while producing workload for sectors working below capacity. This could incur a net productivity gain. However, the penalty associated with this gain is the user's cost of flying the additional mileage required by rerouting.

2. Compiling and Forwarding Delays Informations

Current local flow control concepts involve using the en route computers to compile and forward ATC assigned ground delays and en route hold delays to subsequent ARTCC's for the purpose of equalizing delays to the users. The delay information would be displayed (on request) on the local controller PVD or printed at the local flow controller position. No controller productivity benefits seem to be attainable due to this function. In fact, this function could have a negative effect on the controller productivity since it could require an approach or a transition controller to work aircraft out of a holding stack (for example) on a delay priority, rather than applying the first-come-first-served concept. Additionally, the checking of the delay information would add to the controllers workload.

Thus, the above factors contribute one positively and one negativley to controller productivity. Based on this, it is assumed here that local flow control function would have no net impact on controller productivity.

7.3.5 Area Navigation

The use of Area Navigation in the en route system raises some productivity issues. Figure 7-2 illustrates RNAV offsets from VOR Routes A and B. Normally, without RNAV, the controller concentrates on the intersection of Routes A and B and keeps the aircraft converging on that intersection separated by means of an altitude or time separation. With RNAV and because of the many possible offsets as shown in Figure 7-2, the controller would have to survey many more intersections than without RNAV. This is especially true if the traffic density is relatively high. An increase in workload results since the controller performs some computations mentally in his attempt to accurately locate the aircraft.

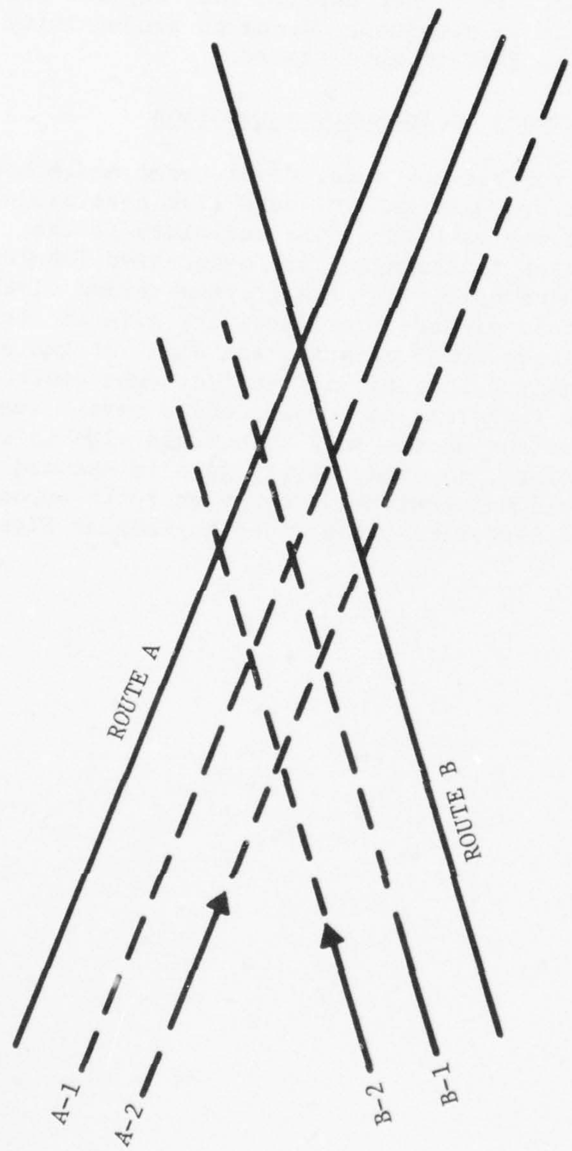


FIGURE 7-2
RNAV OFFSET ROUTES

So, here again, as in the Terminal System, while it is true that RNAV does reduce the communications workload, surveillance workload may increase. It is not certain that any net reduction in workload would be obtained. Hence no productivity gain is assumed due to RNAV in this report.

7.4 Productivity Summary of En Route Automation

The only automation program now under development and scheduled to be implemented before DABS and its data link, that could result in a productivity gain with some certainty, is the Control Sector Position Redesign and its associated Tabular Display and Flight Data Handling. The implementation of this automation system could produce a productivity gain of about 35 percent. Other improvement programs are aimed at increased safety and reduced user delays and not at increased controller productivity. These improvements, however, could have a small productivity gain but the uncertainty associated with this gain is high. Therefore, no productivity gain is assumed in this report that could be attributed to any en route automation programs except Sector Position Redesign/Tabular Display.

8. STAFFING COSTS

8.1 Terminal System Staffing Costs

It was shown earlier that the unrestrained growth in Terminal Staffing could lead to about a 50 percent increase in total terminal system staff over the next decade. Figures 2-2 and 2-3 show the growth in the terminal traffic and staffing of the current system assuming no automation. Since the terminal facilities can be readily divided into the two categories: ARTS-III and non-ARTS-III, it is of interest to observe the unrestrained growth in either category. The total terminal system staffing was calculated using the FAA staffing equation. The ARTS-III system staffing was calculated using the staffing model as developed in Section 4. The difference between the two is the "other" terminal staffing. Figure 8-1 shows the unrestrained staffing of the terminal system broken down into these categories. The figure shows that the growth for the next decade in both the ARTS-III and non-ARTS-III facilities would be about 50 percent. In order to compute the staffing requirements of the improved system, an UG3RD improvement implementation schedule has to be assumed. Figure 8-2 shows what the FAA* considers as the likely schedule of implementation of all automation improvements that impact productivity. Those programs related to the data link are not discussed here but will be the subject of Part II of this report. The FAA* schedule shows that the implementation of basic contributors to productivity in the 1975-1985 time frame, namely ADH, and M&S are expected to begin around 1980, with the last site equipped by 1983. Two years are assumed to elapse beyond the implementation of the last site before the full productivity benefits of automation are realized. A linear increase in productivity is assumed between 1980 and 1985, corresponding to an assumed linear implementation program. Figure 8-3 shows the effective productivity as a function of time for the ARTS-III and other terminal categories. Note that the schedule in Figure 8-2 shows that the ARTS-II implementation would be accomplished by 1978, so that any productivity impacted by the ARTS-II in combination with the ADH system can be realized in the 1980-1985 time frame.

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*FAA Office of Systems Engineering Management.

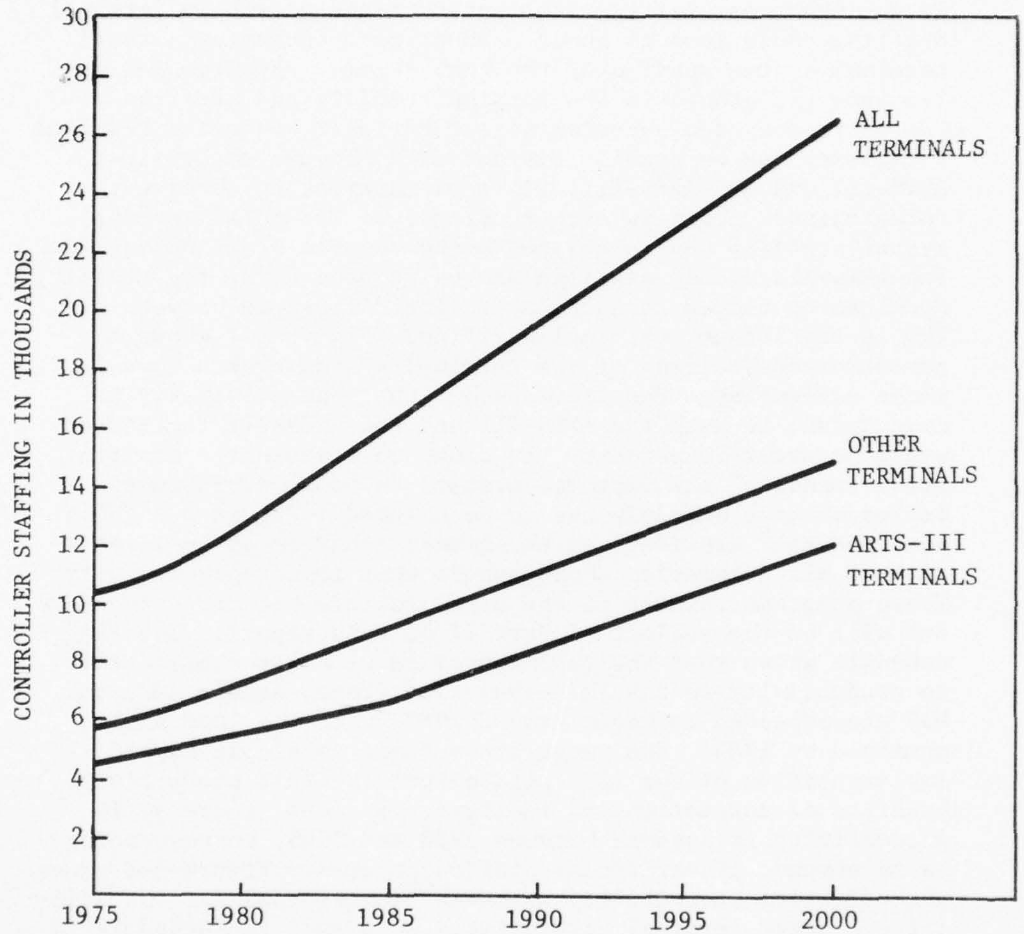

FIGURE 8-1
STAFFING REQUIRED IN ARTS III AND OTHER TERMINAL ATC FACILITIES TO ACCOMMODATE FORECAST DEMAND WITHOUT INCREASE IN CONTROLLER PRODUCTIVITY

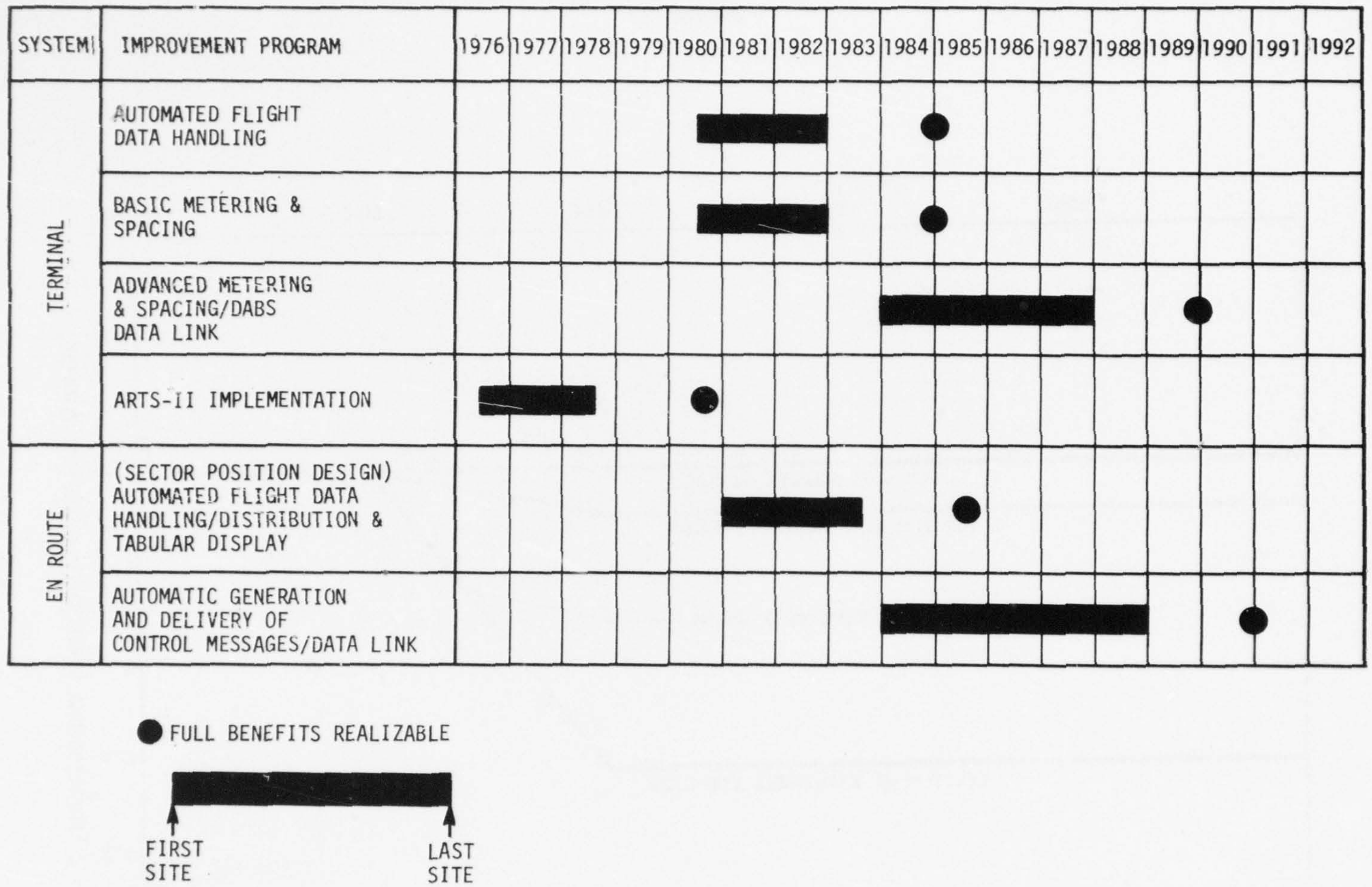

FIGURE 8-2
ESTIMATED SCHEDULE OF UG3RD IMPROVEMENT PROGRAMS THAT IMPACT PRODUCTIVITY

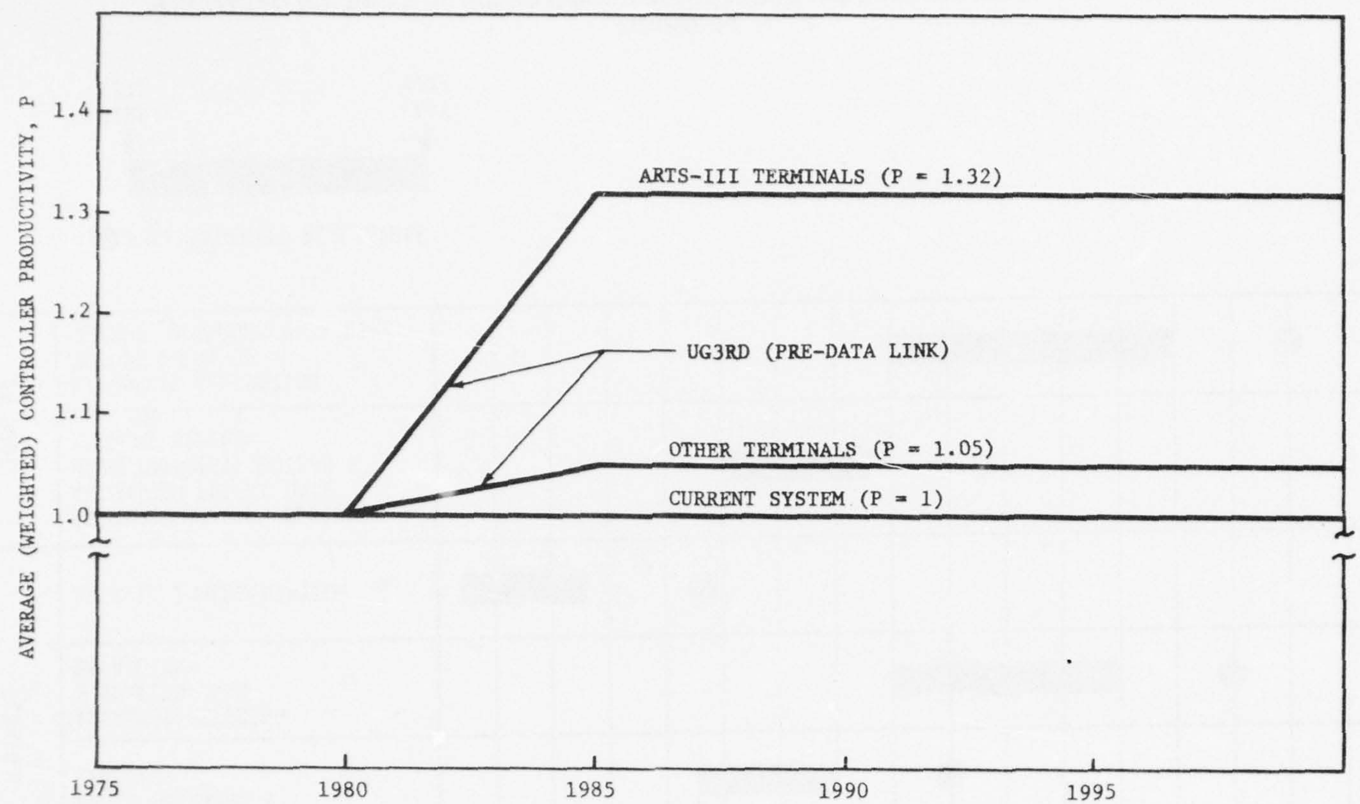

FIGURE 8-3
AVERAGE (WEIGHTED) CONTROLLER PRODUCTIVITY IN TERMINAL SYSTEM

The staffing of the improved system due only to the improvements of the pre-data link era, was calculated by dividing the baseline system staffing of Figure 8-1 by the productivity values of Figure 8-3. This was done both for the ARTS-III and for the "other" terminals, and the sum of the two is the total UG3RD terminal system staffing requirement. The results shown in Figure 8-4, indicate that the staffing increase in the 1980-1985 time frame in the ARTS-III system would be arrested and the system would even have a slight decrease in staffing. The other terminals would continue to require staffing increases at a slightly reduced rate. The total terminal system staff tends to plateau in that period but would then continue to increase (as expected) beyond 1985 due to increases in traffic, if no other productivity improvements are implemented (see Part II of this report). The impact of those improvements to be implemented in the pre-data link era is clearly shown in Figure 8-5. The potential savings in staffing requirements up to the year 2000 will be about 50,000 man-years corresponding to an O&M savings of 1.25 billion dollars in terms of constant 1975 dollars.

8.2 En Route System Staffing Costs

The unrestrained growth of staff in the en route system can be found by using the FAA staffing equation for the en route system, which is as follows:

$$S_E = 36.2N + 0.413 \times \text{IFR Handles}$$

According to this equation, the baseline staff grows by about 250 percent for about a 270 percent increase in en route traffic. This growth will be restrained by en route automation which is assumed (Figure 8-2) to begin by 1980 with the implementation of the Sector Position Re-design at its first NAS Stage A facility. The full productivity benefits are assumed to be in hand by 1985, two years after the implementation at the last NAS Stage A facility in 1983. As in Terminal Automation, assuming a linear implementation schedule between 1980 and 1985, the en route controller productivity would increase from 1.0 prior to 1980 to its full value by 1985. It was shown in Section 7 that the full productivity impact of UG3RD improvement programs to be implemented between 1975 and 1985 is expected to be 1.35. Using a linear increase in productivity (see Figure 8-6) and the unrestrained staffing (as computed by the staffing equation), the staffing requirements of the UG3RD en route system was computed and is shown in Figure 8-7. The potential savings in

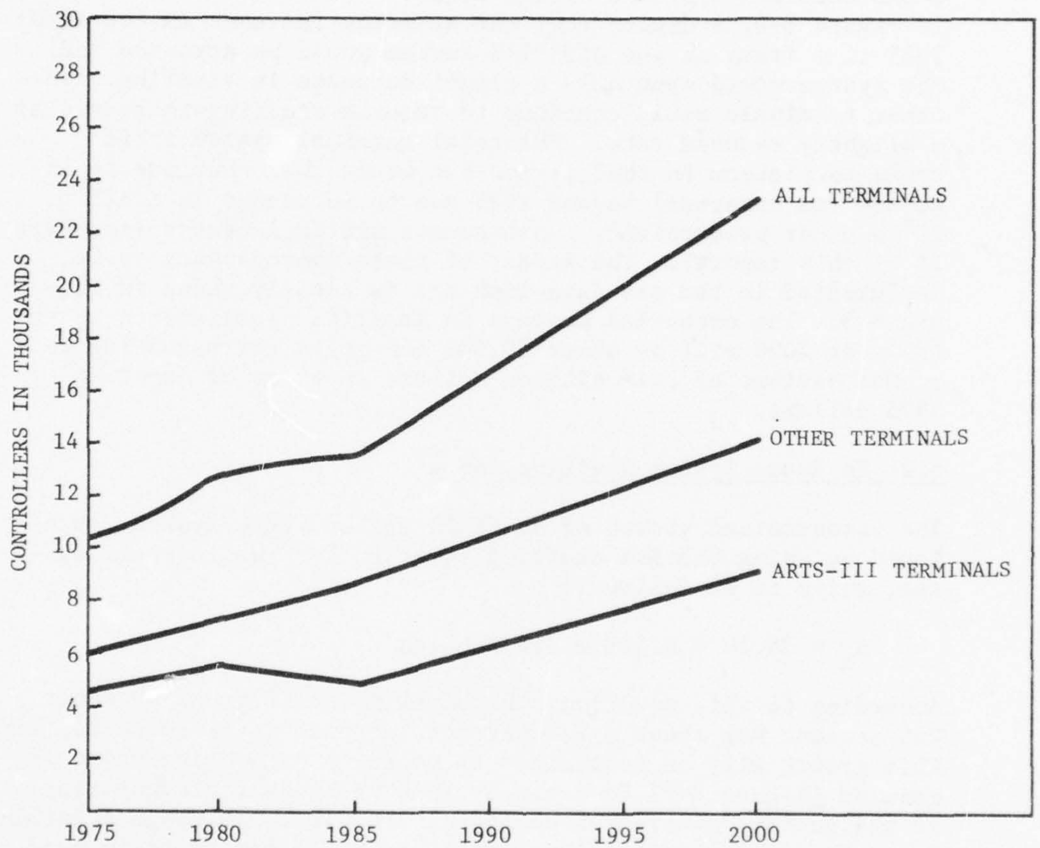

FIGURE 8-4
TERMINAL STAFF IN UG3RD SYSTEM (PRE-DATA LINK)

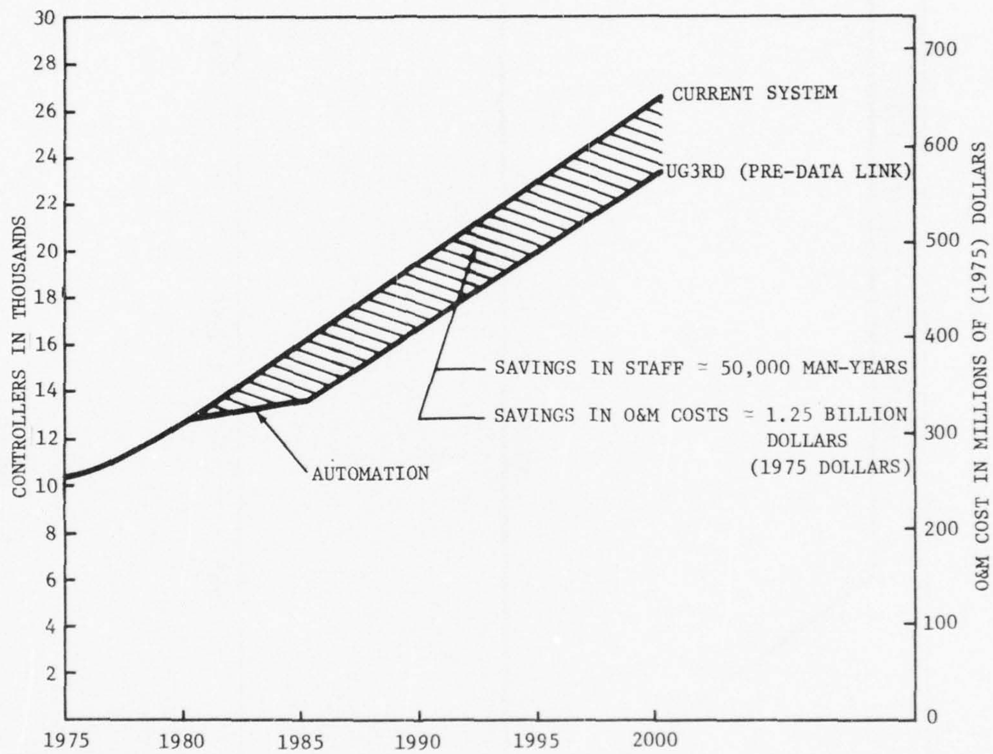

FIGURE 8-5
POTENTIAL SAVINGS IN TERMINAL SYSTEM O&M COSTS DUE TO UG3RD IMPROVEMENTS (PRE-DATA LINK)

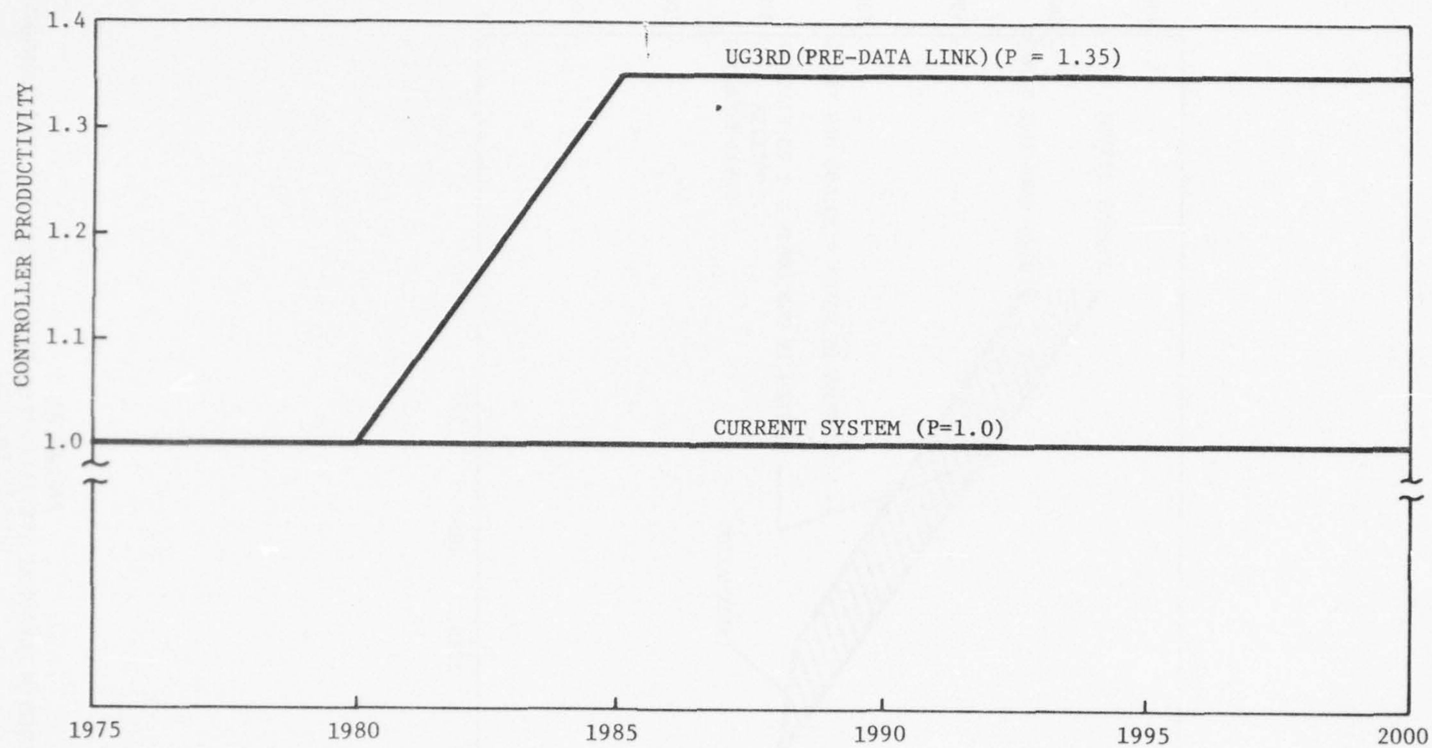

FIGURE 8-6
CONTROLLER PRODUCTIVITY IN EN ROUTE SYSTEM

staff over the next 25 years due to these improvements are 100,000 man-years, corresponding to a potential dollar savings of 2.5 billion dollars in terms of constant 1975 dollars.

8.3 Total (En Route and Terminal) System Staffing Cost

The total staffing costs in the en route and the terminal systems are shown in Figure 8-8. By the year 2000 the baseline system's staffing costs amount to 1350 million dollars annually (1975 dollars) if there is no increase in controller productivity. The UG3RD system improvements may make it possible to reduce that amount by about 270 million dollars or 20 percent. The total reduction in staff over the 20 year period (1980-2000) could be as much as 150,000 man-years at a cost of 3.75 billion dollars (constant 1975 dollars). This potential cost savings is only due to those improvements implemented in the pre-data link era. For costs and savings due to improvements in the data link era see Part II of this report.

It must be emphasized that the savings identified above, due to increased controller productivity resulting from implementation of certain features of the UG3RD E&D program, are savings which are believed to be potentially achievable. The degree to which those savings can, in fact, be realized will depend on many management considerations which go beyond what is technically feasible.

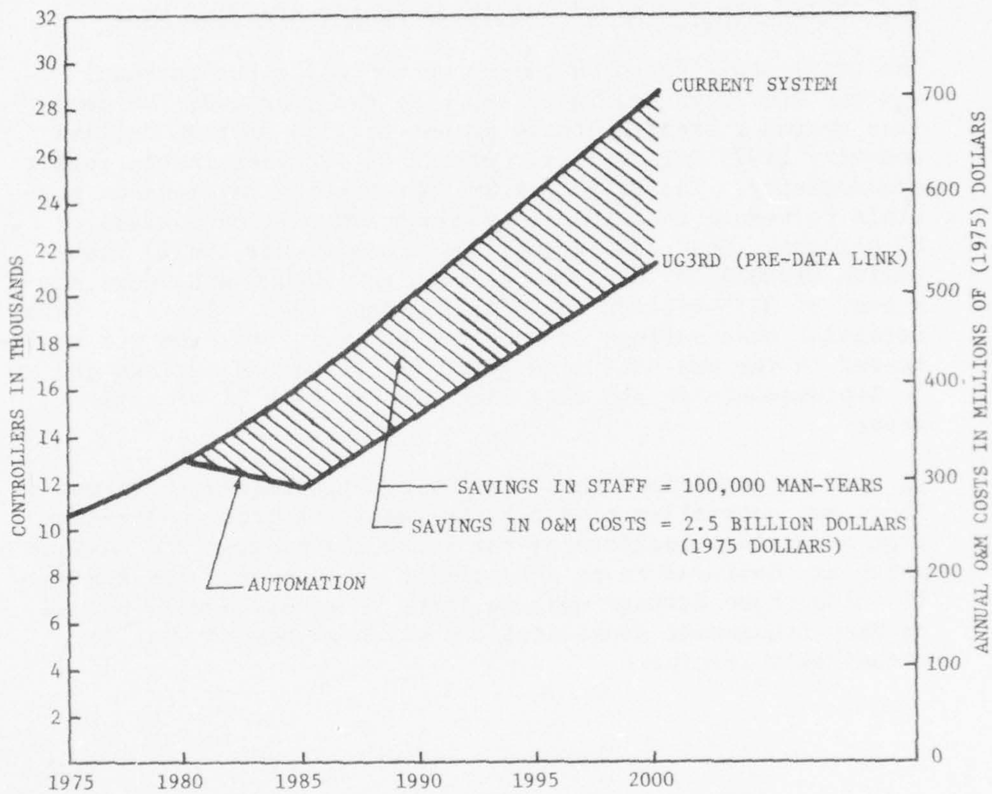

FIGURE 8-7

POTENTIAL SAVINGS IN EN ROUTE SYSTEM O&M COSTS DUE TO UG3RD IMPROVEMENTS (PRE-DATA LINK)

AD-A034 527 MITRE CORP MCLEAN VA F/G 1/2

CONTROLLER PRODUCTIVITY IN THE UPGRADED THIRD GENERATION AIR TR--ETC(U)

JUL 76 F S KEBLAWI DOT-FA70WA-2448

UNCLASSIFIED MTR-7212 FAA-EM-76-3 NL

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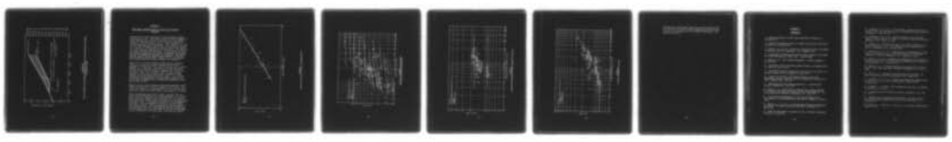

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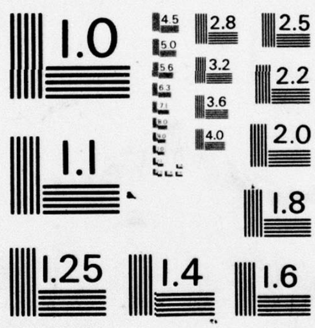

MICROCOPY RESOLUTION TEST CHART
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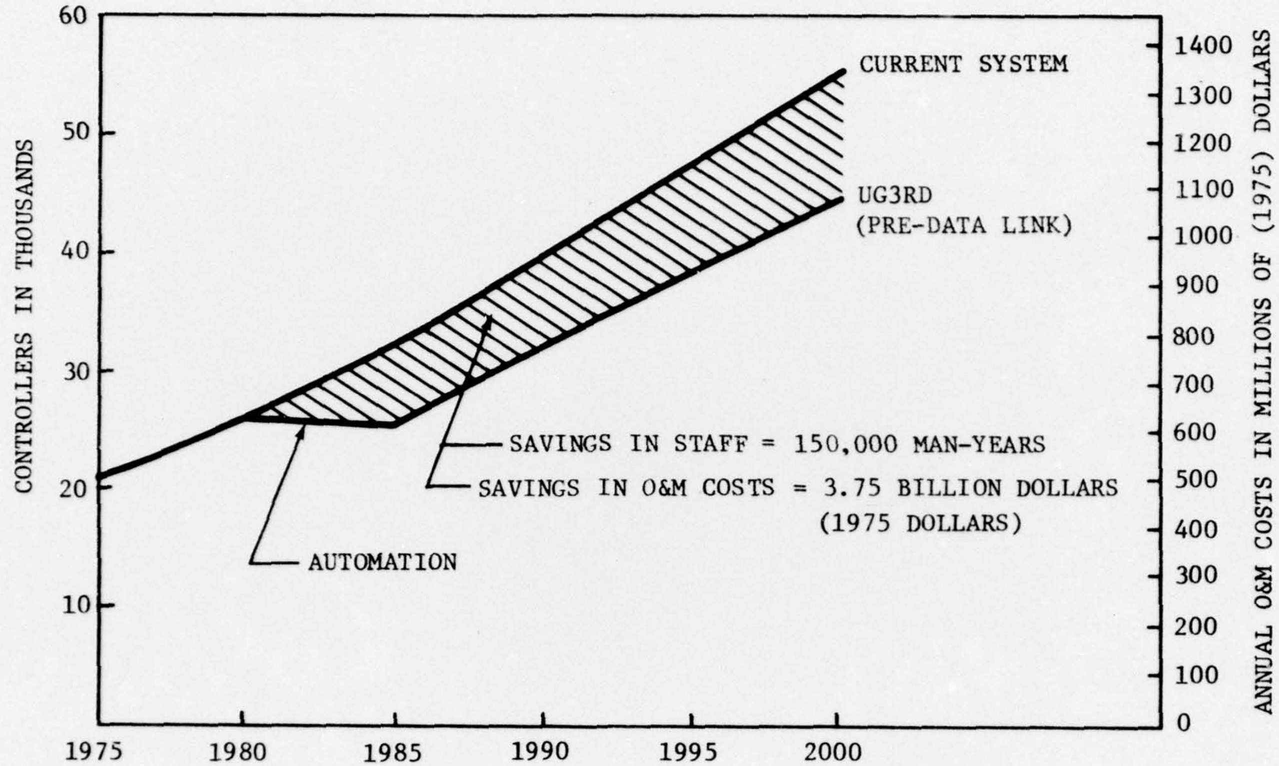

FIGURE 8-8
TOTAL POTENTIAL SAVINGS IN UG3RD EN ROUTE AND TERMINAL SYSTEMS
(PRE-DATA LINK)

APPENDIX A

RELATIONSHIP BETWEEN FACILITY STAFF AND AIR TRAFFIC ACTIVITY

Several factors cause variations in staffing among terminal facilities to occur. The primary factor is that the number of radar complexes per facility is not defined by the staffing standard. A secondary factor is due to the allowances of unused capacities of varying amounts. Other factors stem from the fact that additional justification for staffing is allowed for a variety of reasons based on the approval of the region. For these reasons, an examination of the statistics of staffing and traffic activity was undertaken. Data was obtained from AAT-130 which represents the results of applying the staffing standard (including the required justification). This data was analyzed for relationships between traffic and staffing. These relationships are shown in Figures A-1 through A-4.

Figure A-1 is a scatter diagram of staff versus instrument operations in type 9 facilities (TRACONS with No CAB). Examples of facilities of this type are the New York IFR Room, RAPCONS, etc. Generally, there are no aircraft operations associated with these facilities although, there are two exceptions to this rule in Alaska. Figure A-2 is a similar diagram for three types of facilities: TRACONS with CAB, TRACABS, and Limited Approach Control Towers. All of these facilities are influenced by both instrument operations (IO) and aircraft operations (AO), although the predominant influence is that of IO's.

Figure A-3 is a scatter diagram for Non-Radar Approach Control Towers and Figure A-4 is such a diagram for VFR towers. The latter do not seem to be influenced by the level of instrument operations, while the former exhibit some sensitivity to them.

These relationships were used in order to estimate the projected (future) staffing in the following manner. For a given year, the traffic forecast of IO's and AO's was first distributed among the terminal types of facilities in the proportions existing in 1974. An adjustment was made for the upgrading of facilities. Then the average AO and IO per facility within each type was found. These two parameters, and the figures of this appendix were used to determine the average staffing per facility within each type; and, therefore, the staff requirement for all facilities of a certain type. This was then used to

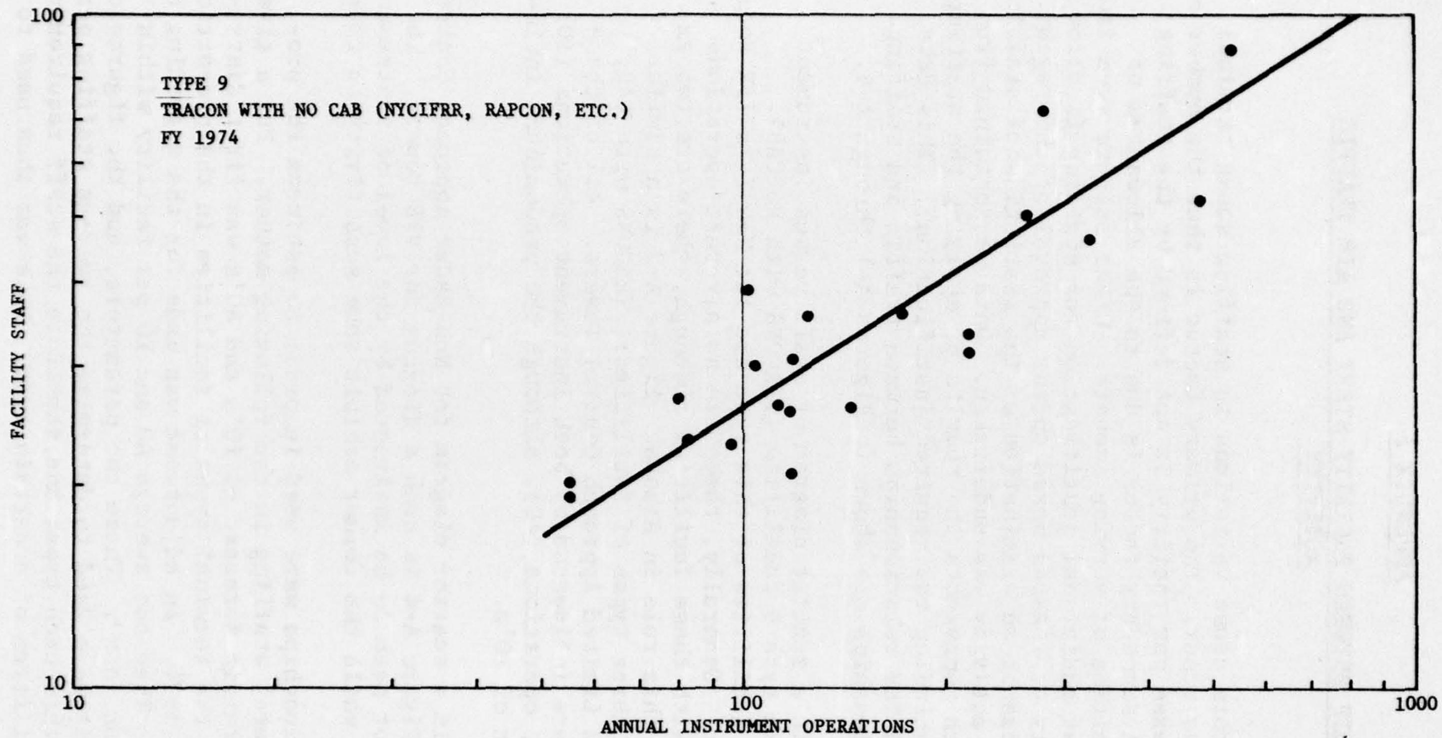

FIGURE 4-2
TRAFFIC ACTIVITY AND STAFFING OF TRACONS WITH NO CAB

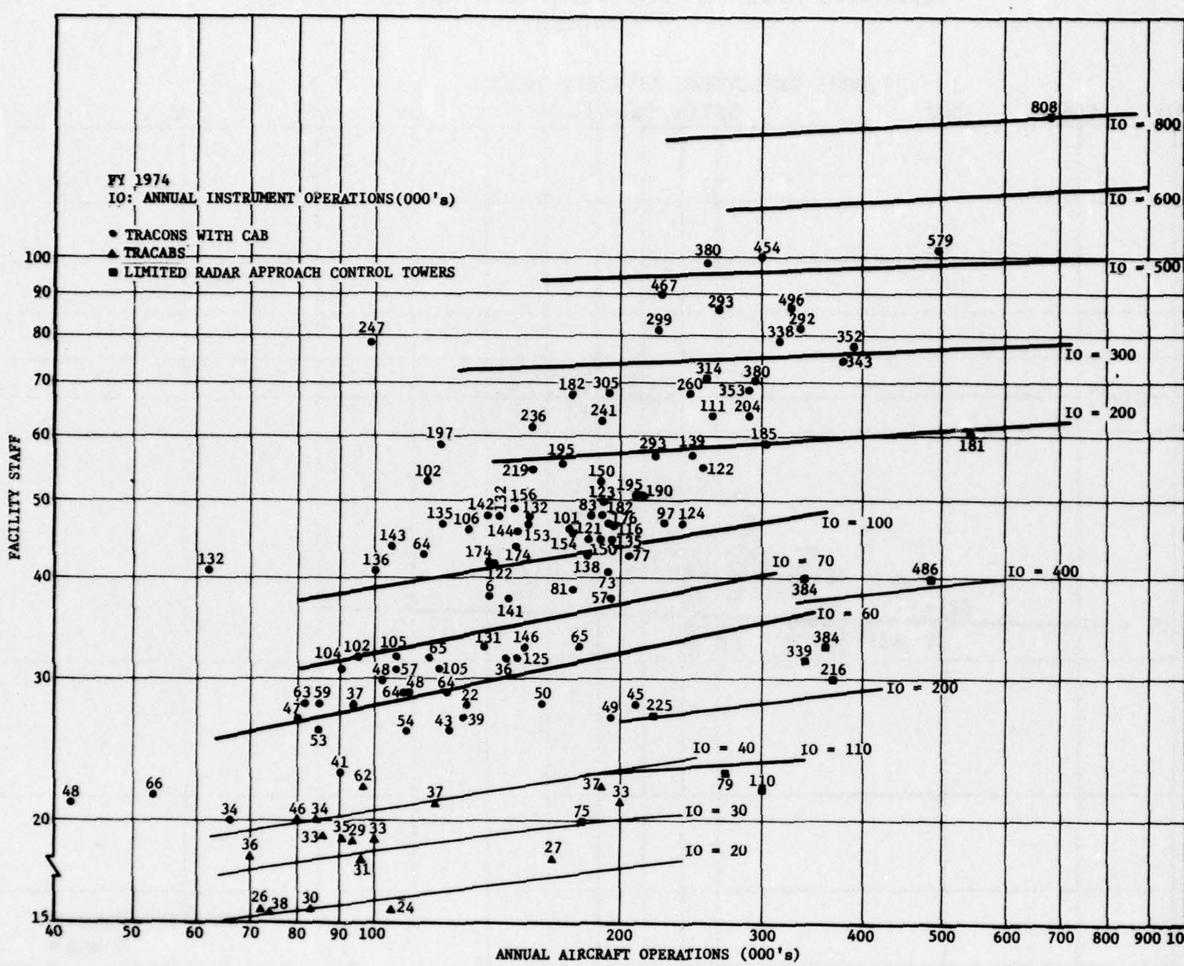

FIGURE A-2
TRAFFIC ACTIVITY AND STAFFING OF TRACONS, TRACABS AND LIMITED RADAR APPROACH CONTROL TOWERS

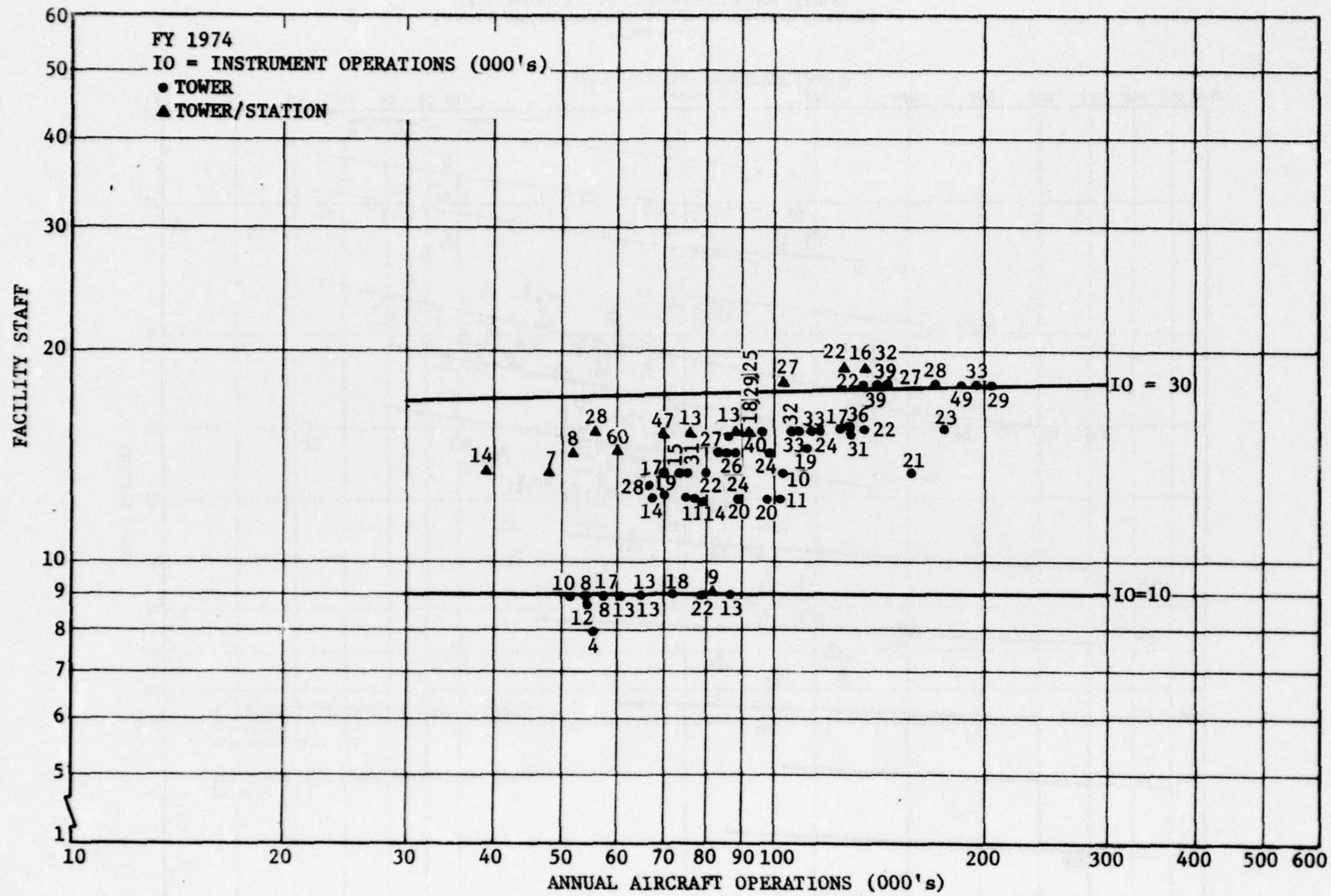

FIGURE A-3
STAFFING OF NON-RADAR APPROACH CONTROL FACILITIES

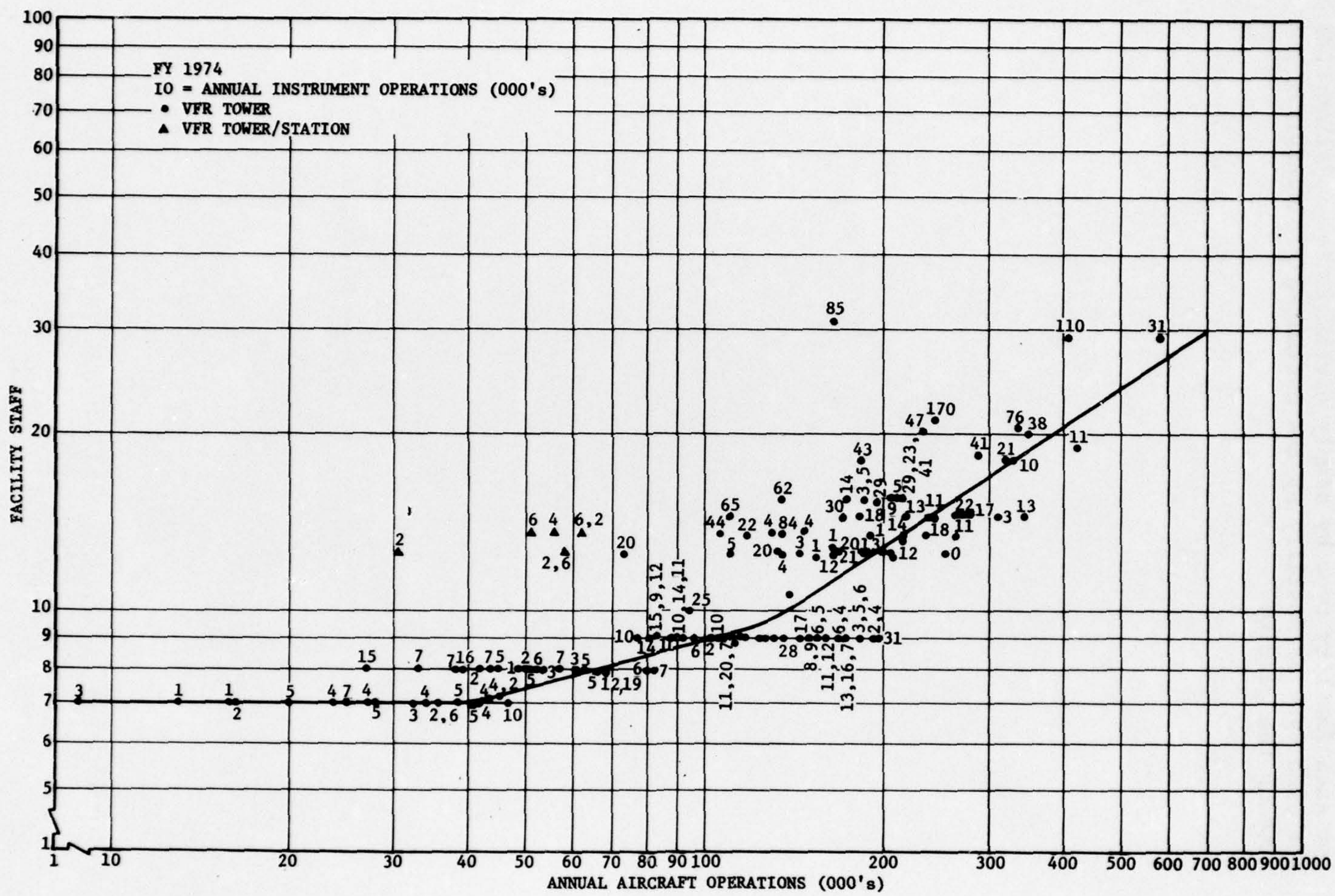

FIGURE A-4
STAFFING OF NON-APPROACH FACILITIES

determine the total terminal staff for any given productivity for each facility type by simply dividing the projected staff for each type of facility by the estimated productivity, and summing the results.

APPENDIX B

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