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AUTOMATION APPLICATIONS IN AN ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

Volume IVA: Automation Requirements

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AUGUST 1974

FINAL REPORT

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16. Abstract

The Advanced Air Traffic Management System (AATMS) program is a long-range investigation of new concepts and techniques for controlling air traffic and providing services to the growing number of commercial, military, and general aviation users of the national airspace. This study of the applications of automation was undertaken as part of the AATMS program. The purposes were to specify and describe the desirable extent of automation in AATMS, to estimate the requirements for man and machine resources associated with such a degree of automation, and to examine the prospective employment of humans and automata as air traffic management is converted from a labor-intensive to a machine-intensive activity.

Volume IV describes the automation requirements. A presentation of automation requirements is made for an advanced air traffic management system in terms of controller work force, computer resources, controller productivity, system manning, failure effects, and control/display requirements. It also includes a discussion of the application of the study results to the design and development of AATMS.

Volume IVA includes Sections 1.0 through 4.3; Volume IVB includes Sections 5.0 through Appendix C and References.

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1.0 PREFACE

1.1 ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM STUDY

This report is one of a series produced by the TRW-Planar group in a study of automation applications for an Advanced Air Traffic Management System (AATMS), work performed for the Department of Transportation, Transportation Systems Center (DOT/TSC) under contract number DOT-TSC-512. The reports in this series are:

- Automation Applications in an Advanced Air Traffic Management System - Volume I, Summary. TRW Report No. 22265-W008-RU-00, December 1973.

  This is a summary document, stating the background and objectives of the study and describing the major study results. It also contains a discussion of the implications of the results for an advanced air traffic management system and a suggested strategy for implementation of automation.

- Automation Applications in an Advanced Air Traffic Management System - Volume II, Function Analysis of Air Traffic Management. TRW Report No. 22265-W006-RU-00, December 1973.

  This volume provides an analysis and description of air traffic management activities at three levels of detail - functions, subfunctions, and tasks. A total of 265 tasks are identified and described, and the flow of information inputs and outputs among the tasks is specified.

- Automation Applications in an Advanced Air Traffic Management System - Volume III, Methodology for Man-Machine Task Allocation. TRW Report No. 22265-W007-RU-00, December 1973.

  This volume contains a description of man and machine performance capabilities and an explanation of the methodology employed to allocate tasks to human or automated resources. It also presents recommended allocations of tasks at five incremental levels of automation.

- Automation Applications in an Advanced Air Traffic Management System - Volume IV, Automation Requirements. TRW Report No. 22265-W009-RU-00, December 1973.

  This volume is a presentation of automation requirements for an advanced air traffic management system in terms of controller work force, computer resources, controller productivity, system manning, failure effects, and control/display requirements. It also includes a discussion of the application of the study results to the design and development of AATMS.

- Automation Applications in an Advanced Air Traffic Management System - Volume V, DELTA Simulation Model. TRW Report No. 22265-W010-RU-00, December 1973.

  This volume includes all documentation of the DELTA (Determine Effective Levels of Task Automation) computer simulation developed by TRW for use in the Automation Applications Study. The volume includes a user manual, programmers manual, test case, and test case results.

The results which have been documented in these volumes represent a team effort. However, it is most appropriate to recognize the contributions of the following individuals who were responsible for major elements of the study:

Mr. R. Jones	TRW	Volume II, Functional Analysis
Mr. L. Jenney	The Planar Corp.	Volume III, Man-Machine Allocation Methodology and Volume IV, Failure Modes and Displays
Mr. E. C. Barkley	TRW	Volume V, DELTA Simulation
Mr. K. Willis	Metis Corp.	Volume V, Algorithm Development

1.2 PHASE C STUDY EFFORT

Phase C of the automation applications study was devoted to delineation of system requirements arising from a chosen level of system automation. This was not a system design exercise in the classical sense. Rather, the study was directed at specification of only those system characteristics and requirements which were direct consequences of automation itself. Thus here, as in the earlier phases of the study, the objective was to detail a generic system concept which would be independent of equipment considerations and means of mechanization. This point about the generic nature of the system description has been made several times in preceding volumes of this report. At the risk of overemphasis, it must again be stated that the study was conducted in such a way that the eventual choice of system hardware would have the smallest influence on the applicability of study results.

The basic question posed in Phase C can be stated as follows. Given a functional description of the system and a scheme of man-machine allocation, what are the implications of a selected level of automation in terms of resource requirements and operational characteristics? The answer to this question has several elements:

a. Manpower requirements

b. Data processing requirements

c. Productivity estimates

d. Failure modes requirements

e. Control and display requirements

These elements can be added up to produce an evaluation of the system according to three basic criteria -- safety, effectiveness and cost.

Manpower and data processing requirements, of course, are direct contributors to the cost of the system. Productivity is a measure of system effectiveness, in that it is an expression of the amount of demand (number of airspace users) that can be handled by given resource units. Failure effects analysis is a way of getting at the level of safety which the system can achieve and maintain in the face of equipment adversities. Analysis of failures can also provide a secondary measure of system effectiveness in that it identifies circumstances where capacity or efficiency will be unfavorably influenced by loss of resources. Control and display requirements help to define the operational character of the system by indicating ways in which information must flow across the man-machine interface to attain safe and effective operations.

Thus, Phase C of the study was a series of exercises in derivation and evaluation, the purpose of which was to develop guidelines for the design of an advanced air traffic management system embodying a high level of automation. The basis for this work was the system functional description and man-machine allocations developed in Phases A and B. Collectively, the products of study Phases A and B constituted definition of a theoretical system. To move the definition one step closer to the realm of practicality, it was necessary to add certain assumptions as to how the system might be configured and deployed and as to the traffic demand which might be placed upon it. This was not an excursion into system design. The assumptions were only of the most general nature, and they were limited to those features of the system which had to be made specific in order to state design requirements realistically.

Figures 1.2-1 through 1.2-5 on the following pages illustrate the approach employed in developing major end products in Phase C of the study. Each figure is a diagram of the work steps by which the results of previous study phases were combined with assumptions about system configuration and deployment in order to produce a set of design requirements. In the diagrams, rectangles denote Phase A and B products which served as inputs to Phase C. The circles stand for items which were assumed as givens, based on information supplied by DOT/TSC. Arrows indicate the combination and sequence of elements making up the final products, which are represented by triangles. The items not enclosed in any of the above symbols are intermediate products, which are shown to clarify the steps by which each set of requirements was derived.

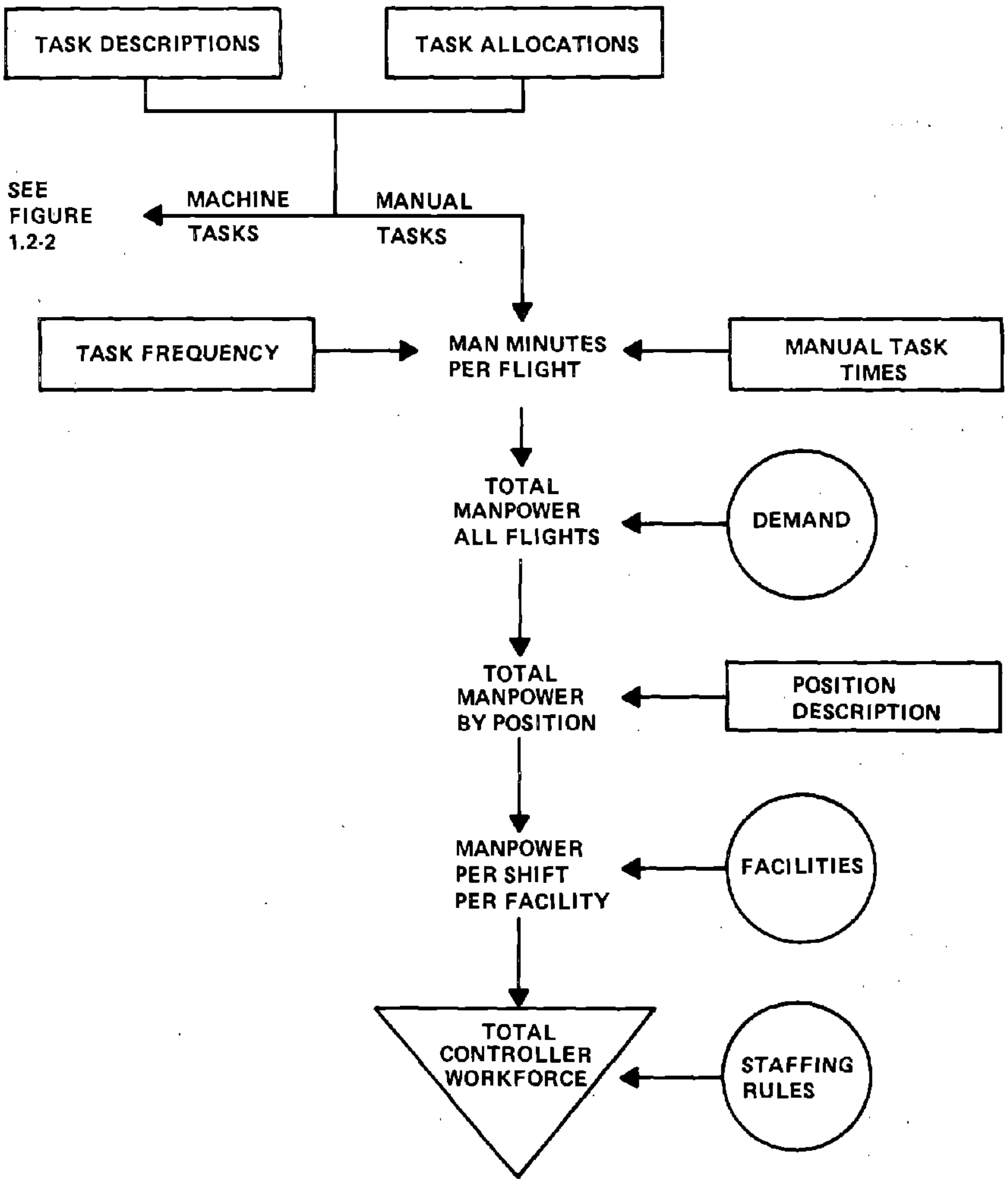

FIGURE 1.2-1 DERIVATION OF SYSTEM MANNING REQUIREMENTS

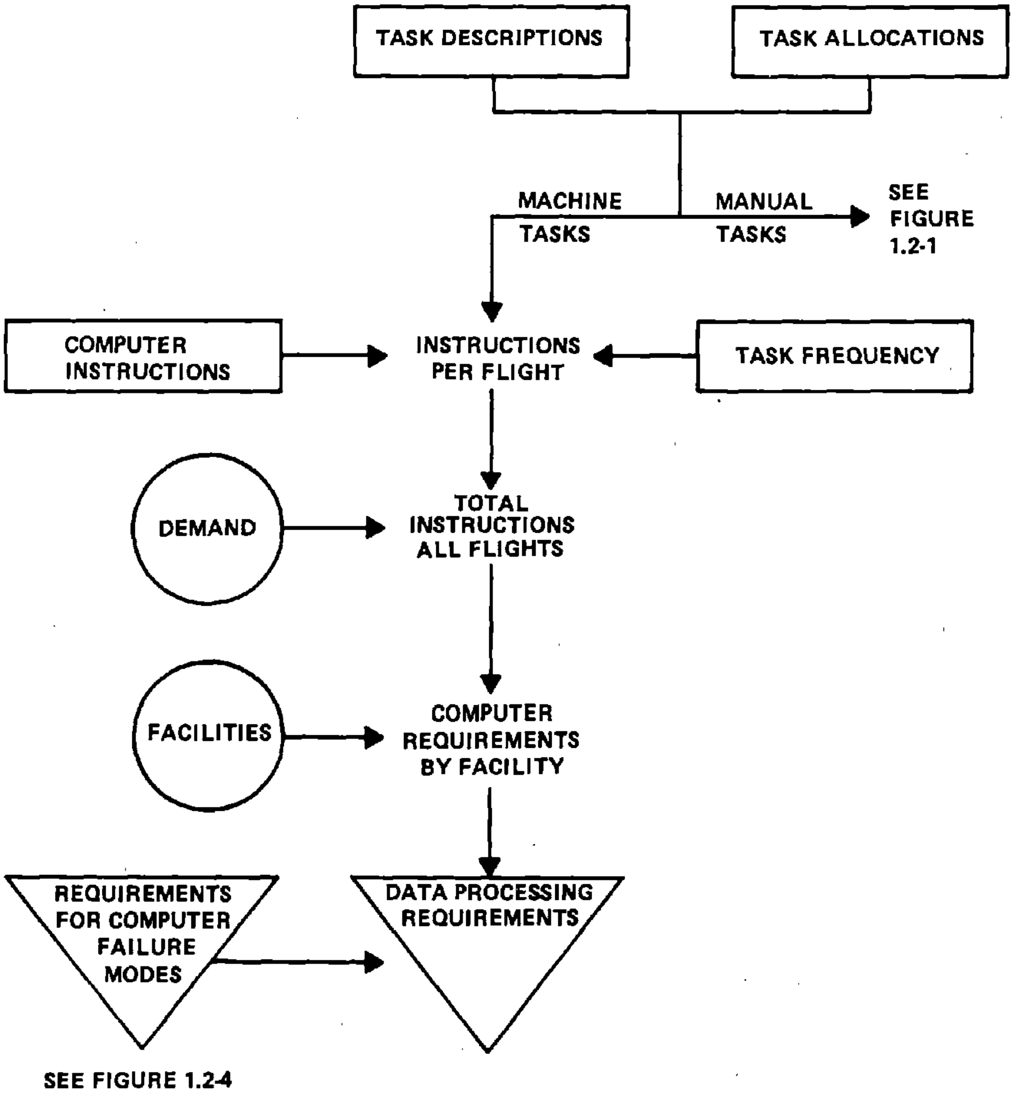

FIGURE 1.2-2 DERIVATION OF DATA PROCESSING REQUIREMENTS

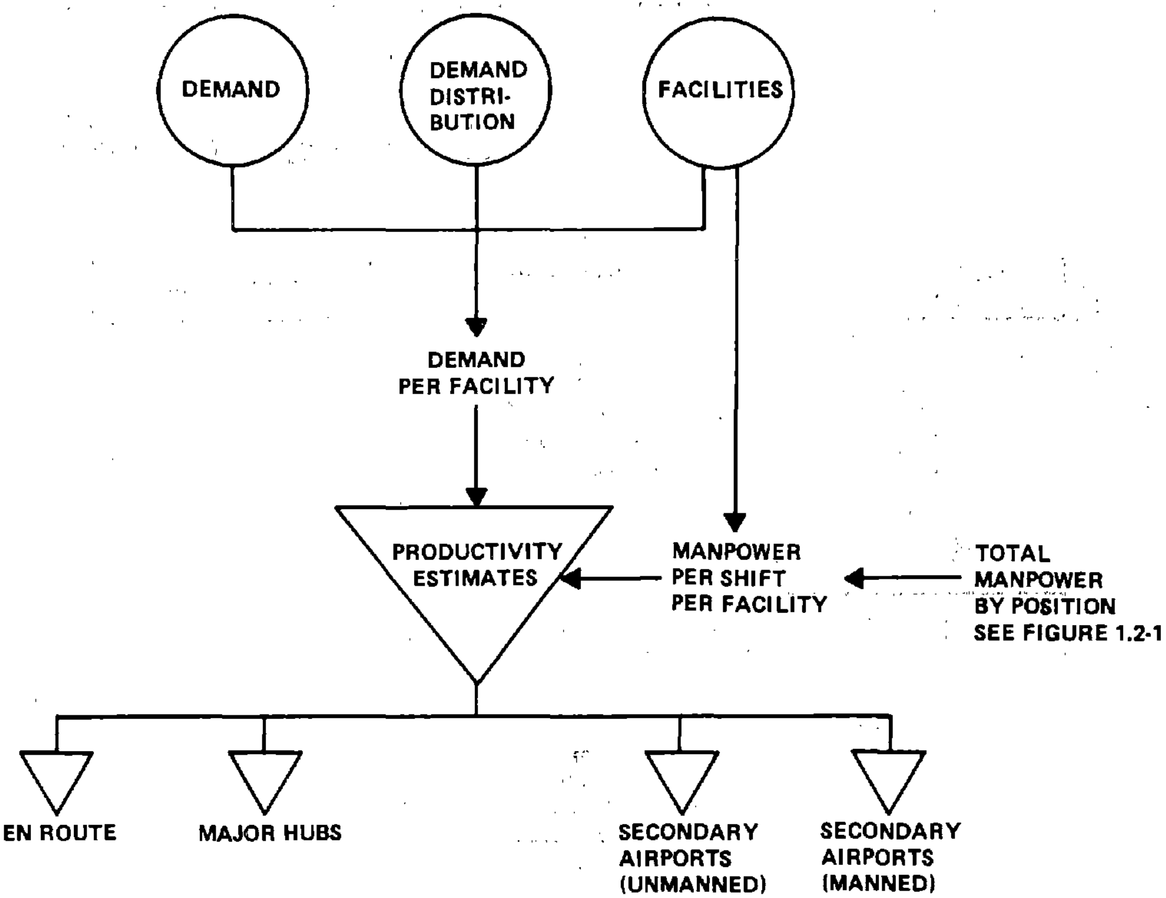

FIGURE 1.2-3 DERIVATION OF PRODUCTIVITY ESTIMATES

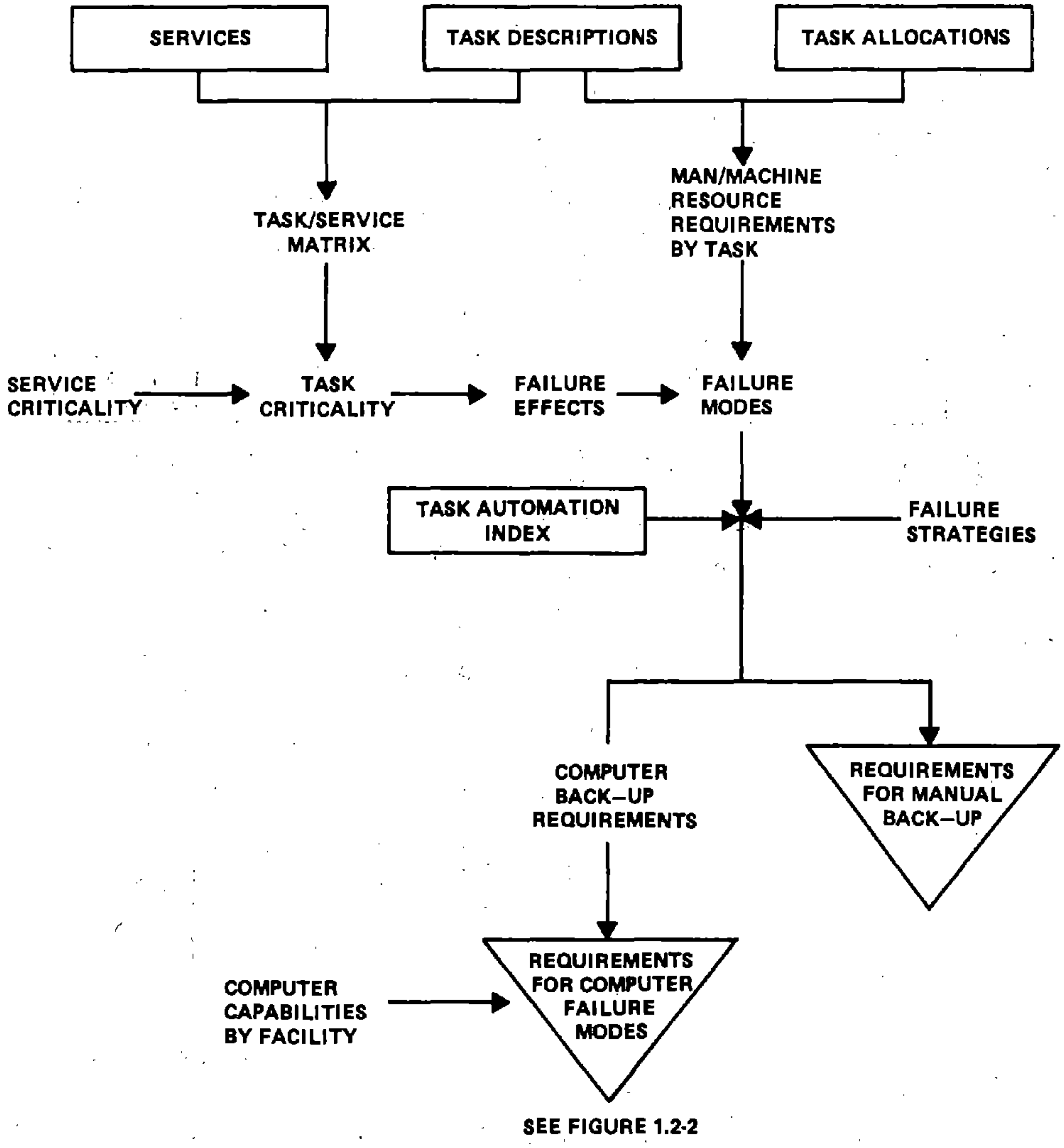

FIGURE 1.2-4 DERIVATION OF FAILURE MODE REQUIREMENTS

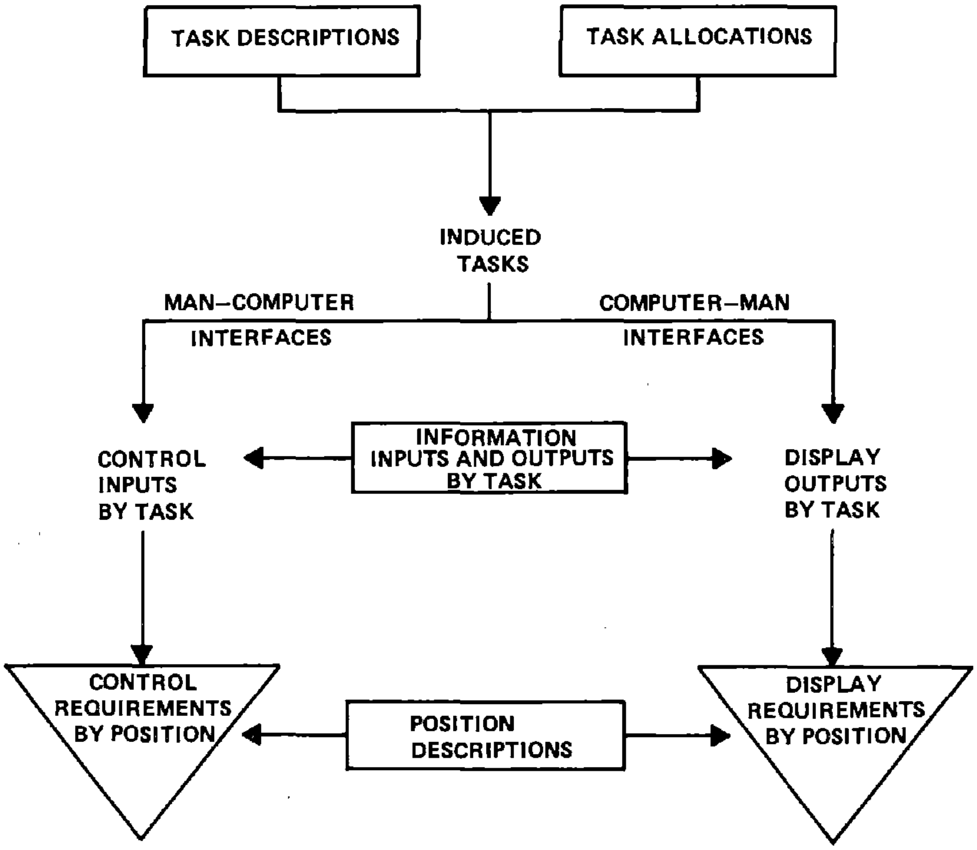

FIGURE 1.2-5 DERIVATION OF CONTROL AND DISPLAY REQUIREMENTS

1.3 PHASE C PRODUCTS

Collectively, the products of Phase C constitute a statement of requirements for design of an advanced and highly automated air traffic management system. They represent a generic automated system concept in which safety and effectiveness (e.g., capacity with a given delay and demand) are balanced against cost, expressed in terms of man and machine resources. These three system parameters (safety, effectiveness, and cost) can be traded off in a variety of ways. In this case, the system concept is an equation in which safety and effectiveness were held virtually constant while cost was allowed to vary. That is, the concept is predicated on the ability of the system to handle a given peak demand and to maintain a nearly steady level of safety in both normal and degraded operating states. The man and machine resources necessary to achieve these ends become the cost variable of the system.

Thus, the system requirements set forth in this volume are a general and partial blueprint for design -- general in the sense that the requirements apply to any of several projected hardware concepts, partial in the sense that the requirements apply only to those aspects of the system which are impacted by the selected level of automation. It is intended that future system designers take these requirements not as a prescription for hardware but as a statement of what the hardware must do, whatever its particular physical characteristics. The reader approaching this report looking for a specification of equipment and system architecture will be disappointed. This level of specificity is not here, nor was it intended to be. On the other hand, those looking for a general answer to how automation can be applied in a future air traffic management system may find this report a helpful guidepost.

The products of the final phase of this study are set out under five major headings:

- Chapter 2 - General System Characteristics, which includes descriptions of services, functional components, operational concepts, facilities, manning structure, and capacity to handle traffic demand.
- Chapter 3 - Controller Manpower and Data Processing Requirements, which consist of the number of controller personnel by type and the computer capacity (computational volume) required to operate the system in a normal mode for a given demand level.

- Chapter 4 - Controller Productivity, which contains estimates of the number of aircraft that can be handled by a controller at one time, differentiated by type of facility and phase of flight.
- Chapter 5 - Failure Mode Requirements, which include identification and description of the impact of equipment failure in terms of loss of service and recommended strategies for reallocation of human and automated resources in response to equipment failures.
- Chapter 6 - Control and Display Requirements, consisting of identification and description of information outputs from machine to man (display requirements) and instruction inputs from man to machine (control requirements).

The report concludes with two chapters whose purpose is to relate the study results to the area of research and development. Chapter 7 is a discussion of the implications of the study for matters such as allocation of air-ground responsibility, computer architecture, personnel training and selection, and cost analysis. Appendix B is a RDT&E plan, which prescribes the critical RDT&E activities needed to carry the air traffic management system design forward from the concept stage to an operational state.

2.0 GENERAL SYSTEM CHARACTERISTICS

The first two phases of the study resulted in definition and description of an advanced air traffic management system in terms of generic functions and tasks. While this definition was sufficient for the purposes of man-machine allocation and identification of incremental automation levels, it was too general to permit a meaningful extrapolation of system resource requirements. Therefore, as a first step in Phase C, it was necessary to extend the definition of the system to include additional detail relating to operational concept, facilities, and resource deployment.

This chapter is a description of the characteristics which emerged from this refinement of the system definition. In some cases, the characteristics were derived by a process of inference and extrapolation from the Phase B function analysis and task descriptions. In other cases, it was necessary to make certain assumptions based on the system concept characteristics supplied by DOT/TSC. In both cases, however, care was taken not to push the process of definition too far. System characteristics were stipulated only insofar as necessary to support the Phase C work of specifying requirements and laying down guidelines for system design. This conservative approach was consistent with the basic purpose of the study which was not to design a system but to delineate design goals and man-machine requirements arising from a high level of automation.

The general characteristics of such an advanced air traffic management system that are of primary concern to automation are set forth under six major headings in the sections which follow:

- Air Traffic Services
- Air Traffic Management Functions
- Operational Concepts
- Facilities
- Operator Positions, Tasks and Duties
- Capacity and Demand

2.1 AIR TRAFFIC SERVICES

An air traffic system exists to provide services to airspace users. The entire complex of men and machines which make up the system, regardless of how it performs its work, can therefore be judged in terms of the services it renders. Thus, the ultimate measure of the system is its product, not its processes.

Early in the study a list of basic ATC services was defined.* They have been described earlier in this report (Volume I, Chapter 4, and Volume II, Chapter 2) and will not be further elaborated here. A total of ten basic services were identified as outputs of the air traffic system. They are given below with a condensed paraphase of the definitions given in earlier volumes.

- Airport/Airspace Use Planning - strategic or long-range control service concerned with efficient airport and airspace use.
- Flight Plan Conformance - strategic or long-range service concerned with implementation of airport/airspace use plans.
- Separation Assurance - short-term, safety-related service concerned with conflict and collision prevention.
- Spacing Control - short-term service related to efficiency and involving scheduling, sequencing, and spacing of aircraft in the terminal area.
- Airborne, Landing, and Ground Navigation - service concerned with providing aircraft with the capability to locate their position.
- Flight Advisory Services - information services provided during all flight phases to assist the pilot in the conduct of flight.
- Information Services - services similar to the preceding except that they are provided during the preflight planning phase.

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*The definition of services used in this study stemmed from a cooperative effort by the TRW/Planar contractor team and representatives from the MITRE Corporation, the FAA Office of Systems Engineering Management, and the DOT Transportation Systems Center.

- Record Services - services concerned with maintaining the required historical record of operations and events.
- Ancillary Services - services related to assisting and facilitating special, non-routine use of the airspace and system facilities.
- Emergency Services - services provided in response to aircraft and airborne equipment failures.

From the definitions offered briefly here and more extensively in earlier volumes, it can be seen that the ten basic services can be differentiated along at least three dimensions. First, it is possible to distinguish among the services in terms of their relationship to safety. For example, separation assurance is clearly more important to safety of airspace use than record services. Similarly, it is possible to differentiate services with respect to their influence on capacity and efficiency. For instance, airport/airspace use planning services have more to do with promoting capacity and efficiency than do flight advisory services. A third dimension of services is their short-range or long-range nature. Some services have a strategic purpose; others are tactical.

These three dimensions are not wholly independent. Services performed primarily for reasons of safety have an impact on system capacity and efficiency of airspace use. Similarly, services which promote efficiency or which affect capacity will, in the long run, influence the safety of flight operations. (Accidents cause traffic jams, and traffic jams cause accidents.) In the same way, it is impossible to extricate strategy and tactics cleanly from safety and capacity/efficiency. Generally, the more long-range the service, the more it has to do with capacity and efficiency. The short-range services tend to be more closely related to safety. But again, the relationship is not monotonic. Consider the example of spacing control, which is a tactical service, yet it is performed primarily to promote efficiency of runway use.

Despite these interrelationships, it is possible to order services with respect to these three dimensions separately -- providing one is willing to forego precise discriminations. Table 2.1-1 shows such a ranking, where the first positions indicate services having a strong relationship with safety, capacity/efficiency, or strategic importance. As one progresses down the list, the relationship grows generally weaker.

TABLE 2.1-1 SERVICES IN RELATION TO SAFETY, CAPACITY/EFFICIENCY, AND STRATEGIC IMPORTANCE

SAFETY	CAPACITY/EFFICIENCY	STRATEGIC IMPORTANCE
Separation Assurance	Airspace Use Planning	Airspace Use Planning
Emergency	Spacing Control	Information
Navigation	Flight Plan Conformance	Flight Plan Conformance
Spacing Control	Navigation	Navigation
Flight Plan Conformance	Information	Flight Advisories
Flight Advisories	Flight Advisories	Spacing Control
Information	Separation Assurance	Separation Assurance
Airspace Use Planning	Ancillary	Ancillary
Ancillary	Emergency	Emergency
Records	Records	Records

Accepting these rankings with the understanding that there is some uncertainty about the exact serial position of services along each dimension, it is possible to develop a composite ranking. First, however, it is necessary to make some assumptions about how the three separate dimensions are to be used.

Because of the overriding importance of safety in air traffic control, the ranking of services in relation to safety should be given primacy. However, as one progresses down the list of safety-related services, their relevance to safety begins to grow rather weak after the first five (Separation Assurance, Emergency, Navigation, Spacing Control, and Flight Plan Conformance). The ranking according to capacity/efficiency can be brought to bear here to help establish a position for the remaining services. Thus, the position of the other five services is determined by the degree to which they promote efficiency or influence system capacity -- resulting in the order Airport/Airspace Use Planning, Information Services, Flight Advisories, Ancillary, and Records.

The dimension of strategic importance can be used to test the rankings and make the order more precise. Safety is essentially a tactical matter; and so the safety-related services should show an inverse relationship to their position on the dimension of strategic importance. Examining the uppermost services on the safety-related list in Table 2.1-1, it can be seen that they appear in an order which is the reverse of their order on the list of strategic importance. The only exception is Emergency Service which comes after Separation Assurance on the safety list, when it should come ahead of Separation Assurance according to its position in the strategic-tactical domain. Aside from this minor anomaly, the predicted relationship of safety and strategic importance holds true, viz. the services more closely related to safety also tend to be the more tactical.

Capacity and efficiency are largely matters of effective planning of airspace use. Since planning is more of a strategic than a tactical exercise, it would be expected that the order of services with respect to capacity/efficiency should correspond to the ranking according to strategic importance. Comparison of these two listings in Table 2.1-1 shows that such is the case. The higher a service stands with respect to capacity/efficiency, the higher it also stands in strategic importance.

Combining the rankings along the three dimensions, according to the general rules outlined above, produces an ordering of air traffic services in terms of what may be called "criticality". This listing is given in Table 2.1-2. Criticality should be interpreted as a term denoting the overall importance of the service within the framework of system operations. The primary value of the concept of service criticality is in its application to assessment of failure effects, presented in Chapter 5 of this volume. For now, however, criticality may be taken as a way of relating system services to the criteria of safety and capacity/efficiency, which have been established as the basic measures of the air traffic system.

TABLE 2.1-2 AIR TRAFFIC SERVICE CRITICALITY

SAFETY-RELATED SERVICES - HIGH CRITICALITY ● Separation Assurance ● Spacing Control ● Airborne, Landing, and Ground Navigation ● Emergency
CAPACITY/EFFICIENCY-RELATED SERVICES - MEDIUM CRITICALITY ● Flight Plan Conformance ● Airport/Airspace Use Planning ● Flight Advisory ● Information
SUPPORTING SERVICES - LOW CRITICALITY ● Ancillary ● Record

Note in Table 2.1-2 that the ten air traffic services have been grouped under three major categories: Safety-related Services, Capacity/Efficiency-related Services, and Supporting Services. Because of the uncertainties inherent in the ranking process, undue importance should not be attached to the position of services within each category. However, the relationship between categories is significant.

The first two categories are self-explanatory and derive directly from the method of analysis described above. The category of Supporting Services was created to set ancillary services and record services in proper perspective. It will be observed that both services fall at the bottom of the rankings according to safety and capacity/efficiency shown earlier in Table 1.2-1. This suggests that they have a very weak relationship to either aspect of system operation and that they are the least critical of ATC services. Still, it is important that these services be performed -- ancillary services in the interest of allowing freedom of airspace use, and record services for the purpose of accountability. Setting these services aside in a special category seemed justified on two grounds. First, they are clearly less important to fundamental ATC operations than the other services. Second, because they have the least influence on either safety or capacity/efficiency, they could be dispensed with if the system were forced to restrict its operations due to failure of some of its resources. This latter point will have particular importance in the subsequent analysis of failure effects presented in Chapter 5.

2.2 AIR TRAFFIC MANAGEMENT FUNCTIONS

The outputs, or products, of an air traffic system are services to airspace users. Functions are the processes by which these services are rendered. Functions embrace all the activities by men and machines in receiving and processing data, in making decisions, and in implementing actions necessary to provide the ten user services enumerated in the previous section.

Air traffic system functions were extensively analyzed in Phases A and B of this study, which resulted in a definition and description of system activities to the task level of detail. Volume II of this report contains the results of the function and task analysis, including detailed diagrams which articulate the flow of information inputs and outputs within the functional network.

A total of seventeen generic functions were isolated and defined. By title and identifying number, they were:

1. Provide Flight Planning Information
2. Control Traffic Flow
3. Prepare Flight Plan
4. Process Flight Plan
5. Issue Clearances and Clearance Changes
6. Monitor Aircraft Progress
7. Maintain Conformance with Flight Plan
8. Assure Separation of Aircraft
9. Control Spacing of Aircraft
10. Provide Airborne, Landing and Ground Navigation Capability
11. Provide Aircraft Guidance
12. Issue Flight Advisory and Instructions
13. Handoff

14. Maintain System Records
15. Provide Ancillary and Special Services
16. Provide Emergency Services
17. Maintain System Capability and Status Information

Functions may be related to services by matching the outputs of functions to the services which they facilitate or implement. Generally, a function can be related to a service in any of the following ways:

- A function produces information outputs needed to provide the service.
- A function produces decisions directly associated with the service.
- A function produces actions by which the service is directly implemented.

The relationship of functions to services is illustrated in Table 2.2-1, which shows a crossplot of the seventeen generic functions with the ten basic services. The nature of the relationship is shown in each cell by the entries I, D, and A, which stand for Information, Decision, and Action as defined above.

In the preceding section, services were categorized by their relationship to the safety and capacity/efficiency of the system, and an overall hierarchy of service criticality was developed. Since services can be related to functions, the concept of criticality can be transferred to functions through the function-service matrix shown in Table 2.2-1. Thus, it is possible to describe functions by the way in which they contribute to the three classes of services: safety-related services, capacity/efficiency-related services, and supporting services. Further, the hierarchical relationship among classes of services can be extended to functions to provide an indication of functional importance, i.e., the degree to which a function promotes the ends of safety or capacity/efficiency.

Table 2.2-2 shows a categorization of functions in relation to classes of service. The shaded cells indicate functions producing decisions or actions which are required to perform a service of a given class. That is,

TABLE 2.2-1 RELATIONSHIP OF FUNCTIONS TO SERVICES

SERVICES / FUNCTIONS	Separation assurance	Spacing control	Airborne, landing and ground nav.	Emergency services	Flight plan conformance	Flight advisory services	Airport/airspace use planning	Info services (flight planning)	Ancillary services	Record services
1. Provide flight planning information								IDA		I
2. Control traffic flow		I			I		IDA			
3. Prepare flight plan							I	I	I	
4. Process flight plan	I	I		I	IDA	I	I			I
5. Issue clearances & clearance changes		IDA			IDA					I
6. Monitor aircraft progress	I	I		ID	I				I	I
7. Maintain conformance with flight plan	I	I			IDA		I			I
8. Assure separation of aircraft	IDA	I			I					I
9. Control spacing of aircraft		IDA			I		I			
10. Provide airborne, landing and ground navigation capability			IDA							
11. Provide aircraft guidance	IDA	IDA		IDA	IDA					I
12. Issue flight advisory & instructions				I		IDA				I
13. Handoff	IDA	IDA			IDA					I
14. Maintain system records										IDA
15. Provide ancillary & special services	I	I			I	I			IDA	I
16. Provide emergency services	I	I		IDA		I	I			I
17. Maintain system capability & status information	I	I	I	I	I	I	I	I	I	I

I = Information
D = Decision
A = Action

the function produces a decision or an action whose immediate and direct result is a service to airspace users. That is the same function-service relationship as that denoted by D or A in Table 2.2-1 above.

Functions may also have an indirect relationship to services. They may produce information which constitutes an input used by another function as the basis for decisions or actions. An asterisk (*) is used in Table 2.2-2 to denote this kind of function-service relationship. The asterisk is also used to indicate a second kind of indirect relationship. This is the case where Function A produces a decision or an action which flows to Function B, where it forms the basis for a subsequent decision or action, resulting in Service X. Thus, the decision or action of Function B has a direct relationship to Service X, while the decision or action of Function A has an indirect relationship to Service X. In Table 2.2-2, therefore, the shaded cells denote functions with direct and immediate decision-action relationships to classes of service. The cells marked with an asterisk denote functions which have a secondary relationship to classes of service because they produce either information or intermediate decisions and actions.

While Table 2.2-2 represents function-service relationships at only the most general level, it does serve to show a hierarchy of functional importance. It is possible to distinguish those functions having direct or indirect importance for the safety of the system. Likewise, the relationship of functions to system capacity and efficiency are made clear. For the moment, this will suffice to describe the general operational characteristics of the system. In Chapter 5, this line of reasoning will be extended to produce definitions of fail-operational and fail-soft and to describe the specific effects of failure of functional components. At that time the concepts of functional importance and service criticality outlined here will be brought to bear in specifying man-machine requirements in response to functional component failure and in detailing operations in degraded system states.

TABLE 2.2-2 FUNCTIONAL IMPORTANCE IN RELATION TO CLASS OF SERVICE

FUNCTION	SERVICE CRITICALITY		
	SAFETY	CAPACITY/ EFFICIENCY	SUPPORTING
1. Provide Flight Planning Information		▨	*
2. Control Traffic Flow	*	▨	
3. Prepare Flight Plan		*	
4. Process Flight Plan	*	▨	*
5. Issue Clearances and Clearance Changes	▨	▨	*
6. Monitor Aircraft Progress	▨	*	*
7. Maintain Conformance with Flight Plan	*	▨	*
8. Assure Separation of Aircraft	▨	*	*
9. Control Spacing of Aircraft	▨	▨	
10. Provide Airborne, Landing and Ground Navigation Capability	▨		
11. Provide Aircraft Guidance	▨	▨	*
12. Issue Flight Advisory and Instructions	*	▨	*
13. Handoff	▨	▨	*
14. Maintain System Records			▨
15. Provide Ancillary and Special Services	*	*	▨
16. Provide Emergency Services	▨	*	*
17. Maintain System Capability and Status Information	*	*	*

▨ = Direct decision/action relation of function to class of service

* = Information or indirect decision/action relation of function to class of service.

2.3 CONCEPTS OF OPERATION

The network of advanced air traffic management system functions described in this report embodies four major concepts of operation. They are:

- Strategic and Tactical Planning
- Tactical and Strategic Safety
- Management by Exception
- Centralization

To some extent, these concepts may be considered as givens, in the sense that they stem from preliminary AATMS design studies performed by other contractors and set down as a baseline by DOT/TSC. However, these concepts also derive in part from the more general notion of a highly automated system of air traffic management. In particular, the concept of "management by exception" reflects a scheme of man-machine task allocation whereby men participate in rectifying unusual situations while machines deal with routine activities. Thus, the operational concepts outlined here grow both from externally postulated system features and from the analyses of generic functions and automation levels carried out in the study. Hence, the modes of operation may be taken as general features of any air traffic management system, that is, any system characterized by extensive automation of its internal processes and dedicated to regulation and management of traffic rather than just ground-based control of aircraft.

2.3.1 Strategic and Tactical Planning

The system achieves maximum and efficient use of its capacity through a series of strategic and tactical planning activities. The most strategic, or long-range, of these activities is flow control (Function 2), whose purpose is to estimate capacity and demand and to draw up a general plan for balancing demand against capacity throughout the national airspace. The plan is embodied in flow control directives, which set limits on arrivals and departures in terminal airspace and on use of heavily travelled portions of the en route system, if need be. Flow control may be exercised up to several hours in advance of actual operations.

It is clear that, if flow control is to be effective, the system must have two features. First, there must be advanced and somewhat detailed information about the planned use of the airspace. Users must make their intent known in advance of the actual flight. Second, flow control depends upon extensive and detailed information about current and predicted operational conditions -- notably weather, capacity, and runway availability. Both features imply that there must be a large, flexible, and frequently up-dated body of capacity and demand data available within the system. In fact, the success of the strategic planning process can be said to rest upon the degree of the system's awareness about its current and predicted state and the anticipated traffic load.

The first steps toward implementation of the strategic plan for management of traffic flow are the processes of flight plan preparation and approval (Functions 3 and 4). These activities are less strategic than flow control, in the sense that they deal with individual flights not overall traffic; and they are not as long-range -- although they still occur in advance of the flight itself. Flight plan preparation is a pilot responsibility, and it results in a statement of proposed use of the airspace. The companion process of the air traffic system is flight plan processing and approval (Function 4), whose result is an accepted flight plan, constituting a form of "contract" for airspace use and its attendant services.

Again, it is evident that the flight planning and approval processes are heavily dependent upon the system data base. Flight planning requires information about weather, routes, terminal availability, anticipated traffic, rules, procedures, and so on -- all contained in Function 17 and provided through the agency of Function 1 (Provide Flight Planning Information). Function 4 (Process Flight Plan) uses this same information to determine the acceptability of the proposed flight plan and to make appropriate provisions for system services to support the conduct of the flight.

An important feature of the approval process is the review of the proposed flight against other flight plans to assure that there is no conflict of intentions. Thus, in order to be accepted, each flight must not interfere with the planned use of the airspace by other aircraft. This feature of system operations is known as conflict prevention through planning. A "conflict-free" flight plan simply means that the plan is mutually consistent with all other plans and that, insofar as the plan is a forecast of the actual flight, it will neither interfere with other aircraft nor be interfered with by them. This freedom from conflict is implicit in the acceptance and approval of the flight plan by the system, which in effect guarantees the aircraft a reserved block of airspace over time.

Implementation of the plan begins with the flight itself which, from the standpoint of the ground-based system, is controlled by the clearance and flight plan conformance monitoring processes (Functions 5 and 7). These processes represent the beginning of the tactical domain. Of the two, the clearance function is more long-range in that it may extend approval to continue for the entire duration of the flight. Alternatively, clearance may be given for only one segment of the flight at a time. Flight plan conformance monitoring is more short-range, looking ahead from the present for a period of perhaps 10-15 minutes. These processes are tactical in that they deal not just with short-range plans and intentions but also with actual flight data (present position, track history, and short-term extrapolations).

The final process for assuring efficient airspace use is spacing control (Function 9), which embraces all the activities necessary to arrange aircraft in a precise sequence for takeoff or landing or for passage through any "gate" en route. The process is both medium-term (10-15 minutes) and short-term (3-5 minutes). In its medium-term aspects, the process is sometimes called tactical flow control because it involves tactical adjustments and modifications of the strategic flow control plan. Departures and arrivals allotted to major 10-15 minute time blocks by strategic flow control are refined and interleaved by Function 9 to produce a runway arrival-departure schedule and a short-term metering of traffic flow. This schedule, in turn, is further refined by the purely tactical activities of sequencing and spacing, which results in the individual aircraft being arranged in a precise sequence for runway use, with the proper time and distance separation.

Thus, the strategic and tactical planning for efficiency of airspace use and the implementation of these plans are accomplished by series of functions, covering a spectrum of long- to very short-term. The individual processes may be visualized as a group of concentric shells, each serving to implement or refine the outcome of its predecessors. Figure 2.3-1 depicts the mutually supporting nature of strategic and tactical planning functions. At the core is the most strategic and long-range process, flow control. Moving outward from this core, the processes become more tactical, and they operate for a shorter and shorter term. Each process serves to backstop and refine the preceding one and to carry the implementation of traffic planning one step forward. The outermost shell is purely tactical and represents the culmination of the traffic plan in an orderly sequence of arrivals and departures at the runway.

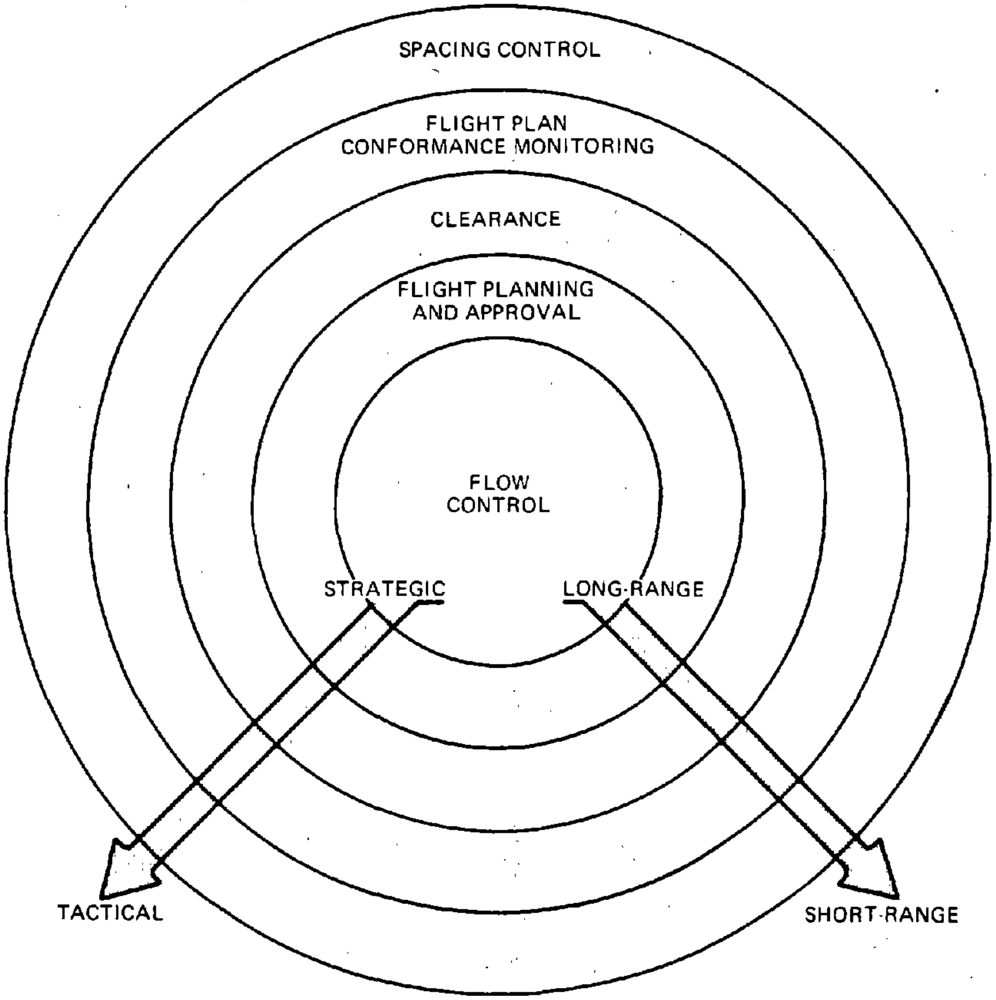

FIGURE 2.3-1 STRATEGIC AND TACTICAL PLANNING PROCESSES

2.3.2 Tactical and Strategic Safety

The processes assuring the safety of airspace use may also be visualized as concentric shells. However, in this case, the progression is reversed -- going from tactical and short-range at the center to strategic and long-range at the outer perimeter. This arrangement of safety-related functions is shown in Figure 2.3-2.

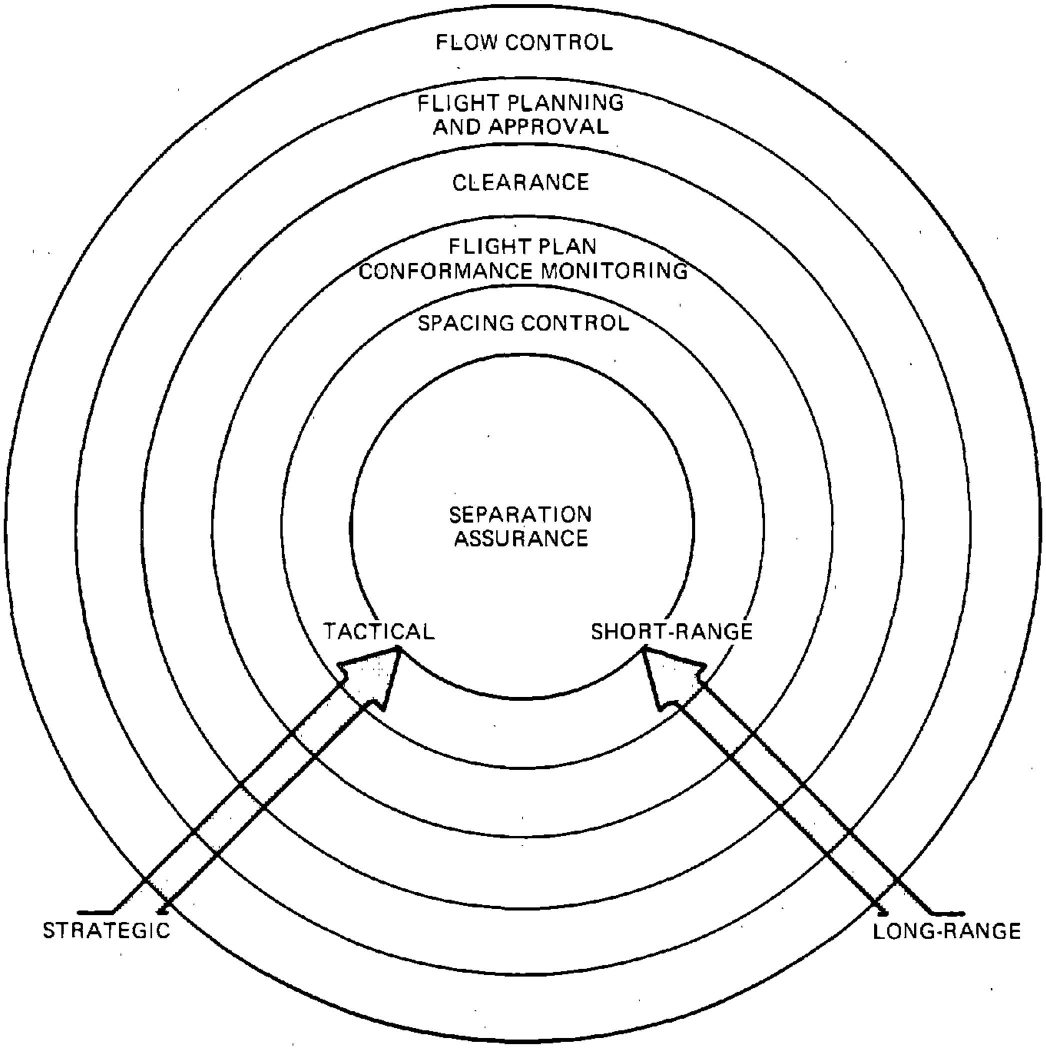

FIGURE 2.3-2 TACTICAL AND STRATEGIC SAFETY PROCESSES

At the heart of the system is the process of separation assurance (Function 8). It consists of two interlocking sets of activities. The first is conflict prediction, which looks ahead for a short time span (say, 3-5 minutes) and resolves any situation where aircraft are predicted to be in conflict. Conflict prediction is anticipatory in nature; its purpose is to prevent conflicts from occurring by foreseeing them and taking corrective action before they do. Despite these precautions, conflicts may still occur. Thus, the second and innermost part of the separation assurance is conflict detection and resolution, which acts as a final safeguard to the inviolability of the airspace about each aircraft. This process is tactical, very short-range, and entirely reactive. It comes into play only when other processes have failed to maintain separation between aircraft, and it operates only insofar as necessary to direct aircraft to a safe distance apart.

Arranged around this inner core of separation assurance are other protective processes, which transition from tactical to strategic and from short range to long range as they progress outward. In order these processes are:

- Spacing Control (Function 9), which -- through tactical means -- maintains aircraft in an orderly sequence at a safe distance;
- Flight Plan Conformance Monitoring (Function 7), which watches to assure that aircraft stay on their intended paths;
- Clearance (Function 5), whose purpose is to exercise control over the implementation of the flight plan;
- Flight Planning and Approval (Functions 3 and 4), which produce flight plans that are free of conflict in intent and compatible with other traffic, weather, and operational conditions;
- Flow Control (Function 2), which provides an overall balance of demand and capacity to eliminate potential congestion.

Thus, safety of airspace use is assured by a layering of system functions which operate both strategically and tactically to maintain the integrity of a moving volume of airspace about each aircraft. At the strategic end conflicts to plans are precluded, insofar as possible, by flow planning and by an approval process which makes a far-reaching check among flights for compatibility of intentions. In the intermediate strategic-tactical range the clearance and flight plan conformance monitoring functions act as modulators to assure the continued compatibility of flight plans while flights are in progress, with a feedback provided to flight planning itself, so that conflict-free revision of flight plans can be made as necessary. In the tactical realm, spacing control acts to predict and resolve potential conflicts by establishing an individual order of precedence for arriving and departing aircraft in terminal areas, where flights converge and the possibility for conflict increases. In cases where all these preventive measures are not adequate, there is the additional safeguard of conflict prediction, which forms part of the separation assurance function. The other aspect of separation assurance is conflict detection and resolution, which acts as the ultimate shield for the aircraft.

Since the processes which promote efficiency of airspace use also come into play in assuring safety of flight, it can be seen that strategy and tactics have a reciprocal relationship in air traffic management. Insofar as capacity and efficiency are concerned, the system operates from strategic plans to tactical implementation through a sequence of functions which progressively "fine tune" the planned flow of traffic. In the area of safety, the sequence is reversed. The system starts at the purely tactical level with separation assurance and then wraps around this core successive layers of more and more strategic functions, each for the purpose of regularizing traffic and making it more orderly, thereby precluding the need for tactical intervention. The temporal and strategic-tactical relationships of system functions in relation to safety and efficiency are illustrated and compared in Figure 2.3-3.

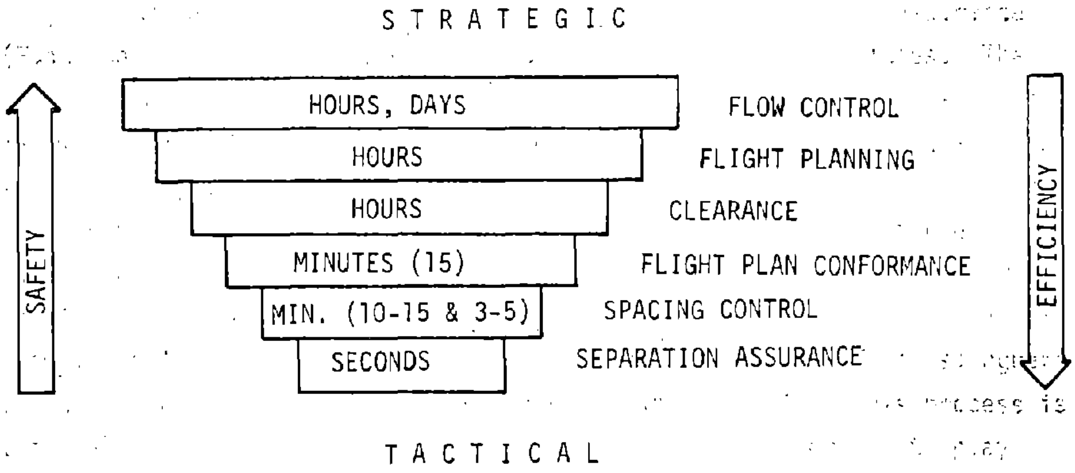

FIGURE 2.3-3 SYSTEM FUNCTIONS IN RELATION TO SAFETY AND EFFICIENCY

2.3.3 Management by Exception

The design emphasis on strategic planning and anticipatory actions is intended to reduce to a practical minimum the need for tactical intervention and reactive measures. In theory at least, an aircraft with an approved flight plan should be able to proceed from the departure gate to its destination without intervention by the ground-based system, so long as the agreed-upon plan of flight is actually maintained. This is the implication of the "contract" between the user and the system, as embodied in the approved flight plan.

In practice, however, this theoretical ideal will not be uniformly realized. Weather may interfere. The aircraft may not be able to keep up with its intended time-position profile through the airspace. Navigational errors may occur. Operational conditions may change. Traffic may build up in an unexpected way. Human errors can happen. In any of these circumstances, the air traffic management system will have to respond through the appropriate combination of strategic and tactical measures to correct the imbalances and to reestablish a smooth and orderly traffic flow.

This is the essence of management by exception. The resources of the system are called upon to intervene only when the established plan is not working out. The normal course of events demands a minimum of tactical and reactive interchange with the aircraft. When the abnormal occurs, the proportion of tactical response rises in the short term, but then subsides as the more strategic and long-range functions act to restore balance. In effect, the advanced air traffic management system is a self compensating system. It plans its work so as to require a minimum of tactical effort. When circumstances force the system to work harder tactically, it compensates by making an additional strategic effort, whose result is to eliminate the need for tactical activity and to reestablish the original level or effort.

It could be argued that the abnormal or crisis mode is actually the prevailing state of affairs in a system which is so highly dependent on weather. Meteorological conditions are always changing, and the weather is always below minima somewhere in the system. Thus, it might be concluded that the only way for the system to work as intended would be to have total control of weather. This is an intriguing line of reasoning, but it misses the point. Weather is not an adversary to be mastered, but a disruptive phenomenon that must be dealt with. Hence, the true design goal of the system is not to control weather but to foresee and plan for its effects. In fact, this is how the present system tries to operate, albeit somewhat imperfectly. This same spirit of coping with the effects of weather phenomena is reflected in the advanced system design, with automation providing added flexibility and speed of response in actions ranging from helping individual aircraft avoid bad weather to restoring traffic flow when whole terminals have been forced to suspend operations. Management by exception is thus a concept that applies equally to unusual situations arising from environmental factors and to those originating in traffic demand.

2.3.4 Centralization

The ability to make comprehensive and detailed plans and the capacity to retain flexibility in the face of changing environmental and operational conditions demands a large and dynamic data base. Incoming information about present and future events must be correlated in multiple ways, acted upon promptly, and then distributed to all affected parties. Thus, the operational concept and the recommended level of automation advanced here suggest strongly that the system must have an unparalleled degree of awareness about its capability and status. This is true not only for strategic functions, where the information must flow inward and upward to be aggregated and abstracted, but also for tactical activities where information must move in the opposite direction and be recombined as particular data packages for individual recipients.

This is an enormous data processing task. For the simple reasons of efficiency and economy, the resources to carry out this data processing will have to be centralized to the extent possible. For the more strategic functions, centralization seems to be the only practical course. In fact, the present system is already moving in this direction in the area of centralized flow control and airport reservations. For tactical functions, the case is more complicated.

As a whole, tactical functions demand the preponderance of data processing capacity. (This point is supported in Chapter 3, which contains an analysis of data processing requirements.) This suggests that the payoff of centralization would be highest in the tactical functions. However, tactical activities by their nature tend to be widely distributed throughout the physical locations of the system. Further, because tactical activities are strongly related to safety features of the system, it might not be wise to centralize these functions and run the risk of having all eggs in one basket in the event of automated resource failure. Thus, tactical functions pose a dilemma. For efficiency and economy, they should be centralized. For operational and safety reasons, they should be distributed throughout the ground-based system.

The AATMS concept offers a compromise. The data base for tactical functions, insofar as it consists of generalized information, is centrally collected and managed. Specialized and particular data needed to support tactical decisions and actions on site, are collected and managed locally (or, in some cases, regionally for subsequent distribution locally). The allocation of data processing to central or distributed facilities is not a strict either-or matter. There is extensive data sharing, but not redundant processing, between central, regional, and local sites and among local sites with overlapping or contiguous jurisdictions. In effect, this allows sites to "know" what others are doing and to take these factors into account for local operations. Because the data base is widely shared, sites (or jurisdictions) with similar capabilities can back each other up in case of failure or temporary overload.

A more detailed examination of centralization is beyond the scope of this report. Neither is it necessary for the purpose here, which is to outline operational concepts only to the extent needed for understanding of automation-related requirements presented in subsequent chapters. The reader who wishes to pursue the topic will find extensive treatment in four documents which describe the AATMS design concept (Boeing, 1972; Autonetics, 1972; Rockwell, 1973; DOT/TSC, 1973).

2.4 FACILITIES

As an operational system, AATMS will be deployed in facilities with specific functional and jurisdictional responsibilities. The function analysis carried out in this study was performed without reference to facilities, apart from the general presuppositions that the system would have en route and terminal control jurisdictions and that users would have access to the system for information and flight plan filing through some network of flight service stations. For the purpose of describing the system at the functional level, these assumptions were entirely adequate. In fact, the absence of detailed assumptions about the number and type of facilities served to advantage because it helped assure the applicability of the function analysis to any physical configuration that might be selected for the system.

In Phase C, however, it was necessary to have a specific facility configuration as a basis for deriving man and machine resource requirements. As a minimum, the description of facilities had to include the type and number of installations in which the system would be deployed and the general responsibilities of each. As part of the overall AATMS program, DOT/TSC had earlier prepared a description of a nominal facility configuration (DOT/TSC, 1973). This documentation was reviewed, and the essential details were extracted to form a working definition of system facilities. Thus, with respect to the automation applications study, the facility configuration was not a derived product but a given drawn from the work of other contractors and DOT/TSC.

2.4.1 Air Traffic Management Facilities

The advanced air traffic management system is made up of the following facilities, with responsibilities as shown:

1. Continental Control Center (CCC), located in the central region of the United States, has the following functions:
    - Performs the national flow control functions
    - Coordinates with the National Flight Service Center (NFSC) to acquire the weather data needed for national flow planning
    - Serves as a backup to either Regional Control Center

2. Regional Control Centers (RCC), two centers located in the eastern and western U. S., perform the following function:

   - Provide en route traffic management services for domestic en route traffic
   - Provide traffic advisories and perform handoff coordination for traffic in the adjacent oceanic region
   - Serve as a backup to the Transition/Hub Centers and Airport Control Centers to which they are connected
   - Coordinate with their respective Regional Flight Service Stations to obtain weather data as required for regional-level air traffic management

3. Transition/Hub Centers (THC), twenty geographically distributed centers, perform the following functions in their respective areas of jurisdiction:

   - Conduct terminal area operations for secondary terminals with unmanned towers
   - Manage the transition of aircraft control assignments between the associated Regional Control Center and secondary terminals with unmanned towers
   - Manage the traffic within the largest major hubs but outside of airport control zones (e.g., provides services similar to those of today's Common IFR Room for the New York City Hub area)
   - Coordinate with their respective Hub Flight Service Stations to obtain weather data as required

4. Airport Control Centers (ACC) are of three types:

   - Primary Terminals - 133
   - Secondary Terminals (manned towers) - 359
   - Secondary Terminals (unmanned towers) - 227

Primary terminals and secondary terminals with manned towers manage the traffic within their respective airport control zones, providing all required services for aircraft in the approach, landing, taxi, takeoff, and departure phases of flight. Services for aircraft at secondary terminals with unmanned towers are provided by Transition/Hub Centers as described above.

Figure 2.4-1 is a schematic representation of the air traffic management facilities configuration. The figure also shows flight services facilities and the points of interface with air traffic management facilities. A description of flight service installations is provided on the following page.

2.4.2 Flight Service Facilities*

The configuration of flight service facilities closely parallels that of air traffic management facilities, in that it consists of national, regional, and local components that are collocated with their air traffic management counterparts. The flight service facilities and their respective functions are enumerated below.

1. National Flight Service Center (NFSC), collocated with the CCC, performs the following functions:
    - Contains the national central processing facility and data base (including weather information, Notices to Airmen, and Pilot Reports)
    - Provides weather data as required by the Continental Control Center and the Western and Eastern Regional Flight Service Centers
    - Serves as a backup for the two Regional FSCs
2. Regional Flight Service Centers, collocated with either their associated RCCs or with THCs, have the following functions:
    - Route weather data to their associated Regional Control Centers
    - Serve as Hub FSSs in their local areas
    - Serve as backups for other Hub FSSs, described below

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*The AATMS flight service station configuration described herein was developed by DOT/TSC and is based on the DOT study entitled A Proposal for the Future of Flight Service Stations, Volume I-IV, dated Dec. 1972.

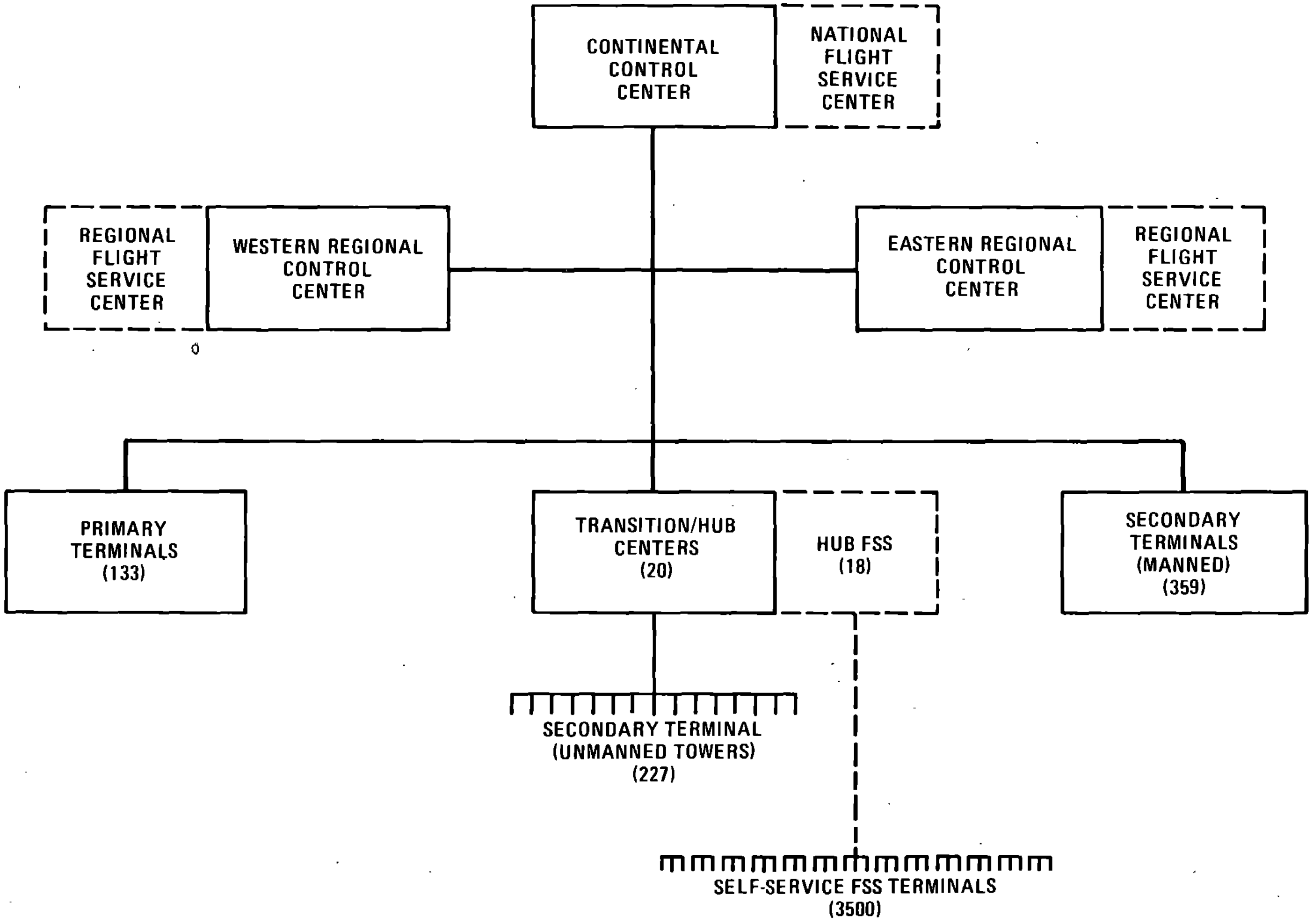

FIGURE 2.4-1 AATMS FACILITIES CONFIGURATION

3. Hub Flight Service Stations, of which there are eighteen, perform the following functions:

   - Provide weather data to primary and secondary airports in their area
   - Process flight plans and distribute flight plan data to other system components and facilities
   - Support approximately 175 remote FSS self-service terminals by providing flight planning and information services

4. Self-Service FSS Terminals, consisting of approximately 3500 unmanned units located at airports or other sites convenient for users, will:

   - Process pilot-entered requests for weather and flight planning data
   - Provide plain language displays of pilot requested weather and flight planning data
   - Receive pilot-filed flight plans

2.5 OPERATOR POSITIONS, TASKS, AND DUTIES

The air traffic management system will be manned by personnel with various specialities and responsibilities, which will be reflections of their functional assignments. Thus, the controller positions were defined in this study in terms of groupings of the 17 functions derived in this study. In the present system, there are three basic controller jobs, or "options", which are subdivided into "positions". The three options are identified in terms of the type of facility where the controller works: en route, terminal, and FSS. Positions, on the other hand, are defined in terms which are a mixture of functional assignment (e.g., clearance delivery, radar controller, or handoff) and work site (e.g., tower cab). The controller designations used in this study preserve the concepts of option and position, but all are defined in purely functional terms.

2.5.1 Functional Assignments

The basic personnel structure of AATMS consists of three options, of which two are further divided into two positions each:

- I. Data Management Option
    - A. Data Base Officer
    - B. Flight Information Services Officer
- II. Operations Planning Option
    - A. Flight Plans Officer
    - B. Flow Control Officer
- III. Flight Surveillance and Control Option

Each option and position is assigned responsibility for one or more generic air traffic management functions. All functional assignments are unique, i.e., each function is assigned as a whole to one, and only one, position. Table 2.5-1 shows the allocation of functions to positions.

TABLE 2.5-1 ALLOCATION OF FUNCTIONS TO POSITIONS

POSITION	FUNCTIONAL ASSIGNMENT
IA Data Base Officer	14. Maintain System Records 17. Maintain System Capability and Status Information
IB Flight Information Services Officer	1. Provide Flight Planning Information 12. Provide Flight Advisory and Instructions
IIA Flight Plans Officer	4. Process Flight Plan 15. Provide Ancillary and Special Services
IIB Flow Control Officer	2. Control Traffic Flow
III Flight Surveillance and Control	5. Issue Clearances and Clearance Changes 6. Monitor Aircraft Progress 7. Maintain Conformance with Flight Plan 8. Assure Separation of Aircraft 9. Control Spacing of Aircraft 11. Provide Aircraft Guidance 13. Handoff 16. Provide Emergency Services

Figure 2.5-1 presents a related view of the system by depicting the general lines of functional flow among positions.

It will be noted that a total of only fifteen functions have been allotted to positions. The two unassigned functions are 3, Prepare Flight Plan and 10, Provide Airborne, Landing, and Ground Navigation Capability. Function 3 was not included as a controller responsibility because this activity is performed by pilots and so imposes no workload on system personnel. Function 10 is somewhat similar. Function 10 consists of those means by which the system provides signals that are used onboard the aircraft to determine position. Controllers do not have a direct involvement in this function today, except for providing emergency navigation service for lost or disoriented aircraft. The trend in navigational equipment is to make it less dependent on human operation. This trend seems likely to continue, so that by the time AATMS is scheduled to become operational, there is scant probability that anything more than exceptional controller involvement will be called for. A second reason for omitting Function 10 from the list of controller responsibilities is that navigation pertains more to sensors and effectors than to internal air traffic management processes. Since only the latter domain is of concern in this study, Function 10 is outside the scope of interest.

2.5.2 Duties and Responsibilities

A more detailed view of each position can be obtained by examining the subfunctions and tasks which make up each function. Tabulations of specific duties and responsibilities associated with the functional assignments for each position are presented beginning on page 2.5-5.

2.5.3 Position Assignments by Facility

The duties and responsibilities of controller positions are defined in purely functional terms. Since facilities can also be described by the functions they perform, it is possible to specify the general staffing pattern for AATMS installations. Table 2.5-2 shows the relationship of positions, functions and facilities.

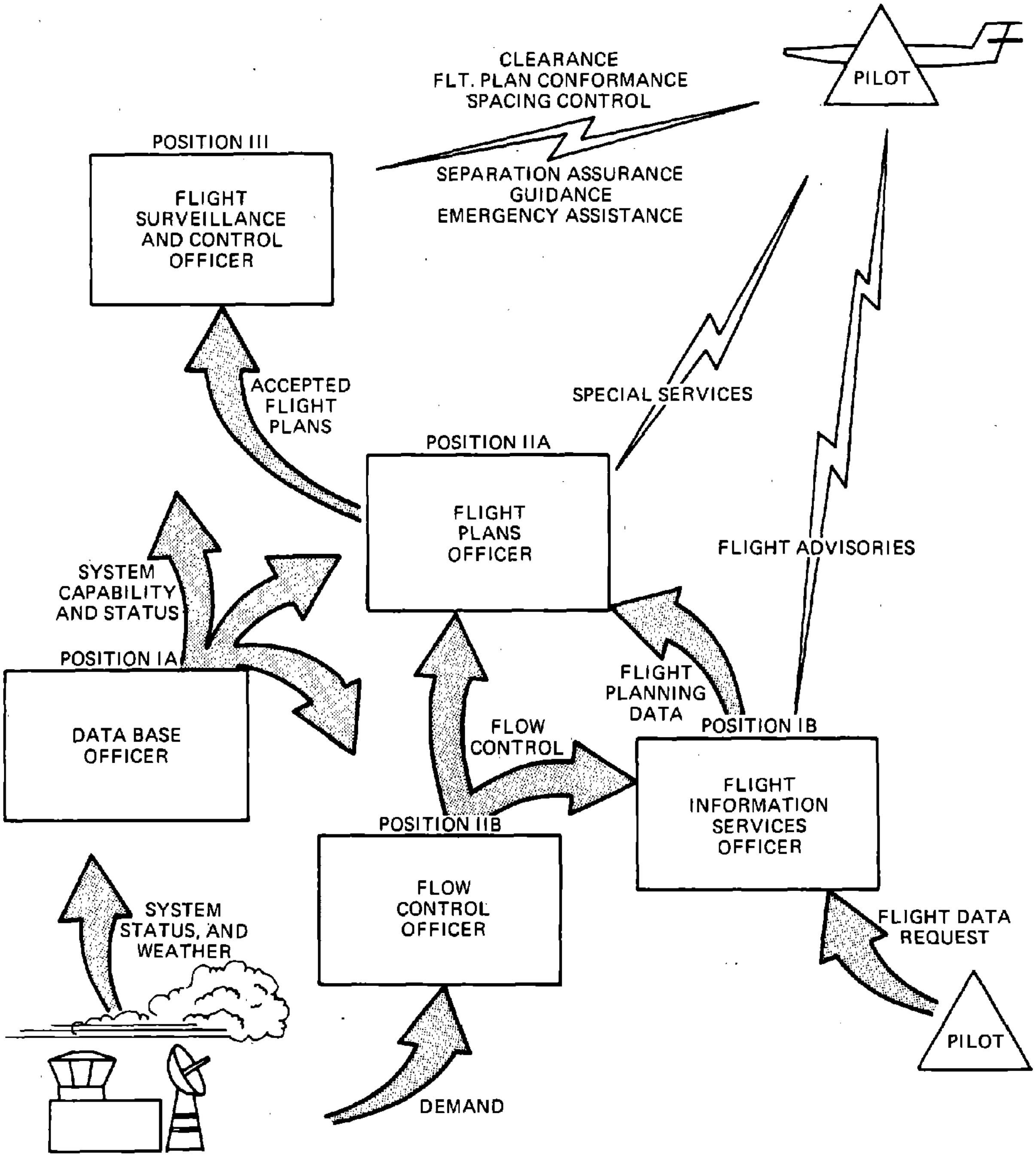

FIGURE 2.5-1 FUNCTIONAL RELATIONSHIPS AMONG POSITIONS

POSITION IA - DATA BASE OFFICER

Duties and Responsibilities

- Maintain current and forecast weather information (Function 17)
- Maintain operational data base concerning rules, procedures, airspace structure, routes, airspace restrictions, and hazards to flight (Function 17)
- Maintain operational data base concerning the capability and status of the communication-navigation system and of ground facilities (Function 17)
- Maintain operational records and statistics (Function 14)
- Prepare operational and statistical reports (Function 14)

POSITION IB - FLIGHT INFORMATION SERVICES OFFICER

Duties and Responsibilities

- Provide flight planning information and related information services (Function 1)
- Provide inflight advisories and instructions (Function 12)
- Disseminate hazardous weather advisories (Function 12)

POSITION IIA - FLIGHT PLANS OFFICER

Duties and Responsibilities

- Review and approve flight plans (Function 4)
- Modify or assist pilot in modifying flight plans (Function 4)
- Assign responsibility for control of flight and assign communication channels (Function 4)
- Review and approve requests for special and ancillary services (Function 15)
- Initiate action to provide special or ancillary service and monitor progress of service (Function 15)

POSITION IIB - FLOW CONTROL OFFICER

Duties and Responsibilities

- Determine the capacity of individual terminals and jurisdictions and assess the effects of environmental and operational factors (Function 2)
- Estimate demand at individual terminals and jurisdictions (Function 2)
- Resolve capacity overload situations (Function 2)
- Issue flow control directives and guidelines (Function 2)

POSITION III - FLIGHT SURVEILLANCE AND CONTROL

Duties and Responsibilities

- Compile and issue clearances (Function 5)
- Monitor flight progress and predict future positions and ETAs of aircraft (Function 6)
- Monitor aircraft capability and status (Function 6)
- Detect long-term conflicts among flight plans and propose flight plan revisions (Function 7)
- Determine current deviations and predict future deviations from flight plan (Function 7)
- Resolve flight plan deviations and propose flight plan modifications as required (Function 7)
- Predict and resolve conflicts and assure minimum separation (Function 8)
- Maintain arrival/departure schedule for runway or terminal (Function 9)
- Sequence and space arrivals and departures (Function 9)
- Provide guidance to aircraft as required (Function 11)
- Assure continuity of surveillance and control through giving and receiving handoffs (Function 13)
- Detect and assess emergencies and provide appropriate assistance to aircraft in emergencies (Function 16)

TABLE 2.5-2 POSITION AND FUNCTION ASSIGNMENTS BY FACILITY

FACILITY	ASSIGNED POSITIONS	FUNCTIONS
Continental Control Center and National Flight Service Center	IIB	2. Control Traffic Flow
	IA	14. Maintain System Records 17. Maintain System Capability and Status Information
Regional Control Center	III	5. Issue Clearances and Clearance Changes 6. Monitor Aircraft Progress 7. Maintain Conformance with Flight Plan 8. Assure Separation of Aircraft 9. Control Spacing of Aircraft 11. Provide Aircraft Guidance 13. Handoff 16. Provide Emergency Services
Hub Flight Service Station (including Regional Flight Service Center)	IB	1. Provide Flight Planning Information 12. Issue Flight Advisories and Instructions
	IIA	4. Process Flight Plan 15. Provide Ancillary and Special Services
Primary Terminal	III	Same as Regional Control Center
Secondary Terminal (manned tower)	III	Same as Regional Control Center
Transition/Hub Center	III	Same as Regional Control Center

2.6 CAPACITY AND DEMAND

Capacity refers generally to the volume of the system and its ability to accommodate users of airspace and terminal facilities. Demand is the number of users requesting accommodation. Thus, in simplest terms, capacity is the ability to handle demand.

Capacity is influenced by many factors, notably the number of airports, runway characteristics, availability of terminal gates, route structure, navigation and surveillance system accuracy, aircraft separation requirements, and the ubiquitous effects of weather. To the extent that any of these can be controlled or compensated for by the system designer, capacity can be increased to suit any postulated level of demand. In fact, the ultimate goal in the design of the operational AATMS complex will be to compensate for physical factors in such a way that the required capacity can be attained.

Despite their obvious importance for the eventual design of the system, none of the above considerations was germane to the goals of the automation applications study because they lie in the domain of sensors and effectors, in the physical characteristics of the system or in the intractability of the environment. The automation applications study was focussed on determining the man and machine resources needed to carry out the internal processes of the system. The approach here involved the assumption that external physical resources were not a limiting factor and that design solutions would be found to enlarge the capacity of sensors, effectors, and facilities as dictated by demand. Therefore, the proposition examined in this study can be stated as: For any given demand, and assuming no contraining physical factors, what quantity and proportion of man and machine resources will be needed to conduct air traffic management operations? In this sense, it can be said that man and machine resource requirements were driven by demand. The variable in the equation was the level of automation, with values assumed for capacity and demand. Thus, the equation to be solved was for the resources required to handle a given demand.

Demand can be described in a number of ways. The size of the aviation fleet and the number of operations annually or monthly are possible expressions, but they would not be suitable for the present case. What is needed is an indication of the maximum workload (demand for services) that may be imposed on the system over some relatively brief period of time. The statistic which comes closest to expressing this is the peak instantaneous airborne count (peak IAC), which is an estimate of the greatest number of aircraft in flight throughout the continental United States at any one time.

Projections of the peak IAC for the 1995 time period were available from three sources. ATCAC (1969) estimated a peak IAC of 54,400 (4,600 air carrier, 46,300 general aviation, and 3,500 military). More recent investigations indicate, however, that the ATCAC figures may be as much as 50% too high. An analysis by DOT/TSC (1973) scaled the peak IAC down to about 37,000 (5,331 air carrier + 30,828 general aviation + 863 military = 37,022) for a 1995 nominal demand case. The DOT/TSC calculation was based on the growth record of particular airports and the historical increase of demand for air transportation services between and within major cities. A study by MITRE (1973) reported essentially the same 1995 peak IAC projection as DOT/TSC. MITRE drew on data from (1) en route estimates developed by Autonetics and used in an analysis by R. Dixon Speas, (2) a detailed "snapshot" of the Los Angeles Basin developed by MITRE, and (3) an analysis of terminal area traffic for all hubs in CONUS.

The demand figures used in this study were based on the DOT/TSC and MITRE estimates, with an adjustment for the number of VFR general aviation aircraft in uncontrolled terminal airspace. These aircraft, because they are uncontrolled, do not impose a demand for services on the air traffic management system. Hence, they had to be factored out of the demand pool used to calculate man and machine resource requirements. DOT/TSC and MITRE estimated that the number of such aircraft would be approximately 3,300. Therefore, the general aviation portion of the traffic mix was reduced from 30,828 to 27,528. This produced a peak IAC of 5,331 air carrier, 27,528 general aviation, and 863 military -- or a total of 33,722. For simplicity of calculation, the total was rounded off to 33,750, with the components increased proportionately.

For the purpose of calculating resource requirements, it was necessary to make certain assumptions about the distribution of the demand across en route and terminal portions of the system. First, the average length of a flight was assumed to be two hours, of which 20 minutes would be spent in the departure terminal area, 80 minutes en route and in transition to and from terminal areas, and 20 minutes in the arrival terminal area. Applying these proportions to the peak IAC yielded an instantaneous count of 22,500 aircraft of all types in the en route part of the system and 11,250 in terminal areas (5,625 arriving and 5,625 departing). Within terminal areas, it was further assumed that 50% of the aircraft would be in the control zone of one of the 133 primary airports and 50% would be in the control zone of one of the 586 secondary airports. It was logical to assume a distribution of this sort for terminals since it would place almost four and one-half times as many aircraft in primary terminals as in secondary terminals -- a ratio which is in general accord with available data on airport operations.

Finally, for simplification, two assumptions were made about the homogeneity of demand distribution. First, it was stipulated that the proportion of air carrier, general aviation, and military aircraft was uniform throughout the airspace. Second, it was assumed that demand variations within either primary or secondary terminal areas could be disregarded. Thus, each primary terminal was considered to have an equal share of the demand; and each secondary terminal likewise. Table 2.6-1 below shows the peak IAC estimate used in this study and its distribution across the system.

TABLE 2.6-1 DISTRIBUTION OF PEAK INSTANTANEOUS AIRBORNE COUNT - 1995

FLEET TYPE	EN ROUTE	PRIMARY TERMINALS	SECONDARY TERMINALS
Air Carrier	3,555	890	890
General Aviation	18,367	4,592	4,592
Military	578	143	143
Total	22,500	5,625	5,625

3.0 MANPOWER AND DATA PROCESSING REQUIREMENTS

3.1 OBJECTIVE AND APPROACH

One of the principal goals of the automation applications study was to determine the appropriate level of automation for an advanced air traffic management system. For the purposes of the study, the term "appropriate" meant that the aggregation of performances allocated to men and machines on a task level would present a cohesive and meaningful role for the human operator at the system level, with a similarly reasonable epistemology for machines.

To serve this purpose, a method was devised to associate manpower and machine requirements with the five incremental levels of automation which had been defined for the generic AATMS system. (They are described in Volume III of this report). A preliminary choice was made by examining the machine and manpower requirements for each theoretical increment and then selecting the one conforming most closely to the given limits. Next, this generally acceptable specification of resource requirements was reviewed in light of task logic, task interrelationships, and automation indices. The results, when all final adjustments were complete, was the automation level of choice -- a recommended allocation of 256* applicable AATMS generic tasks to either human or automated performance means.

Once the recommended automation level had been selected, it was possible to derive, from the undistributed manpower requirements associated with the recommended level, a set of staffing requirements for AATMS facilities. Thus, the pool of human resource requirements necessary to meet the specified demand was converted to numbers of men per facility per shift.

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*Because Function 3 (Prepare Flight Plan) is performed not by the ground-based system but by the pilot, it was excluded from these considerations. Pilots are assisted in flight planning in Function 1 (Flight Plan Preparation); review of flight plans is done in Function 4 (Flight Plan Processing).

3.2 METHOD

3.2.1 Summary of Procedure

Deriving the recommended automation level required both qualitative and quantitative data about each of the 256 applicable AATMS tasks. Qualitative data consisting of task descriptions, the inputs required to perform the tasks, the outputs produced in each task, and the logic whereby tasks are interrelated had been produced earlier in the project. (These data are documented in Volume II of this report.) The qualitative statements about each task were used in two ways. They provided the basis for deriving the nature and number of the tasks induced at each automation level by the requirement for man-machine resource units to interact. They also served as an aid to carrying out the refinement from a generally acceptable level of automation to the final level of choice.

Some quantitative task data had also been derived earlier in the project, in the form of automation indices for the AATMS tasks. (Automation indices are discussed in Volume III of this report.) These data were used to define the five theoretical increments of system automation from which initial resource computations were made.

Making resource computations required additional quantitative task data, of three types*:

1. How often a task is performed (task frequency)
2. How long it takes a man to do the task (manual performance times)
3. How many machine instructions are required to perform the task (instruction counts).

With this additional information in hand, the total human and machine resources for a particular automation level could be computed. In general, the computation proceeded as follows:

1. Manual task performance time multiplied by task frequency gives total human operator man-hours required, which can be translated into system staffing estimates,
2. Number of machine instructions multiplied by task frequency gives total instruction execution rates required, which can be used as a rough index of computer size.

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*These data were also utilized in the DELTA Simulation Model (See Appendix C).

3.2.2 Task Types

Task frequencies, task times, and instruction count estimates were required for each of two task types. For purposes of this discussion, the two types are termed "fundamental" and "induced". A fundamental task is any of the 256 generic system tasks which must be carried out to perform a system function, such as "determine requirement for issuence of NOTAM" or "inform pilot of out-of-tolerance deviation from flight plan." These tasks represent the fundamental processes whereby the system performs the functions necessary to meet the needs of its users.

The system logic is made up of fundamental tasks linked together in patterns or networks. Each task receives inputs from other parts of the network, performs its particular step or process, and passes the output to other tasks. At a given automation level, some number of the tasks in a network are allocated to machines and some to human operators. A human operator, then, may receive inputs from the machine, carry out his task manually, and pass the result to a machine. For example, he may be alerted to the presence of hazardous weather in the path of an aircraft by the machine, his task being to decide whether to re-route the aircraft, or to keep the same route but change the assigned altitude. Having made the decision, the human operator passes the result to a machine. ("Vector this aircraft in that direction.")

Thus, the effect of choosing a particular automation level, that is, allocating some fundamental tasks to machines and others to men, is to <u>induce</u> a requirement for machines to present information to men and conversely for men to communicate data or instructions to machines. It can be seen that in theory, if the system were either wholly manual or wholly automated there would be no induced task requirements. But at each stage between, both men and machines are present as system performers, and at every specified apportionment of men and machines in the system, certain induced tasks are created.

The condition of necessity, therefore, in deriving the resource requirement associated with a particular automation level was that all applicable fundamental tasks be allocated either to men or machines. The condition of sufficiency was that all induced tasks must be enumerated through study of the system task networks, and the machine resources necessary to generate displays and receive control instructions and the man hours necessary to read displays and set controls be included in the resource requirements totals. The derivation of task performance frequencies, task performance times, and machine instruction counts was thus addressed both to fundamental and to induced tasks in automation level resource requirements computations.

3.2.3 Task Performance Frequency Estimation

It will be recalled that the frequency of performing a given task is common to deriving both manpower and machine resource requirements. That is, frequency multiplied by manual performance times gives manpower, frequency multiplied by instructions gives computer size. To carry out the resource requirement computations required preparing an estimate of the frequency at which each of the 256 applicable generic tasks would be performed, given the system concept and at the anticipated demand level. Knowing the frequency of performance of a given fundamental task also defined the frequency of performance for any associated induced tasks, since there is a correspondence between the rate at which manual tasks are performed and the rate at which information is exchanged between machine and man in the course of their performance.

Frequency estimation was done by a team of three specialists with experience in human factors, systems analysis, and air traffic control. The method of estimation was:

1. Each team member independently estimated frequencies for all tasks.

2. The estimates were then compared, on an interval scale. All cases of agreement were accepted. Cases where two estimates agreed and the third differed by only one interval were resolved by accepting the two agreeing estimates and rejecting the other.

3. Cases in which any one estimate differed from the others by more than one interval, or in which all three estimates disagreed, were set aside.

4. All cases of disagreement were resolved by conference, until agreement was reached on performance frequencies for all 256 tasks.

Wherever possible, estimates were made using the "flight" as a unit. In other words, estimates for as many tasks as possible were expressed as, "so many times per flight." This unit of expression has the advantage of direct relationship to demand. It was, in fact, possible to use "per flight" expressions for 149 of the 256 generic tasks, or 58 percent. The nature of the remaining 107 tasks required different units of expression. For example, there is no logical way to estimate the frequency of weather observations on a per flight basis. Therefore, a unit linked to the system facilities was used. The frequency of weather observation is thus given as so many times per "terminal hour." Similar expressions were used to link performance frequency to the physical or jurisdictional parts of the system. Finally, the calendar was used, so that the frequency of certain tasks (such as report preparation) is given as so many times per month.

A detailed tabulation of the frequencies and appropriate units for each task is given at the end of this section. (Table 3.2-3, page 3.2-16).

3.2.4 Manual Task Performance Time Estimation

Given the frequency of performance, it was also necessary to ascribe a performance time to each manual task in order to form manpower requirements estimates. Deriving manual performance times was done as follows:

1. Internal estimation, using the team approach and procedures like those employed in frequency estimation
2. External derivation, by finding correspondence with actual time measurements in air traffic control systems
3. External derivation, by finding analogies between actual tasks and AATMS tasks and using the observed time as the AATMS estimate.

Early in the project, an estimate of the manual time required to perform each AATMS task was made. Three specialists formed independent estimates, selecting each from a given time range set: (in seconds) 1-2, 2-4, 4-8, 8-15, 15-30, 30-60, 60-120, 120-240, and so on. As was done with task frequencies, procedures for checking estimates for agreement and resolving instances where agreement was lacking were established and followed. In this manner, one source of data consisting of performance time estimates for all of the 256 AATMS tasks was built up.

In the meantime, the research literature was reviewed and other data sources such as the FAA National Aviation Facilities Experimental Center (NAFEC) were queried in a search for empirical data on manual task performance times in air traffic control. Several appropriate sources were found; a discussion of each data source follows.

Davis and Wallace (1961) studied the effects of Positive Control on air traffic controllers. Controllers at three en route centers were observed for a total of 32 hours. The study method involved supplementing the tape recordings of controller/aircraft communications that are routinely made as system records by using a device called a kymograph, which drives a paper tape at a constant speed. The observer, with his kymograph, was stationed in such a way that he could see what the subject controller did, and hear what he said. Whenever the controller performed a manual activity or was involved in a communication that would not be recorded on the magnetic tape, the observer recorded it by suitably marking the kymograph paper tape. The observer marked the tape to indicate the beginning of an activity, recorded a code symbol representing the activity on the tape, and made another mark showing when the activity ended. The frequency of performance and the amount of time required to perform each activity were determined by analyzing the marked kymograph tapes.

In a later study, Davis et al. (1963) used the same data collection method to determine how the work performed by air traffic controllers is affected by differences in sector characteristics. A total of 112 hours of observation took place. Although the study was done using simulated aircraft, the data were considered sufficiently accurate for incorporation in the task time source data pool.

A third published data source was a project designed to measure the effect on controller workload produced by the introduction of NAS Stage A into the ARTCC at Jacksonville (NAFEC, 1970). The data gathering method was identical to the Davis studies. NAFEC carried out a similar NAS A effects analysis at the New York ARTCC. At the time of preparation of this report, the study had not yet been formally published, but the results were made available on an informal basis by NAFEC, and were incorporated with the other source data.

Just as the effects of introducing NAS Stage A into the en route environment were studied, so also were studies made of the introduction of ARTS into terminals. In a published study (NAFEC, 1970) the workload effects of ARTS II on controllers at the Knoxville terminal were evaluated. Again, the data collection techniques were like those used by Davis.

Two unpublished studies of the introduction of ARTS III at Boston and Houston were the source of further data, under the same kind of arrangement made to obtain the unpublished NAS Stage A en route study results. The data pool formed by aggregating all these study results contained two kinds of times: those recorded for activities, and those recorded for communications. Of the communications data, that collected in the NAFEC studies was the primary source of times, because the data collection and analysis techniques were superior to those used in the earlier works, where communications times were used as secondary sources. The manual activity times were all treated equally as sources, since all had been derived using the same observation, recording, and analysis methods.

Two other studies were found to contain task time data that could be used. As a part of their development of engineering staffing standards, the Staffing Standards Branch of the FAA Office of Management Services conducted a study of activities of personnel at Flight Service Stations. Although the final publication of the standard had not been made at the time of the study, the source data were made available to the study team for use in the task times data pool. Although kymographs were not used in the staffing standard study, the method was similar to the other task time studies in that direct observation of activity was carried out and activity categories noted, from which times per activity were derived. In a separate study of flight service station weather briefing content, Holland (1973) had also collected activity times. These were used along with the FAA data in the activity times source pool.

The pool of data thus accumulated was used in two ways. First, it was the source of manual task performance times for all generic AATMS tasks which either matched actual tasks or corresponded by analogy to actual tasks. Second, the source data were used as a check on the accuracy of the internally-generated task time estimates. The paragraphs that follow describe these procedures.

Because the AATMS system description is a generic one (i.e., not linked to specific hardware or to a specific operating concept), there was little expectation that a given AATMS tasks would correspond precisely with a given task in any actual ATC system. AATMS tasks could, however, be related to specific systems tasks by analogy. For example, in the AATMS handoff function there is a task entitled "Determine Availability of Appropriate (Communications) Channels." The title implies that to do the task manually, the person performing it must somehow find out what channels are available to the aircraft, what channels are available in the next jurisdiction of the ground system, and find in these two arrays some matching channel for communication. In the data pool there was an observed, timed task called "Coordinates Frequency Change with Radar Controller." While this task is not precisely like "Determine Availability of Appropriate Channels," it can be seen that it is analogous in the sense that a similar manual activity is implied.

Analogies like the one described were found either in single task times or in combinations of times for many of the 256 generic tasks. A few exact matches were found. In all, times from the pool of empirical data were associated in this manner to 112 of the 256 generic tasks.

The times for the remaining tasks were drawn from the pool of internal estimates produced earlier. Since the estimating team had prepared times for all AATMS tasks, and times were available for many of the same tasks from the empirical data pool, the two data sets were compared as a rough check on the validity of the internal estimates. In most cases, it was found that the estimates either agreed with observed data or were no more than one estimating interval removed from the observed times. This close match gave some confidence in the unsupported estimates which were ultimately used as manual performance times for 144 generic tasks.*

The table given at the end of this section (Table 3.2-3) includes identification of the source of each task time, that is, whether the time matched an observed time (M), was inferred by analogy (A), or was drawn from the pool of estimates (E).

It will be recalled that whenever information or instructions must be passed between man and machine, induced tasks are created. For any given automation level, the number and nature of these induced requirements for interaction between man and machine can be derived by study of the system logic and the allocation of tasks. From the point of view of the human operator, induced tasks add performance time to most manual tasks he does, since he must take time to receive information from the machine, and to communicate his action to the machine after his task is completed. These added times were characterized as "read display" (induced task for machine-to-man linkages) and "enter data" (induced task for man-to-machine linkages).

There is also a third kind of induced task, which occurs whenever one human operator receives information from or gives information to another human operator. This task was termed "coordinate". The number of "coordinate" induced tasks at a given automation level can be determined in the same way as for the other induced tasks.

To ascribe times to the induced tasks, the source data were searched in a manner similar to that described for fundamental tasks to find observations of tasks matching or analogous to "read display", "enter data," or "coordinate". Times were assigned; and, at appropriate automation levels, the induced task times were added as required by the number and kind of induced tasks present. (See Table 3.2-3, page 3.2-16.)

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*The reader will note that as system automation increases, the total human resource requirement becomes more dependent on the times of the few manual tasks remaining, and on the time required to perform induced tasks, that is, to interact with machines.

3.2.5 Computer Instruction Requirements for Automated Tasks

The manual activities of the air traffic control system have been studied extensively, with the result being a reasonably large body of empirical data from which human resource performance requirements could be estimated. However, there is at present no corresponding history for computer requirements in an automated air traffic system. Therefore, computer size requirements had to be developed by engineering estimation. The procedure was to have computer science specialists form an estimate of the number of FORTRAN statements that would be required for programming a given fundamental AATMS task and then convert the estimates into the form of number of machine language instructions. Estimates were made for all 256 AATMS tasks and used for that portion of the tasks automated at the various automation levels investigated.

Just as induced manual tasks require additional human resources, so also do induced tasks affect machines. Whenever an induced "read display" or "enter data" task exists on the human operator side at a given automation level, there is also a "create display" or "receive data" task on the machine side. The effect on machine requirements is that an instruction capability must be provided to create each display, and in the same way an instruction capability must be provided to receive each entry. For purposes of the study, it was estimated that creating a display would require 1500 machine instructions and receiving an entry would require 500. These counts were added at man-machine interface points in the computation of resource requirements for certain of the automation levels investigated in the study.

Machine instruction count requirements estimates are included in the consolidated data tables given at the end of this section.

3.2.6 Method of Computation

The computation method is illustrated below in stepwise fashion, using algebraic notation. Important numerical results are presented in Section 3.3. (Note that Step 7 is performed once, while Step 1 through 6 and Step 8 are performed for each automation level.)

STEP 1 - Compute total man time for demand stimulated tasks, in man-hours per hour (T_{MD}):

$$T_{MD} = \frac{K\ I_{AC} \sum f_{Di}\ M_i}{D_A}$$

where K = number of hours per second

I_{AC} = instantaneous count of airborne aircraft

f_{Di} = frequency of performance of task i, times per flight

M_i = median performance time of manual task i, including induced tasks, in seconds

D_A = average flight duration, in hours

STEP 2 - Compute total man time for terminal time stimulated tasks, in man-hours per hour (T_{MT}):

$$T_{MT} = K\ N_T \sum f_{Ti}\ M_i$$

where N_T = number of terminals

f_{Ti} = frequency of performance of task i, times per terminal hour

STEP 3 - Compute total man time for facility time stimulated tasks, in man hours per hour (T_{MF}):

$$T_{MF} = K\ N_F \sum f_{Fi}\ M_i$$

where N_F = number of facilities

f_{Ti} = frequency of performance of task i, times per facility-hour

STEP 4 - Compute total man time for jurisdiction time stimulated tasks, in man hours per hour (T_{MJ}):

$$T_{MJ} = K\ N_J \sum f_{Ji}\ M_i$$

where N_J = number of jurisdictions

f_{Ji} = frequency of performance of task i, times per jurisdiction-hour

STEP 5 - Compute total man time for per month time stimulated tasks, in man hours per hour (T_{MM}):

$$T_{MM} = K\ K_1\ K_2 \sum f_{Mi}\ M_i$$

where K_1 = number of months per day

K_2 = number of days per hour

f_{Mi} = frequency of performance of task i, times per month

STEP 6 - Compute number of total operating personnel, uncalibrated (P_{OU}):

$$P_{OU} = F(T_{MD} + T_{MT} + T_{MF} + T_{MJ} + T_{MM})$$

where F = shift/leave/traing factor (a multiplier which converts busy shift manning to full time operation manning)

STEP 7 - Compute calibration factor (C). This is done by performing STEPS 1 through 6 using 1972, rather than 1995 values for demand level and number of terminals, facilities and jurisdictions. For purposes of computation, the 1972 system is assumed to be wholly manual. Before this is done, intermediate steps are required to account for the fact that essentially all flights in 1995 will be receiving ATM services, in contrast with a smaller fraction of total flights in 1972.

STEP 7.1 - Perform STEP 1 using 1972 data. Obtain T_{MD}.

STEP 7.2 - Compute adjustment factor (A) for I_{AC} which accounts for the difference in the fraction of controlled flights in 1972:

$$A = \frac{\text{number of IFR flights (1972)}}{\text{total number of flights (1972)}}$$

STEP 7.3 - Adjust value obtained in STEP 7.1 to obtain T_{MD} (adjusted). Assume that VFR flights in 1972 receive 10 percent of the demand-stimulated control effort that IFR flights receive:

$$T_{MD}\ \text{(adjusted)} = I_{AC}[AT_{MD} + (1\text{-}A).1\ T_{MD}]$$

STEP 7.4 - Perform STEPS 2 through 5 using 1972 data. Perform STEP 6 using results of STEPS 2 through 5 and result of STEP 7.3. Obtain P_{OU} (1972).

STEP 7.5 - Compute calibration factor (C):

$$C = \frac{\text{actual personnel (1972)}}{P_{OU}\ (1972)}$$

STEP 8 - Compute calibrated operating position personnel (P_0) for AATMS:

$$P_0 = C\ P_{OU}$$

The computation method for data processing requirements is illustrated below in a stepwise fashion which is very similar to the method used for manpower requirements in the above. Algebraic notation is also used, and important numerical results are presented in Table 3.3-1, along with the manpower requirements.

STEP 1 - Compute instruction execution rate for demand stimulated tasks (R_D) in thousands of instructions per second (KIPS):

$$R_D = \frac{K\ I_{AC} \sum f_{Di}\ I_i}{D_A}$$

where I_i = number of instructions for automated task i, including induced task instructions, in thousands of instructions

STEP 2 - Compute instruction execution rate for terminal time stimulated tasks, in KIPS (R_T):

$$R_T = K\ N_T \sum f_{Ti}\ I_i$$

STEP 3 - Compute instruction execution rate for facility time stimulated tasks, in KIPS (R_F):

$$R_F = K\ N_F \sum f_{Fi}\ I_i$$

STEP 4 - Compute instruction execution rate for jurisdiction time stimulated tasks, in KIPS (R_J):

$$R_J = K\, N_J \sum f_{Ji}\, I_i$$

STEP 5 - Compute instruction execution rate for per month time stimulated task, in KIPS (R_M):

$$R_M = K\, K_1\, K_2 \sum f_{Mi}\, I_i$$

STEP 6 - Compute total calibrated data processing requirements (R) in thousands of instructions per second (KIPS):

$$R = C(1 + C_1 + C_2 + C_3)\ (R_D + R_T + R_F + R_J + R_M)$$

where C_1 = adjustment factor for data management systems programs

C_2 = adjustment factor for executive programs

C_3 = adjustment factor for support programs

Table 3.2-1 shows the values of the constants used in the computations along with their sources.

3.2.7 Consolidated Data Tabulations

For the reader's convenience, the frequencies, task times, and instruction counts for each fundamental and induced task have been consolidated in a single table. It will be noted that manual task times are given as a range rather than as a single figure. For task times derived from empirical data, this range is from the first to third quartile of the distribution of timed observations. For estimated task times the range is the low and high points of the estimating interval.

A range of task times was used so as to take into account the variability of human performance and to indicate the nature of the distribution. The midpoint of the distribution (the median) is also given. The net effect recognizes that there is for a given manual task a short performance time that very few operators go below, and that on the other hand

CONSTANT	VALUE	SOURCE
K	2.77×10^{-4}	--
K_1	$\frac{1}{30}$	--
K_2	$\frac{1}{24}$	--
I_{AC} (1972)	15,000	TSC
I_{AC} (1995)	33,750	TSC
D_A	2	TRW Estimate
N_T (1972)	346	TSC
N_T (1995)	719	TSC
N_F (1972)	367	TSC
N_F (1995)	515	TSC
N_J (1972)	1542	*
N_J (1995)	2623	**
F	3.5	SRI
No. of IFR Flights	7M	ATCAC (1968)
Total Flights	24M	ATCAC (1968)
C	.598	TRW Calculation
C_1	0.1	ATCAC
C_2	1.0	ATCAC
C_3	0.02	ATCAC

*N_J (1972) - Assumed four jurisdictions per primary terminal (41 primaries-TSC) and two per secondary terminal (305 secondaries-TSC) and 768 en route jurisdictions.

**N_J (1995) - Assumed five jurisdictions per primary terminal (133 primaries-TSC) three per secondary terminal (586 secondaries-TSC) and 200 en route jurisdictions.

TABLE 3.2-1 CONSTANTS USED IN COMPUTATIONS some operators in some circumstances need a long time to accomplish a task. When the DELTA model is run, it will select one of two distributions formed from the time ranges. The first distribution extends from the median to the first quartile, and the second from the median to the third quartile. The model will then sample from the chosen distribution to obtain the manual task time required.

Table 3.2-2 below gives the manual times derived for each type of induced task for use in the resource requirements computations.

	FIRST QUARTILE	MEDIAN	THIRD QUARTILE
READ DISPLAY	4.67	8.13	10.33
ENTER DATA	4.80	5.62	7.15
COORDINATE	6.67	10.17	18.67

TABLE 3.2-2 INDUCED TASK TIMES, (SECONDS)

Table 3.2-3, beginning on the next page, is a consolidation of task performance frequency requirements, task time ranges in seconds, task time data sources (M = match, A = analogy, E = estimate), and instruction requirements in units of 1000 for each of the 256 fundamental tasks. These are the values used in the computations described previously and discussed in the next section.

TABLE 3.2-3 TASK DATA

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
1.1.1	Accept Data Link Request	9.32	11.50	14.04	A	2	1				
1.1.2	Accept Telephone Request	9.32	11.50	14.04	A	10	1				
1.1.3	Enter Request into System	6.20	8.53	18.39	A	1	2				
1.2.1	Select Preformatted Reply	8.13	9.13	11.17	A	1	1				
1.2.2	Retrieve Information Requested	6.06	8.75	17.0	A	6.7	1				
1.3.1	Compile Non-Preformatted Response	5.74	15.70	21.20	A	6.7	2				
1.3.2	Display Information Requested	4.96	12.08	23.37	A	6.7	1				
1.3.3	Transmit Requested Information Via Telephone	6.52	9.40	12.04	A	10	1				
2.1.1	Select Terminal or Jurisdiction and Time Period to be Considered	2.0	3.0	4.0	E	30		1			
2.1.2	Determine Effects of Weather on Capacity	7.15	9.70	10.50	A	20		1			
2.1.3	Determine Effects of Airspace Restrictions on Capacity	6.50	11.0	16.50	A	15		1			
2.1.4	Determine Effects of Ground Equipment Capability and Status on Capacity	6.50	11.0	16.50	A	15		1			

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
2.1.5	Determine Effects of Flight Hazards on Capacity	6.50	11.0	16.50	A	15		1			
2.1.6	Determine Total Effect on Capacity	30.0	45.0	60.0	E	40		1			
2.2.1	Determine Jurisdiction/Terminal Demand due to Commercial Schedule	480.0	720.0	960.0	E	25		1			
2.2.2	Process and Store Reservations	15.0	22.50	30.0	E	10		1			
2.2.3	Determine Jurisdiction/Terminal Demand due to Reservations	15.0	22.50	30.0	E	20		1			
2.2.4	Determine Total Jurisdiction/Terminal Demand	960.0	1440.0	1920.0	E	20		1			
2.3.1	Compare Capacity with Demand	30.0	45.0	60.0	E	30		1			
2.3.2	Determine Origins of Demand in Capacity Overload Situations	480.0	720.0	960.0	E	75		.04			
2.3.3	Determine What Number of Aircraft are to be Delayed for What Period of Time	240.0	360.0	480.0	E	10		.04			
2.3.4	Determine Where Delays are to be Absorbed	240.0	360.0	480.0	E	75		.04			
2.3.5	Formulate Flow Control Directives	240.0	360.0	480.0	E	50		.04			

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
4.1.1	Determine Points for Which ETOV's are to be Computed	5.10	9.10	34.15	M	40	1.37				
4.1.2	Compute ETOV's/ETA	34.20	59.40	99.90	M	3	1.37				
4.2.1	Compare Flight Plan with Aircraft Capability and Status	8.40	10.20	11.30	A	10	1.37				
4.2.2	Compare Flight Plan with Operational and Environmental Conditions	6.70	8.0	26.80	A	25	1.37				
4.2.3	Probe for Conflicts Among Flight Plans	15.0	22.5	30.0	E	75	1.37				
4.2.4	Compare Flight Plan with Flow Control Directives and Guidelines	8.0	11.50	15.0	E	25	1.37				
4.2.5	Compare Flight Plan with Rules and Procedures	8.0	11.50	15.0	E	3	1.37				
4.2.6	Compare Flight Plan with Flight Progress	10.50	16.50	22.80	A	.5	.01				
4.2.7	Compare Flight Plan with User Class/Pilot Qualifications	4.0	6.0	8.0	E	1	1.37				
4.2.8	Compile List of Discrepancies	8.0	11.50	15.0	E	1	1.37				
4.2.9	Determine Flight Plan Priority	7.70	12.60	25.70	E	5	1.37				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
4.2.10	Determine Acceptability of Flight Plan	4.0	6.0	8.0	E	15	1.37				
4.2.11	Identify Flight Plans that must be Modified as a Result of this Approval	4.30	6.30	12.80	A	10	1.37				
4.2.12	Inform Pilot of Flight Plan Approval	8.0	11.50	15.0	E	2	1.37				
4.2.13	Determine Special Services Required	4.0	6.0	8.0	E	10	1.37				
4.3.1	Determine Changes Required to Make Flight Plan Acceptable	45.15	59.27	106.75	A	150	.137				
4.3.2	Determine Responsibility to Modify the Flight Plan	4.0	6.0	8.0	E	5	.137				
4.3.3	Inform Pilot of Unacceptable Flight Plan	15.0	22.50	30.0	E	2	.07				
4.3.4	Compile Modified Flight Plan	120.0	180.0	240.0	E	40	.067				
4.4.1	Receive and Enter Pilot's Response	1.0	2.58	4.30	A	4	.07				
4.4.2	Cancel Flight Plan	13.30	13.30	13.30	M	3	.005				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
4.4.3	Designate Responsible Jurisdictions	8.0	11.50	15.0	E	5	1.23				
4.4.4	Designate Communication Links between ATM and Aircraft	5.90	8.30	13.70	A	10	1.23				
5.1.1	Determine if Identification Code Assignment is Required	5.97	8.60	12.23	E	20	1.2				
5.1.2	Compare Flight Progress with Clearance Limit and EFC Time	4.30	8.60	20.40	A	5	20				
5.1.3	Determine Pilot Intentions Following Missed Approach	13.59	13.93	14.41	A	20	0.01				
5.2.1	Assign Identification Code	5.60	6.10	7.70	A	3	1				
5.2.2	Determine Clearance Tolerances	7.80	10.50	21.30	A	10	5				
5.2.3	Determine Clearance Limit	5.40	7.30	13.70	A	10	5				
5.2.4	Determine Required Clearance Instructions	15.0	22.50	30.0	E	15	8				
5.3.1	Compile Clearance to be Issued	15.0	22.50	30.0	E	10	8				
5.3.2	Transmit Clearance Message	10.20	15.25	20.60	A	8	8				
5.3.3	Receive Acknowledgement of Clearance	1.50	2.81	3.34	A	5	8				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
6.1.1	Receive/Enter Correlated Position and Identification	4.81	6.73	10.92	A	0.5	216				
6.1.2	Receive/Enter Position	8.45	14.76	21.35	A	0.3	24				
6.1.3	Correlate Position and Identification	3.55	3.99	6.31	A	2	24				
6.1.4	Request Aircraft Identity	2.29	3.19	3.38	M	1	2				
6.1.5	Assign Arbitrary Aircraft Identification	2.58	3.77	4.05	A	5	0.01				
6.2.1	Initiate Aircraft Actual Time-Position Profile	4.65	7.35	16.67	A	5	1				
6.2.2	Update Aircraft Actual Time-Position Profile	6.67	11.33	21.0	A	0.3	240				
6.3.1	Derive Rate of Change of Position	7.11	10.0	17.62	A	0.1	240				
6.3.2	Compute Short-Range Extrapolations	3.77	5.28	16.84	A	0.5	240				
6.3.3	Compute Long-Range Extrapolations	3.73	4.05	7.31	A	2.5	24				
6.4.1	Determine Aircraft Readiness	2.25	2.61	3.0	A	5	10				
6.4.2	Detect Aircraft Emergencies	2.24	2.58	2.90	A	200	0.001				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
6.4.3	Determine Nature of Emergency	2.24	2.58	2.90	A	500	0.001				
6.4.4	Receive and Enter Aircraft Status Changes	2.24	2.58	2.90	A	5	.1				
6.4.5	Update Aircraft Status	3.42	3.77	3.78	A	50	.1				
6.4.6	Receive and Enter Reports of Aircraft Capability Changes	2.24	2.58	2.90	A	2.5	.1				
6.4.7	Update Aircraft Capability	3.42	3.77	3.78	A	5	.2				
7.1.1	Specify Time Period to be Checked	2.0	3.0	4.0	E	1				.5	
7.1.2	Construct Pairs of Flight Plans to be Compared	30.0	45.0	60.0	E	30				4	
7.1.3	Select Relevant Portion of each Pair Member's Intended Time-Position Profile	15.0	22.50	30.0	E	10	8				
7.1.4	Compare Intended Time-Position Profiles for Intersections in x, y, h & t	15.0	22.50	30.0	E	50	8				
7.1.5	Propose Revised Flight Plan to Correct Long-Term Conflicts Among Flight Plans	30.0	45.0	60.0	E	150	.1				
7.2.1	Determine Aircraft's Intended Present Position	4.83	9.0	18.0	A	0.2	24				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
7.2.2	Compute Deviations between Aircraft's Intended and Actual Present Position	4.0	6.0	8.0	E	0.5	24				
7.3.1	Determine Aircraft's Intended Future Positions	4.69	7.31	17.62	A	5	24				
7.3.2	Compute Short-Range Deviations (in x, y, h) from Flight Plan	8.0	11.50	15.0	E	10	24				
7.3.3	Compute Long-Range Deviations (in t) from Flight Plan	8.0	11.50	15.0	E	25	24				
7.4.1	Compare Deviations with Tolerances	8.0	11.50	15.0	E	0.2	24				
7.4.2	Inform Pilot of Out-of-Tolerance Deviations	4.0	6.0	8.0	E	2	1				
7.4.3	Receive Pilot's Response Concerning Resolution of Out-of-Tolerance Present and/or Long-Range Deviations	2.24	2.81	3.27	A	10	1				
7.4.4	Develop Flight Plan Revisions to Correct Out-of-Tolerance Deviations	10.50	15.62	19.22	A	20	.1				
8.1.1	Select Airspace Volume and Time Frame	1.0	1.50	2.0	E	5				.125	
8.1.2	Predict Aircraft Paths	7.25	10.0	11.0	A	15				24	

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
8.1.3	Identify Path Prediction Profiles for the Airspace and Time Frame	6.95	8.75	13.50	A	10				24	
8.1.4	Pair Path Prediction Profiles for Conflict Comparison	30.0	45.0	60.0	E	2				24	
8.1.5	Determine Conflict Probability for each Pair	7.11	11.0	13.67	A	20				24	
8.1.6	Determine Conflict Imminence for each Pair	7.11	11.0	13.67	A	25				24	
8.1.7	Determine Action Required	2.0	3.0	4.0	E	50				24	
8.1.8	Monitor for Unexpected Deviations	4.67	7.28	13.22	A	2				120	
8.1.9	Determine if Action Classification has been Updated	3.69	4.05	9.13	A	.5				120	
8.2.1	Hypothesize Performance Changes	2.0	3.0	4.0	E	20	1				
8.2.2	Analyze Performance Change for Conflicts	2.0	4.33	8.29	A	150	1				
8.2.3	Format Performance Change Message	2.0	3.0	4.0	E	30	1				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
8.2.4	Transmit Performance Change Message to Pilot	2.80	3.34	3.97	A	2	1				
8.2.5	Determine Performance Change Status	3.70	4.50	8.26	A	1	1				
9.1.1	Determine Identity and ETA of Arriving Aircraft	7.35	14.91	23.75	A	10		6			
9.1.2	Determine Identity and ETD of Departing Aircraft	7.35	14.91	23.75	A	10		6			
9.1.3	List Arriving and Departing Aircraft and ETA/ETD	60.0	90.0	120.0	E	5		6			
9.2.1	Determine Airport Capacity	5.82	11.17	18.50	A	150		1			
9.2.2	Analyze Predicted Schedule for Alternating Periods of Excess Demand and Slack	240.0	360.0	480.0	E	100		6			
9.3.1	Analyze Temporal Distribution of Arrivals and Departures	30.0	45.0	60.0	E	15		6			
9.3.2	Allocate Blocks of Time for Arrivals and Departures	15.0	22.50	30.0	E	10		6			
9.4.1	Compare Predicted Arrival and Departure Times with Runway Schedule	30.0	45.0	60.0	E	30		6			

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
9.4.2	Change ETA's and ETD's to be Compatible with Runway Schedule	30.0	45.0	60.0	E	50		1			
9.5.1	Select Sequence/Schedule Change to be Implemented	2.0	3.0	4.0	E	50	0.1				
9.5.2	Hypothesize Performance Change Required to Implement Desired Sequence/Schedule	2.0	3.0	4.0	E	100	0.2				
9.5.3	Check Proposed Performance Change for Predicted Conflict	2.0	4.33	8.29	E	35	0.2				
9.5.4	Assess Control Implications of Performance Required to Implement Sequence/Schedule Change	8.0	11.50	15.0	E	30	0.1				
9.5.5	Submit Performance Changes within Existing Flight Plan to Clearance Function	6.95	11.0	20.33	A	5	0.09				
9.5.6	Propose Revised Flight Plan to Implement Sequence/Schedule Change	10.50	15.62	19.22	A	300	0.01				
9.5.7	Submit Revised Flight Plan for Approval	13.50	17.90	26.70	A	30	0.01				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
11.1.1	Determine Desired Position	2.0	3.0	4.0	E	3	10				
11.1.2	Determine Requirements for Further Vectoring	2.0	3.0	4.0	E	3	10				
11.2.1	Measure Course and Distance	4.0	6.0	8.0	E	2	6.67				
11.2.2	Compute Time Interval	2.0	3.0	4.0	E	3	6.67				
11.2.3	Compute Ground Speed	4.0	6.0	8.0	E	2	6.67				
11.2.4	Compute Altitude Difference	2.0	3.0	4.0	E	3	3.33				
11.3.1	Compute Airspeed	4.0	6.0	8.0	E	2	6.67				
11.3.2	Compute Vertical Speed	1.0	1.50	2.0	E	2	3.33				
11.3.3	Compute Heading	4.0	6.0	8.0	E	2	6.67				
11.4.1	Compute Heading Command	1.0	1.50	2.0	E	4	3.33				
11.4.2	Compute Airspeed Command	1.0	1.50	2.0	E	4	3.33				
11.4.3	Compute Vertical Speed Command	2.0	3.0	4.0	E	4	3.33				
11.5.1	Compile Vectoring Instructions	2.0	3.0	4.0	E	4	10				
11.5.2	Transmit Vectoring Instructions to Pilot	2.66	3.12	3.85	A	2	10				
11.5.3	Assess Aircraft Response	1.96	2.63	2.92	A	4	10				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
12.1.1	Receive Pilot's Request for Information	7.67	12.78	16.33	M	3	2				
12.1.2	Acknowledge Pilot Request for Information	1.84	2.50	3.50	A	5	2				
12.1.3	Select Applicable Preformatted Messages	8.13	9.13	11.17	A	2	1.8				
12.1.4	Retrieve Information Requested	6.06	8.75	17.0	A	2	.2				
12.1.5	Compile Special Response to Request	5.74	15.70	21.20	A	2	.2				
12.1.6	Transmit Preformatted Advisory to Pilot	5.41	8.50	11.24	A	2	1.8				
12.1.7	Transmit Special Response to Pilot	5.41	8.50	11.24	A	25	.2				
12.2.1	Evaluate Advisory for Data Content	4.0	6.0	8.0	E	5	1				
12.2.2	Determine Aircraft to Which Information Applies	6.97	10.79	16.84	A	2	1				
12.2.3	Determine Method of Flight Advisory Distribution	2.0	3.0	4.0	E	3	1				
12.2.4	Determine Distribution Position for each Identified Aircraft	4.67	7.35	15.67	A	2	1				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
12.2.5	Determine Time of Simultaneous Distribution	4.67	7.35	15.67	A	1	1				
12.2.6	Prepare Transmission Schedule	60.0	90.0	120.0	E	2	1				
12.2.7	Correlate Present Position with Distribution Position	4.30	8.60	12.23	A	3	1				
12.3.1	Determine Endangered Aircraft	6.97	10.79	16.84	A	5	.1				
12.3.2	Compile Alert Message	5.74	15.70	21.20	A	5	.002				
12.3.3	Transmit Warning Advisory to Pilot	3.0	4.32	5.30	A	10	.002				
12.3.4	Receive Pilot's Response	2.0	3.10	5.0	A	5	.002				
13.1.1	Correlate Aircraft Position with Jurisdictional Boundaries	4.30	8.60	20.40	A	2	7				
13.1.2	Determine Functions to be Transferred	2.0	3.0	4.0	E	2	7				
13.1.3	Correlate Aircraft Position with Airspace Structure Boundaries	4.30	8.60	20.40	A	2	7				
13.1.4	Receive Pilot's Request for Transfer of Responsibility	6.33	7.25	11.0	A	5	.02				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
13.1.5	Determine Acceptability to Jurisdictions Involved	6.46	7.86	13.92	A	1	14				
13.2.1	Determine if Communication Channel Change is Required	2.0	3.0	4.0	E	1	7				
13.2.2	Determine Availability of Appropriate Channels	5.35	6.67	11.0	A	.2	7				
13.2.3	Designate Channel to be Used	8.21	10.09	12.34	A	.4	7				
13.3.1	Transfer Responsibility for Control	7.0	9.43	19.25	A	2	14				
13.3.2	Compile Required Information for Clearance Function	4.0	6.0	8.0	E	1	7				
14.1.1	Detect Information Requiring Operational Report	2.24	2.58	2.90	A	50			.5		
14.1.2	Retrieve Applicable Operational Report Format	8.13	9.13	11.17	A	5			.5		
14.1.3	Enter Detected Information	480.0	720.0	960.0	E	5			.5		
14.1.4	Determine Necessity for Additional Information	8.0	11.50	23.0	E	10			.5		
14.1.5	Retrieve Additional Information	11.15	24.20	32.44	A	5			.5		

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
14.2.1	Classify Data Elements	2.0	3.0	4.0	E	.1	283.71		.5	24	
14.2.2	Assign Appropriate Identifiers	2.0	3.0	4.0	E	.1	283.71		.5	24	
14.2.3	Determine if Data Transform/Reformat is Required	1.0	1.50	2.0	E	.05	283.71		.5	24	
14.2.4	Transform/Reformat Data Element	30.0	45.0	60.0	E	.05	283.71		.5	24	
14.2.5	Enter Data Element into Storage	4.0	6.0	8.0	E	.01	283.71		.5	24	
14.3.1	Determine if Report is Available	2.0	3.0	4.0	E	100			.125		
14.3.2	Retrieve Format	8.13	9.13	11.17	A	100			.125		
14.3.3	Develop Format	120.0	180.0	240.0	E	100			.125		
14.3.4	Retrieve Required Data	120.0	180.0	240.0	E	100			.125		
14.3.5	Analyze Data	480.0	720.0	960.0	E	100			.125		
14.3.6	Compile Report	960.0	1440.0	1920.0	E	50			.125		
15.1.1	Compile/Update Description of Special Service Required	13.67	20.33	25.67	A	50	0.01				
15.1.2	Monitor Progress of Service	4.33	7.32	12.18	A	2	0.05				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
15.2.1	Determine Requirement for Special Flight Plan Priority	7.70	12.60	25.70	A	1	0.01				
15.2.2	Establish Area of Restriction	5.67	7.15	12.18	A	10	0.01				
15.2.3	Determine Guidance Service Required	4.33	5.91	42.0	A	5	0.01				
15.2.4	Determine Special Separation Minima	10.50	15.67	21.33	A	2	0.01				
15.2.5	Determine Advisories Required	4.88	6.87	8.83	A	4	0.01				
15.2.6	Determine Necessity for Issuance of NOTAM(s)	5.67	7.58	8.44	A	20	0.01				
16.1.1	Determine Adequacy of Emergency Description	2.0	3.0	4.0	E	4	0.001				
16.1.2	Request Additional Required Information	11.15	24.20	32.44	A	2	0.0005				
16.1.3	Compile Description of Emergency	8.0	11.50	15.0	E	6	0.001				
16.2.1	Determine Required Ground Support Assistance	5.67	8.0	11.02	A	2	0.001				
16.2.2	Determine Assistance Required from Other Aircraft	4.0	6.0	8.0	E	2	0.001				

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
16.2.3	Determine Aircraft to Provide Assistance	4.67	6.97	9.45	A	3	0.0005				
16.2.4	Issue Instructions to Aircraft Providing Assistance	8.0	11.50	15.0	E	10	0.0005				
16.2.5	Determine Required Technical Instructions to Aircraft in Emergency Situation	4.0	6.0	8.0	E	100	0.0001				
16.2.6	Determine Emergency Flight Plan	10.50	15.62	19.22	A	50	0.001				
16.2.7	Determine Requirement for Use of Emergency Communication Link	5.67	6.75	11.33	A	2	0.001				
16.2.8	Inform Pilot of Change to Emergency Frequency Link	8.78	10.18	14.83	M	5	0.0006				
16.2.9	Determine Required Guidance Assistance	4.33	5.91	42.0	A	100	0.001				
16.2.10	Issue Instructions to Ground Support Facility	7.0	9.12	14.71	A	20	0.0005				
17.1.1	Determine if Weather Observation Report is Required	8.0	11.50	15.0	E	10		1			
17.1.2	Determine if Supplemental Data is Required	8.0	11.50	15.0	E	10		1			

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
17.1.3	Request PIREP	15.0	22.50	30.0	E	2		.125			
17.1.4	Receive Supplemental Data	30.0	45.0	60.0	E	5		.5			
17.1.5	Make Weather Observation Report	480.0	480.0	480.0	E	10		1			
17.1.6	Transmit Weather Observation Report	8.0	11.50	15.0	E	2		1			
17.1.7	Receive and Enter Weather Information	60.0	90.0	120.0	E	1		40			
17.1.8	Store Weather Information	30.0	45.0	60.0	E	2		1			
17.2.1	Determine Data Base Item Affected	15.0	22.0	30.0	E	1			.125		
17.2.2	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100			.125		
17.2.3	Determine Required Change to the Data Base Item	4.0	6.0	8.0	E	5			.125		
17.2.4	Purge Affected Data Base Item	2.0	3.0	4.0	E	100			.125		
17.2.5	Format New Data Base Item	60.0	90.0	120.0	E	5			.125		
17.2.6	Store Data Base Item	30.0	45.0	60.0	E	100			.125		
17.3.1	Determine Data Base Item Affected	15.0	22.0	30.0	E	1			.0125		

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
17.3.2	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.3.3	Determine Required Change to the Data Base Item	4.0	6.0	8.0	E	5			.0125		
17.3.4	Purge Affected Data Base Item	2.0	3.0	4.0	E	100			.0125		
17.3.5	Format New Data Base Item	60.0	90.0	120.0	E	5			.0125		
17.3.6	Store Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.4.1	Determine Data Base Item Affected	15.0	22.0	30.0	E	1			.0125		
17.4.2	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.4.3	Determine Required Change to the Data Base Item	4.0	6.0	8.0	E	5			.0125		
17.4.4	Purge Affected Data Base Item	2.0	3.0	4.0	E	100			.0125		
17.4.5	Format New Data Base Item	60.0	90.0	120.0	E	5			.0125		
17.4.6	Store Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.5.1	Determine Data Base Item Affected	15.0	22.0	30.0	E	1			.0125		
17.5.2	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100			.0125		

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
17.5.3	Determine Required Change to the Data Base Item	4.0	6.0	8.0	E	5			.0125		
17.5.4	Purge Affected Data Base Item	2.0	3.0	4.0	E	100			.0125		
17.5.5	Format New Data Base Item	60.0	90.0	120.0	E	5			.0125		
17.5.6	Store Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.6.1	Determine Data Base Item Affected	15.0	22.0	30.0	E	1			.0125		
17.6.2	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.6.3	Determine Required Change to the Data Base Item	4.0	6.0	8.0	E	5			.0125		
17.6.4	Purge Affected Data Base Item	2.0	3.0	4.0	E	100			.0125		
17.6.5	Format New Data Base Item	60.0	90.0	120.0	E	5			.0125		
17.6.6	Store Data Base Item	30.0	45.0	60.0	E	100			.0125		
17.7.1	Monitor COMM and NAV Systems for Status Change	4.67	7.28	13.22	A	100			.125		
17.7.2	Activate Standby Equipment	30.0	45.0	60.0	E	100			.125		
17.7.3	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100			.125		

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
17.7.4	Format New Data Base Item	60.0	90.0	120.0	E	100			.125		
17.7.5	Store Data Base Item	30.0	45.0	60.0	E	100			.125		
17.8.1	Monitor Ground Facilities for Status Change	4.67	7.28	13.22	A	5		4			
17.8.2	Activate Standby Equipment	30.0	45.0	60.0	E	100		.0125			
17.8.3	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100		.0125			
17.8.4	Format New Data Base Item	60.0	90.0	120.0	E	100		.0125			
17.8.5	Store Data Base Item	30.0	45.0	60.0	E	100		.0125			
17.9.1	Receive and Index User Class Information	8.0	11.50	15.0	E	5					10
17.9.2	Retrieve Affected Data Base Item	30.0	45.0	60.0	E	100					10
17.9.3	Determine Change Required	4.0	6.0	8.0	E	20					10
17.9.4	Purge Affected User Class Data Base Item	60.0	90.0	120.0	E	100					10
17.9.5	Format User Class Data Base Item	60.0	90.0	120.0	E	5					10
17.9.6	Store User Class Data Base Item	30.0	45.0	60.0	E	25					10

TABLE 3.2-3 TASK DATA (cont'd)

TASK NO.	TASK TITLE	TASK TIME				NO. OF INSTRS. X 1000	TASK FREQUENCY				
		Q_1	$\hat{X}$	Q_3	SOURCE		PER FLT.	PER TERM. HR.	PER FAC. HR.	PER JURIS. HR.	PER MONTH
17.10.1	Maintain Tallies of Active Flight Plans	2.0	3.0	4.0	E	1	1				
17.10.2	Compile ETD's, ETOV's, and ETA's	60.0	90.0	120.0	E	3	1				
17.10.3	Store Traffic Data	30.0	45.0	60.0	E	1	1				
17.11.1	Determine Requirement for Preformatted Data Modules	15.0	22.50	30.0	E	100			1.3333		
17.11.2	Compile Preformatted Data Modules	120.0	180.0	240.0	E	100			1.333		

3.3 INCREMENTAL AUTOMATION AND RESOURCE REQUIREMENTS

The first quantitative analysis of AATMS resource requirements was to generate total manpower and machine resource estimates for each of the theoretical increments of automation derived earlier in the study and discussed in Volume III of this report. The purpose of this initial calculation was, it will be recalled, to find a general approximation of the automation level at which estimated resource requirements fell within the previously established limits for manpower and machines.

The man and machine resource requirements for the five theoretical automation increments were computed using the data and procedures discussed in the previous section. The results are given below in Table 3.3-1.

AUTOMATION LEVEL	MANPOWER REQUIREMENTS (Number of People)			DATA PROCESSING REQUIREMENTS (KIPS)		
	TOTAL	GENERIC	INDUCED	TOTAL	GENERIC	INDUCED
I	413510**	*	*	21589	*	*
II	134377	*	*	25376	19755	5621
III	22279	8427	13852	23469	22514	955
IV	10370	4338	6032	24375	23896	479
V	0	0	0	25502	25502	0

*Not computed separately

**Inflated by 150,000 men required to perform Subfunction 14.2 (Systems Record)

TABLE 3.3-1 MAN/MACHINE RESOURCE REQUIREMENTS BY AUTOMATION LEVEL

The tabulation includes total units of manpower required, (a manpower unit is total man-hours per eight hour shift divided by eight) and total data processing volume required (a KIP is one thousand instructions per second). Where appropriate, subtotals were made in which fundamental generic tasks are discriminated from induced tasks. It will be noted from the table that as automation increases in the theoretical levels compared, the system manpower requirement is correspondingly reduced. For example, a theoretical automation level of IV reduces the manpower required by half, as compared to the next lower level, level III. In general, this decrease in human resource requirement associated with higher system automation levels conformed to expectations. However, on the data processing side, the estimates do not show a corresponding monotonic increase in data processing requirements. As can be seen in Table 3.3-1, there is a sharp increase in data processing requirements from level I to level II, a decrease from II to III, a small increase from III to IV, and another small increase from IV to V. This result, it appears, stems from the reduction of induced tasks. As more and more fundamental generic tasks are allocated to machines, there are fewer and fewer requirements for interaction between man and machines. Inspection of the "induced task" column in the table will illustrate the point. The reduction in induced task data processing requirements tends to offset the additional data processing requirement to perform fundamental tasks as the automation level increases.

The first approximation of resource requiements indicated that the desired level of automation lay somewhere between levels III and IV. The next step was to study that area of automation, to derive a final recommended level. That activity is discussed in the section that follows.

3.4 RECOMMENDED AUTOMATION LEVEL

The additional study of the automation level took into account two factors not incorporated in the Automation Index method for ranking tasks. The first factor stemmed from a limitation in the construction of the measuring instrument. While good confidence could be placed in the ranking position given to most generic tasks, statistical uncertainties of one kind or another were associated with some task indices. The second factor derived from the nature of the measurement itself. Insofar as allocation to man or machine depends primarily on the performance capabilities criteria used to rank tasks, the Automation Index was extremely useful as a systematic approach to making engineering judgements. But, once an approximation of the appropriate level of automation had been reached, the task allocations were examined in the light of additional judgemental criteria. For example, although the rating data provided a clear indication as to the relative automatability of a <u>single</u> task considered in isolation, no similarly clear attribution could necessarily be associated with the <u>chains</u> of tasks which appear in most complex systems. These chains, or clusters, of tasks are roughly analogous to various series and series/parallel electrical networks. The effect of the logical network linkage among the tasks in a cluster is such that when one task in a cluster is performed, all are performed. The task clusters present in AATMS had to be taken into account in order to recognize the need for continuity of performance means in chains of performance where time is a factor, and in order to keep the incidence of reduced tasks to a practical value.

In addition to accounting for cluster effects, rules were formulated and applied to embrace the nature and similarity of tasks according to parameters beyond those used in task performance capability description, to identify unusual task performance frequency requirements, and to take unusual data system programming complexity into account. These rules were used as tests in each case where a question existed about a task allocation. The net effect of the additional study was that a final recommended automation level for the system was derived -- a complete allocation of the 256 applicable generic tasks either to man or machine, and a complete catalog of the nature and number of the induced tasks associated with the final allocation.

The paragraphs that follow detail the procedures that were carried out to produce the system automation level recommended for AATMS.

3.4.1 Rules and Application of Rules

Forty-eight of the 256 generic tasks had some degree of statistical uncertainty associated with their automation indices. (The statistical aspects of the automation index method are described in Volume III of this report.) While all task allocations were reviewed in the final study of the automation level, the primary focus of the work was in the questionable tasks. Thus the major portion of the final allocation of tasks came from the automation index, with the remaining allocation recommendations based on applications of the rules formulated for the purpose. The starting point was the list of allocations of tasks either to man or machine that constituted automation level III; the rules and their applications were as follows.

> Rule 1 - All of Function 16, Provide Emergency Services, was made manual. The impact of this rule on the total system manpower requirement is negligible because of the extremely low frequency of performance of the tasks within the function, i.e., there are not very many emergencies as compared to the total number of flights. Also, because of the nature of the tasks, the data system software complexity associated with automation appeared to be inordinate in comparison with the small savings in human resources that might be gained. (Thus the final automation level recommended excludes Function 16 from automation on the basis described, and also excludes Function 15, Provide Ancillary and Special Services from automation on the basis of the Automation Index. All other functions have some degree of automation at the recommended automation level.)
>
> Rule 2 - Ignore statistical uncertainties after one interval of automation levels. If a questionable task lay in automation level I, it fell more than one increment of automation from the level III starting point. The assumption was made that while it may not be certain that the questionable task actually lies in automation level I, it is highly certain that it lies somewhere below automation level IV. Therefore, the statistical uncertainties associated with those tasks (there were 10 tasks involved) were ignored.
>
> Rule 3 - Task clusters must either be automated or manual, but not mixtures. Thus, if one task in a two-task cluster was automated at level III, the other was automated as well. There are fifty clusters in AATMS, each made up of two or more tasks. The task

numbers in each cluster are given in Table 3.4-1 on the next page. It was decided that the elimination of induced tasks obtained by applying the cluster rule took precedence over the automation index; when the rule was applied 13 tasks which were cluster members were allocated to automated performance means.

Rule 4 - Contains three criteria for studying questionable task allocations. They were:

- Task Similarity - Are other tasks, similar to the questionable task in terms of the kind of work done as well as performance capabilities, automated or manual?
- Task Frequency - What is the required frequency of performance for the questionable task? Consider automation of the task if the frequency is high; consider keeping the task manual if its frequency is low.
- Data System Software - What degrees of difficulty and complexity would be involved in creating algorithms for task executions by automated means?

3.4.2 Recommended Task Allocations

Table 3.4-2, which begins on page 3.4-5, presents the results of the automation level III refinement process. The task number, whether the task is automated or manual as a result of the refinement process, and the level at which the task is designated to be automated by the automation index are contained in the left most section of the table. A mark in one of the five columns of the center section of the table indicates the reason for allocating a task to man or machine. The decision to automate is based either on the automation index or one of the four "rules" mentioned previously. The rightmost section of the table indicates cases where there is statistical uncertainty in the automation index. The statistical problem can be either lack of consensus or lack of consistency or both. (See Volume III for a more detailed discussion of the statistics of the automation indices.)

TABLE 3.4-1 TASK CLUSTERS

1.1.2 1.1.3	5.3.1 5.3.2 5.3.3	7.3.1 7.3.2 7.3.3	11.1.1 11.1.2	12.2.1 12.2.2	14.3.1 14.3.2 14.3.4 14.3.5 14.3.6	17.2 *
1.2.2 1.3.1	6.1.2 6.1.3	8.1.3 8.1.4 8.1.5 8.1.6 8.1.7	11.2.1 11.3.3 11.4.1	12.3.1 12.3.2 12.3.3 12.3.4	15.2.1 15.2.2 15.2.3 15.2.4 15.2.5 15.2.6	17.3 *
2.1.2 2.1.3 2.1.4 2.1.5	6.3.1 6.3.2 6.3.3	9.1 *	11.2.2 11.2.3 11.3.1 11.4.2	13.1.1 13.1.3	16.2.1 16.2.2 16.2.5 16.2.6 16.2.9	17.4 *
2.2.1 2.2.3 2.2.4 2.2.5	6.4.2 6.4.3	9.3.1 9.3.2	11.2.4 11.3.2 11.4.3	13.2.2 13.2.3	17.1.5 17.1.6	17.5 *
2.3.2 2.3.3 2.3.4	6.4.4 6.4.5	9.4.1 9.4.2	11.5.1 11.5.2 11.5.3	13.3.1 13.3.2	17.1.7 17.1.8	17.6 *
4.1.1 4.1.2	6.4.6 6.4.7	9.5.1 9.5.2 9.5.3 9.5.4	12.1.1 12.1.2	14.1.3 14.1.4		17.7 *
4.4.3 4.4.4	7.1.3 7.1.4	9.5.6 9.5.7	12.1.5 12.1.7	14.2.1 14.2.2 14.2.3 14.2.4 14.2.5		17.8 *
	7.2.1 7.2.2					17.9.1 17.9.2 17.9.3
						17.9.5 17.9.6

*All tasks within the Subfunction form a cluster

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
1.1.1	A	III	●						
1.1.2	M	V	●						
1.1.3	M	IV	●						
1.2.1	A	IV					●		
1.2.2	M	IV	●						
1.3.1	M	IV	●						
1.3.2	A	III					●	●	
1.3.3	M	V					●	●	
2.1.1	M	IV					●		●
2.1.2	M	IV	●						
2.1.3	M	IV	●						
2.1.4	M	IV	●						
2.1.5	M	V					●	●	
2.1.6	M	III					●		●
2.2.1	A	II	●						
2.2.2	A	II					●		●
2.2.3	A	II	●						
2.2.4	A	II	●						
2.3.1	A	III	●						
2.3.2	A	III	●						
2.3.3	A	II	●						
2.3.4	A	II	●						
2.3.5	A	I			●			●	
4.1.1	M	V					●	●	
4.1.2	A	III	●						
4.2.1	M	V	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
4.2.2	M	IV	●						
4.2.3	A	III	●						
4.2.4	M	IV	●						
4.2.5	M	V	●						
4.2.6	M	IV	●						
4.2.7	M	V	●						
4.2.8	M	V					●	●	●
4.2.9	M	V	●						
4.2.10	M	IV	●						
4.2.11	A	III	●						
4.2.12	M	V							
4.2.13	M	V	●						
4.3.1	A	III	●						
4.3.2	M	V	●						
4.3.3	M	V	●						
4.3.4	M	IV	●						
4.4.1	M	V					●	●	
4.4.2	M	V					●	●	
4.4.3	M	IV	●						
4.4.4	M	IV	●						
5.1.1	M	IV	●						
5.1.2	A	II	●						
5.1.3	M	V					●		●
5.2.1	A	II	●						
5.2.2	A	III	●						
5.2.3	A	II	●						
5.2.4	A	II	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
5.3.1	A	II	●						
5.3.2	A	V				●		●	
5.3.3	A	V				●			●
6.1.1	A	I	●						
6.1.2	A	I	●						
6.1.3	A	III	●						
6.1.4	M	V					●	●	
6.1.5	M	IV	●						
6.2.1	A	III	●						
6.2.2	A	II	●						
6.3.1	A	II	●						
6.3.2	A	I	●						
6.3.3	A	I	●						
6.4.1	A	II	●						
6.4.2	A	II	●						
6.4.3	A	II					●	●	
6.4.4	A	III	●						
6.4.5	A	IV				●			
6.4.6	A	III	●						
6.4.7	A	III	●						
7.1.1	M	IV	●						
7.1.2	A	I	●						
7.1.3	A	III	●						
7.1.4	A	II	●						
7.1.5	A	II	●						
7.2.1	A	III	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
7.2.2	A	I	●						
7.3.1	A	II	●						
7.3.2	A	I	●						
7.3.3	A	I	●						
7.4.1	A	II	●						
7.4.2	M	V					●	●	
7.4.3	M	IV	●						
7.4.4	A	III	●						
8.1.1	A	II	●						
8.1.2	A	I	●						
8.1.3	A	I	●						
8.1.4	A	I	●						
8.1.5	A	I	●						
8.1.6	A	I	●						
8.1.7	A	I	●						
8.1.8	A	II	●						
8.1.9	A	III	●						
8.2.1	A	II	●						
8.2.2	A	I	●						
8.2.3	A	II					●	●	
8.2.4	A	IV					●	●	
8.2.5	A	III	●						
9.1.1	A	II	●						
9.1.2	A	III	●						
9.1.3	A	II	●						
9.2.1	A	NOT RATED				●			

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
9.2.2	A	III	●						
9.3.1	A	II	●						
9.3.2	A	IV				●			
9.4.1	A	II	●						
9.4.2	A	II	●						
9.5.1	A	III	●						
9.5.2	A	III	●						
9.5.3	A	II	●						
9.5.4	A	II	●						
9.5.5	M	V					●	●	
9.5.6	M	IV	●						
9.5.7	M	V					●	●	
11.1.1	A	II	●						
11.1.2	A	II	●						
11.2.1	A	III	●						
11.2.2	A	II	●						
11.2.3	A	I	●						
11.2.4	A	I			●			●	
11.3.1	A	I	●						
11.3.2	A	I	●						
11.3.3	A	I	●						
11.4.1	A	II	●						
11.4.2	A	II	●						
11.4.3	A	II	●						
11.5.1	A	III	●						
11.5.2	A	IV				●			
11.5.3	A	II	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
12.1.1	M	IV	●						
12.1.2	M	V					●	●	
12.1.3	A	III	●						
12.1.4	A	II	●						
12.1.5	M	IV	●						
12.1.6	A	V					●	●	
12.1.7	M	V					●	●	
12.2.1	A	II	●						
12.2.2	A	III	●						
12.2.3	A	III	●						
12.2.4	A	III	●						
12.2.5	A	III	●						
12.2.6	A	III	●						
12.2.7	M	IV	●						
12.3.1	A	III	●						
12.3.2	A	II	●						
12.3.3	A	V				●		●	
12.3.4	A	V				●			
13.1.1	A	IV				●			
13.1.2	A	III	●						
13.1.3	A	III	●						
13.1.4	M	IV	●						
13.1.5	A	II	●						
13.2.1	M	IV					●		●
13.2.2	A	IV				●			
13.2.3	A	III					●	●	

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
13.3.1	A	V				●		●	
13.3.2	A	III	●						
14.1.1	M	IV	●						
14.1.2	A	III	●						
14.1.3	A	III	●						
14.1.4	A	III	●						
14.1.5	M	III					●	●	
14.2.1	A	III	●						
14.2.2	A	II	●						
14.2.3	A	II	●						
14.2.4	A	II	●						
14.2.5	A	I			●			●	
14.3.1	A	III	●						
14.3.2	A	III	●						
14.3.3	M	IV	●						
14.3.4	A	III	●						
14.3.5	A	II	●						
14.3.6	A	II				●		●	
15.1.1	M	V	●						
15.1.2	M	IV	●						
15.2.1	M	IV	●						
15.2.2	M	IV	●						
15.2.3	M	V	●						
15.2.4	M	IV	●						
15.2.5	M	IV	●						
15.2.6	M	V	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
16.1.1	M	III	●					●	
16.1.2	M	IV	●					●	
16.1.3	M	IV	●						
16.2.1	M	III	●						
16.2.2	M	IV	●					●	
16.2.3	M	II	●						
16.2.4	M	IV	●					●	
16.2.5	M	III	●						
16.2.6	M	II		●					
16.2.7	M	III		●					
16.2.8	M	V		●				●	
16.2.9	M	III		●					
16.2.10	M	IV		●				●	
17.1.1	M	IV	○						
17.1.2	M	IV	○						
17.1.3	M	IV	○						
17.1.4	M	V	○						
17.1.5	M	IV	○						
17.1.6	A	IV					○	○	
17.1.7	A	IV				○			
17.1.8	A	I	○						
17.2.1	A	III	○						
17.2.2	A	I	○						
17.2.3	A	III	○						
17.2.4	A	IV				○			
17.2.5	A	III	○						
17.2.6	A	I			○			○	

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
17.3.1	A	III	●						
17.3.2	A	I	●						
17.3.3	A	III	●						
17.3.4	A	IV				●			
17.3.5	A	III	●						
17.3.6	A	I			●			●	
17.4.1	A	III	●						
17.4.2	A	I	●						
17.4.3	A	III	●						
17.4.4	A	IV				●			
17.4.5	A	III	●						
17.4.6	A	I			●			●	
17.5.1	A	III	●						
17.5.2	A	I	●						
17.5.3	A	III	●						
17.5.4	A	IV				●			
17.5.5	A	III	●						
17.5.6	A	I			●			●	
17.6.1	A	III	●						
17.6.2	A	I	●						
17.6.3	A	III	●						
17.6.4	A	IV				●			
17.6.5	A	III	●						
17.6.6	A	I			●			●	
17.7.1	A	II	●						
17.7.2	A	III	●						
17.7.3	A	III	●						
17.7.4	A	III	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

			AUTOMATION DECISION RATIONALE					STATISTICAL PROBLEM	
TASK NUMBER	AUTOMATED OR MANUAL	AUTOMATION LEVEL	AUTOMATION INDEX	FUNCTION 16 IS MANUAL	ALWAYS AUTOMATE LEVEL I	INTEGRITY OF CLUSTERS	ENGINEERING JUDGMENT	LACK OF CONSENSUS	LACK OF CONSISTENCY
17.7.5	A	I	●						
17.8.1	A	II	●						
17.8.2	A	III	●						
17.8.3	A	III	●						
17.8.4	A	III	●						
17.8.5	A	I	●						
17.9.1	A	IV				●			
17.9.2	A	II					●	●	
17.9.3	A	II	●						
17.9.4	M	IV	●						
17.9.5	A	II	●						
17.9.6	A	I			●			●	
17.10.1	A	I	●						
17.10.2	A	I	●						
17.10.3	A	I			●			●	
17.11.1	A	II	●						
17.11.2	A	II	●						

TABLE 3.4-2 RECOMMENDED AUTOMATION LEVEL (cont'd)

3.4.3 Recommended Automation Level Man/Machine Resource Requirements

At the recommended automation level, the system is 70 percent automated: it consists of 77 manual and 170 automated tasks. By comparison a system with NAS/ARTS would be about 15% automated. Functions 15 and 16 (Ancillary and Special Services and Emergency Services) are entirely manual, while Functions 8 and 11 (Separation Assurance and Guidance) are entirely automated. The remaining functions range from 17 percent automated (Function 4, Flight Plan Processing) to 88 percent automated (Function 6, Monitor Aircraft Progress). Figure 3.4-1 is a schematic representation of the functional automation at level III, level IV, and the recommended automation level. In the following paragraphs, the recommended automation level is briefly discussed in terms of the five operating positions.

In the active control functions, (5, 6, 7, 8, 9, 11, 13 and 16) which as a group make up the Flight Surveillance and Control position, most of the tasks which have remained manual have a common element. They are concerned not with processing "business as usual", but involve exceptional situations. For example, every task in Emergency Services is manual; similarly, Task 5.1.3, Determine Pilot Intentions Following Missed Approach, is manual.

Functions 14 and 17, which form the Data Base position, contain nine manual tasks from a total of 75 tasks. The manual tasks of the Data Base position consist almost entirely of making weather observations and preparing operational reports.

The manual tasks of the Flight Information Services position (Function 1 and 12) are ten out of a total of 26 tasks. Eight of these ten manual tasks involve verbal transactions with the pilot -- receiving an information request, compiling a response to a request, or verbally responding to a request.

In the Flight Plans position, which performs Functions 4 and 15 (Flight Plan Processing and Special and Ancillary Services), 27 of 31 tasks are manual. Special and Ancillary Services contains no automated tasks, as mentioned previously. The automated tasks in the Flight Plan Processing function are computational in nature or involve long repetitive procedures, for example, Probe for Conflicts Among Flight Plans and Compute ETOV's/ETA are automated tasks.

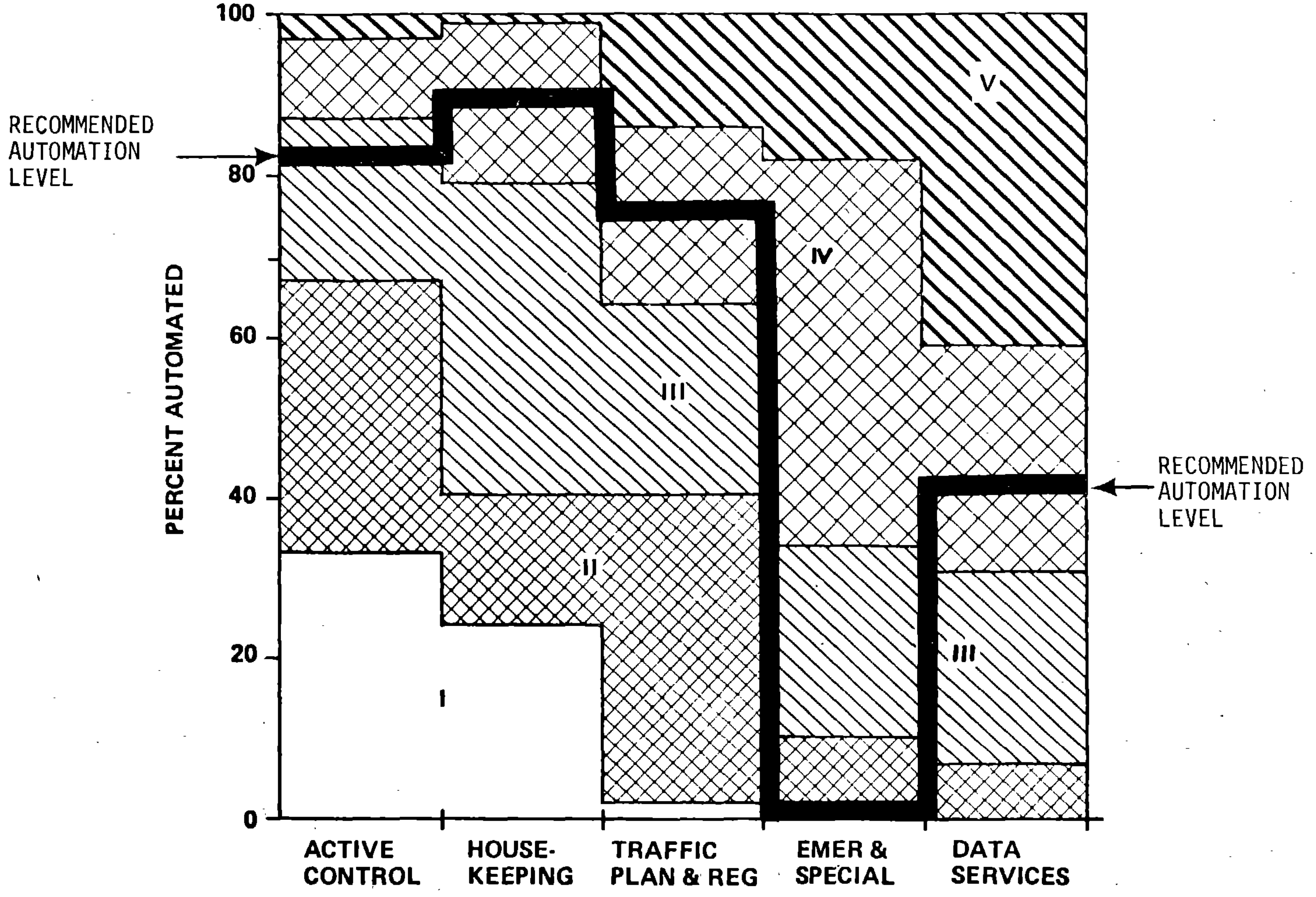

FIGURE 3.4-1 SCHEMATIC REPRESENTATION OF AUTOMATION AT LEVEL III, LEVEL IV, AND RECOMMENDED LEVEL, BY SYSTEM METAFUNCTIONS

The Flow Control position is concerned solely with Function 2, Control Traffic Flow. Of the 15 tasks in this function, six are manual. The six manual tasks form Subfunction 2.1, Determine System Capacity. The determination of demand (Subfunction 2.2) and the resolution of situations in which demand exceeds capacity (Subfunction 2.3) are entirely automated.

The performance of the 77 manual tasks at the recommended automation level required a manpower total of 9317. The number does not include an adjustment for the fact that people are available in integral numbers only (if the workload at a particular airport requires 0.4 of a person on site, an entire person must be assigned) nor does it include supervisory, management or support and maintenance personnel. These deployment adjustments are treated in the following section which deals with system manning. Similarly, manpower numbers do not reflect the men required if a manual rather than automated backup for failure were to be elected. Thus the computed requirement provides a "lumped" measure of how much work is involved in controlling aircraft. The following discussion concerns the components of the "lumped" manpower requirement.

The manpower requirements of the recommended automation level are presented in Table 3.4-3 by function and in Table 3.4-4 by position. The first column of the tables lists either the function or the position. The two tables are identical with respect to the remaining five columns. The second columns show the total manpower requirement in number of people. The third columns show the number of people that would be required if there were only the generic tasks to be performed, i.e., no induced tasks. The fourth, fifth, and sixth columns show the required number of people to perform the induced tasks: read display, coordinate, and enter data, respectively.

The most striking result from these tables is that induced tasks account for 60 percent of the workload. The induced tasks of two functions, 4 and 13, account for 77 percent of the total of induced tasks. Another interesting result is that the Flight Surveillance and Control position, which corresponds more closely than the other four positions to the current air traffic controller in duties and responsibilities, accounts for only

TABLE 3.4-3 RECOMMENDED AUTOMATION LEVEL MANPOWER REQUIREMENTS BY FUNCTION

FUNCTION	LUMPED MANPOWER REQUIREMENTS				
	NUMBER PER FUNCTION	PERCENT OF TOTAL DUE TO: *			
		GENERIC TASKS	INDUCED TASKS		
			READ DISPLAY	COORDINATE	ENTER DATA
1.0 Provide Flight Planning Information	1143	67	14	0	19
2.0 Control Traffic Flow	60	63	28	0	8
4.0 Process Flight Plan	4415	40	30	22	9
5.0 Issue Clearances and Clearance Changes	384	27	25	31	17
6.0 Monitor Aircraft Progress	223	28	72	0	0
7.0 Maintain Conformance With Flight Plan	341	26	25	31	17
8.0 Assure Separation of Aircraft	0	0	0	0	0
9.0 Control Spacing of Aircraft	27	44	30	4	22
11.0 Provide Aircraft Guidance	0	0	0	0	0
12.0 Issue Flight Advisories and Instructions	608	71	18	0	11
13.0 Handoff	1849	11	30	38	21
14.0 Maintain System Records	16	63	19	13	6
15.0 Provide Ancillary and Special Services	28	39	18	21	21
16.0 Provide Emergency Services	2	60	40	0	0
17.0 Maintain System Capability and Status Information	221	100	0	0	0
ALL FUNCTIONS	9317	40	27	20	13

*Percents may not add to 100 because of rounding

TABLE 3.4-4 RECOMMENDED AUTOMATION LEVEL MANPOWER REQUIREMENTS BY POSITION

POSITION	MANPOWER REQUIREMENTS				
	NUMBER OF PEOPLE PER POSITION	PERCENT OF TOTAL DUE TO:			
		GENERIC TASKS	INDUCED TASKS		
			READ DISPLAY	COORDINATE	ENTER DATA
FLIGHT SURVEILLANCE AND CONTROL	2826	17	32	33	18
DATA BASE	237	97	1.3	1.3	0.4
FLIGHT INFORMATION SERVICES	1751	68	15	0	16
FLIGHT PLANS	4443	40	30	22	9
FLOW CONTROL	60	63	28	0	8
ALL POSITIONS	9317	40	27	20	13

30 percent of the workforce. This is because of the high level of automation in the "active control" functions which make up the Flight Surveillance and Control position.

The performance of the 179 automated tasks in the recommended automation level requires a machine instruction execution rate of 23377 KIPS (thousands of instructions per second). This number was derived by performing the computations described in Section 3.2.6.

The data processing requirements of the recommended automation level are presented in Table 3.4-5 by function and in Table 3.4-6 by position. The first column of the table lists either the function or the position. The two tables are identical with respect to the remaining four columns. The second columns show the total data processing requirement in KIPS. The third columns show the number of KIPS that would be required if there were only the generic tasks to be performed. The fourth and fifth columns show the data processing requirement associated with the induced tasks.

In contrast with the manpower requirements, the number of KIPS associated with induced tasks form a small part of the total data processing requirement, only 1.5 percent. This result is probably a reflection of the relative ease with which a computer can drive a display or accept data. A noteworthy result shown in Table 3.4-6 is that the Flight Surveillance and Control position accounts for 92 percent of the total data processing requirement, while this same position accounts for only 30 percent of the manpower requirement. The highly automated nature of this position, and the fact that many of the automated tasks have high frequencies of performance and/or require a large number of machine instructions to execute them, accounts for this result.

It will be noted in Table 3.4-5 that two functions, 15 and 16, which are totally manual, have a quantity (albeit small) of KIPS associated with them. The reason for this is that the KIPS due to "create display" or "accept data" induced tasks have been associated with the manual tasks which must accept the input displayed or must output the data required.

TABLE 3.4-5 RECOMMENDED AUTOMATION LEVEL DATA PROCESSING REQUIREMENTS BY FUNCTION

FUNCTION	DATA PROCESSING REQUIREMENTS			
	TOTAL KIPS	PERCENT OF TOTAL DUE TO: *		
		GENERIC TASKS	INDUCED TASKS	
			CREATE DISPLAY	ACCEPT DATA
1.0 Provide Flight Planning Information	87	66	20	14
2.0 Control Traffic Flow	31	92	6	1
4.0 Process Flight Plans	1002	83	15	2
5.0 Issue Clearances and Clearance Changes	3018	100	0	0
6.0 Monitor Aircraft Progress	2356	99	1	0
7.0 Maintain Conformance with Flight Plan	8892	100	0	0
8.0 Assure Separation of Aircraft	4283	100	0	0
9.0 Control Spacing of Aircraft	532	100	0	0
11.0 Provide Aircraft Guidance	1718	100	0	0
12.0 Issue Flight Advisories and Instructions	153	90	8	2
13.0 Handoff	647	87	10	3
14.0 Maintain System Records	543	100	0	0
15.0 Provide Ancillary and Special Services	0.86	0	62	38
16.0 Provide Emergency Services	0.049	0	82	18
17.0 Maintain System Capability and Status Information	114	100	0	0
	23377	99	1	0

*Percents may not add to 100 because of rounding.

TABLE 3.4-6 RECOMMENDED AUTOMATION LEVEL DATA PROCESSING REQUIREMENTS BY POSITION

POSITION	DATA PROCESSING REQUIREMENTS			
	TOTAL KIPS	PERCENT OF TOTAL DUE TO: *		
		GENERIC TASKS	INDUCED TASKS	
			CREATE DISPLAY	ACCEPT DATA
FLIGHT SURVEILLANCE AND CONTROL	21446	99	0	0
DATA BASE	657	100	0	0
FLIGHT INFORMATION SERVICES	240	81	13	6
FLIGHT PLANS	1003	83	15	2
FLOW CONTROL	31	94	6	0
ALL POSITIONS	23377	99	1	0

*Percents may not add to 100 because of rounding.

3.5 SYSTEM MANNING REQUIREMENTS

After determining the "lumped" or undistributed resources required to service the given demand at the recommended system automation level, the next step in AATMS requirements analysis was to convert the aggregates to numbers of men per shift. This was done by distributing the resources among the various manned facilities envisioned for the system. Again the totals are consistent with use of automated backup for failure. Because machine resource requirements were the subject of further study, they are treated separately in Chapter 5 of this volume. This section, as the title implies, is concerned with system manpower.

3.5.1 AATMS Facilities and Operating Positions

It will be recalled that the types and numbers of AATMS facilities were among the data items supplied to the study team by DOT/TSC. Five facility types are included in the system geography:

- 133 primary airports
- 586 secondary airports (of which 227 are unmanned)
- 20 transition hub centers (THC)
- 2 regional control centers (RCC)
- a continental control center (CCC)

The five AATMS operating positions were allocated to the facility types as follows: The terminal portion of the system was composed of flight surveillance and control operators (Position III) at the 133 primary airports, the 359 manned secondaries, and the 20 THC's. (The 20 THC's are responsible for the 227 unmanned secondary airports.) Position III operators were also placed at the two RCC's, in order to man the en route portion of the system. Flight information services and flight planning positions (Positions IB and IIA) were located at the THC's. The data base position, IA, and the flow control position, IIB, were centrally located at the CCC.

3.5.2 Assumptions

A peak instantaneous airborne count of 33,750 aircraft had been given as the AATMS demand figure. In Chapter 2 of this volume, the distribution of these aircraft in the system airspace was described. The assumptions about demand distribution also apply to workload distribution among system facilities, and so were used in system staffing calculations. The applicable assumptions were the following:

- The number of control actions in terminal airspace in comparison with en route airspace is the ratio of 7 to 3. Therefore, the overall distribution of activity is 70 percent at terminals, 30 percent en route.
- Primary airports are more active than secondaries. Half the total terminal workload occurs at the 133 primaries, the other half at the 586 secondary airports.
- The system demand was assumed to be uniform throughout the system airspace. Therefore, each RCC has an equal portion of the en route workload, and each terminal facility an equal share of the primary or secondary terminal workload.
- The undistributed manpower figures contain no provision for relief, leave, administrative coordination between operator and supervisor, or functional management (overseeing of machine resources). To approximate the effects of these requirements, manpower figures were increased by one third, a factor termed the "busy" factor.
- Facilities staffed by operators require supervisors. Each facility was allocated ten percent of its operator complement as a supervisor staff.

3.5.3 Procedure

The derivation of site manning results was based upon the undistributed manpower requirements for each of the five positions, and on the information and assumptions presented in the preceding paragraphs. The following paragraphs detail the procedure used to derive manning for each facility by operator position.

The Data Base position (IA) will be located at one site only, the CCC. The raw total IA manpower was 237. Removing the 3.5 shift factor leaves 67.7 (≈68) on-duty personnel. Application of the "busy" factor results in 90.7 (≈91) on-duty personnel.

The Flight Information Services position (IB) will be located at the 20 THC's. The raw total IB staff was 1751, which converts to 500.3 (≈501) on-duty personnel. Application of the "busy" factor results in 668 people. Distributing these 668 equally among the 20 THC's results in 33.4 (≈34) per THC.

The Flight Plans position (IIA) will also be located at the 20 THC's. The raw total IIA staff was 4443, which converts to 1269.4 (≈1270) on-duty personnel. Application of the "busy" factor results in 1693.3 (≈1694) people. Distributing these 1694 equally among the 20 THC's results in 84.7 (≈85) per THC.

The Flow Control position (IIB) will be located only at the CCC. The raw total IIB staff was 60, which converts to 17.1 (≈18) on-duty personnel. Application of the "busy" factor results in 24 personnel.

The Flight Surveillance and Control position (III) will be located at four different kinds of sites: (1) the 133 primary airports, (2) the 359 manned secondary airports, (3) the 20 THC's (to handle the work associated with the 227 unmanned secondary airports), and (4) the two RCC's (to handle en route traffic). The raw total was 2827 position III personnel, which converts to 807.7 (≈808) on-duty personnel. Application of the "busy" factor results in 1077.3 (≈1078) people. If the distribution of workload is 70 percent at terminals and 30 percent en route, then the on-duty personnel should be distributed in the same manner: 754.6 (≈755) at terminals and 323.4 (≈324) en route.

The en route personnel were distributed equally to the two RCC's. Because each RCC will be responsible for ten "sectors" (each of which is made up of ten jurisdictions), the total en route workforce was distributed to 20 "sites" which were considered to be different physical places for manning purposes. This resulted in 16.2 (≈17) operators per en route "sector". To provide for the handling of emergencies, and in order to have two men per jurisdiction in normal operations, three supernumeraries were added for a total of 20 operators per en route "sector".

Distributing the terminal workforce of 755 equally between primary and secondary airports resulted in 377.5 (≈378) people to handle the 133 primaries and 378 people to handle the 586 secondaries. The manning at each primary was 378 ÷ 133, or 2.8 (≈3) people. Again, in order to provide for emergencies, one supernumerary was added for a total on-duty staff of four controllers per primary airport.

Unmanned secondary airports make 227 of the 586 total number of secondaries. Of the 378 people required to handle secondary airports, $\frac{227}{586}$ of these, 146.4 (≈147) will be distributed equally among the 20 THC's to handle the unmanned secondaries. This results in 7.4 (≈8) per THC. One supernumerary was added for a total of nine controllers per THC.

Manned secondary airports make up 359 of the 586 total number of secondaries. Of the 378 people required to handle secondary airports, $\frac{359}{586}$ of these, 231.6 (≈232) were distributed equally among the 359 manned secondaries. This results in 0.65 (≈1) per manned secondary. One supernumerary was added for a total of two controllers per manned secondary airport.

Table 3.5-1 presents the results discussed above, along with the total staffing requirement, which includes the ten percent addition to account for supervisory positions. The first column of the table lists the five AATMS sites and the second column lists the number of each type of site. The third column lists the type of position which will man the site. The position types and titles are given below for reference:

IA	Data Base Officer
IB	Flight Information Services Officer
IIA	Flight Plans Officer
IIB	Flow Control Officer
III	Flight Surveillance and Control Officer

The fourth column of the table, titled REQUIRED SHIFT SIZE, shows the number of people required on site full time to perform the duties associated with the position. The next column accounts for the non-existence of fractional numbers of people and for supernumeraries, if any. The column titled

TABLE 3.5-1 SITE MANNING

SITE	NO. OF SITES	MANNED BY	REQUIRED SHIFT SIZE	RECOMMENDED SHIFT SIZE	TOTAL	SUPERVISORY	TOTAL STAFF
PRIMARY AIRPORT	133	III	2.84	4	1862	186	2048
SECONDARY AIRPORT	359	III	0.65	2	2513	251	2764
TRANSITION HUB CENTER	20	IB	33.4	34	2380	238	2618
		IIA	84.7	85	5950	595	6545
		III	7.4	9	630	63	693
REGIONAL CONTROL CENTER	2	III	162	200	1400	140	1540
CONTINENTAL CONTROL CENTER	1	IA	90.7	91	319	32	351
		IIB	24.0	24	84	8	92
TOTALS	515	--	--	--	15138	1513	16651

TOTAL gives the total workforce required to provide the recommended shift size. The numbers in this colume are derived by multiplying the number of sites by the recommended shift size, and that result multiplied by the 3.5 shift factor. In the case of the RCC, 20 was used in lieu of number of sites because there are a total of 20 "sectors", each of which was considered an independent "site" for manning purposes. The column labeled SUPERVISORY lists the number of personnel who would be involved in the direct supervision of the controller force. A ten percent factor was assumed. The right-most column presents the sum of the controller workforce plus supervisory personnel.

3.5.4 Workforce Comparisons: 1972, 1982, 1995

A primary objective in the study of automation applications in traffic control was to explore the possibilities of avoiding some of the system costs associated with labor. A means to aid in making judgements about the degree of economy that is indicated at the recommended automation level in AATMS is to compare staff sizes with earlier systems. Again the manpower is consistent with a system having primarily automated failure backup. It must be kept in mind that this is an incomplete comparison (for example, cost savings associated with a smaller workforce must be set against R&D and F&E costs for the automated system) and that the data involved, except for 1972 historical data, are estimates.

Table 3.5-2 is a comparison of staff size and composition for 1972, 1982, and 1995. The data for the 1972 and 1982 staff were drawn from the National Airspace Ten-Year Plan for 1973-1983 (FAA, 1972); the 1995 data is the AATMS staffing data presented earlier. All salary costs were supplied by DOT/TSC. Several changes contribute to the smaller 1995 staff size given in Table 3.5-2, all of which arise from or are related to automation. First is the higher level of automation proposed for 1995, in which more of the total system work is done by machines, so fewer people are required. Second is the degree of centralization permitted by automation, for example the envisioned unmanned secondary airports planned for AATMS. Third is the alteration of operator job design; in AATMS many tasks now done at active control positions are reassigned to other options. The general level

TABLE 3.5-2 STAFF SIZES: 1972, 1982 AND 1995

POSITION (1972 AND 1982)	AIR TRAFFIC OPERATIONS STAFF SIZE			POSITION (1995)
	1972	1982	1995	
EN ROUTE	10415	13630	1540	FLIGHT SURVEILLANCE AND CONTROL
TERMINAL	9727	13428	5505	
FSS	4566	8002**	9606	DATA BASE, FLIGHT INFORMATION SERVICES, FLIGHT PLANS, FLOW CONTROL
TOTAL	24708	35060	16651	TOTAL
$COST	$457M	$647M	$297M	$/YR*

*Based on TSC supplied costs and costing methodology which states that en route salaries = 19.1K, terminal salaries = 18.4K and FSS salaries = 17.3K for all years under consideration.

**Reduced FSS force of less than 4700 was projected by - A Proposal for the Future of FSS - DOT August 1973 of system automation in AATMS, the high level in certain active control functions, and the reallocation of tasks combine to produce a large shift in the workforce makeup: from about 80% in active control in the 1972-1982 staff to about 40% in AATMS.

In this chapter, the system manning requirements for AATMS were set forth. In the next chapter, the operator productivity associated with the AATMS staff will be discussed.

4.0 CONTROLLER PRODUCTIVITY

4.1 INTRODUCTION

The concept of productivity, i.e., the ratio of products to the number of people involved in production, is not a new one. It has been in use almost since the beginning of the industrial revolution as a measure of human efficiency in getting a job done. The concept is a relatively simple one if the products can be specifically defined and the people involved in their production easily identified. Productivity is relevant and meaningful if, for example, one is discussing the output of an automobile production line with regard to the number of people working on the line. Finished automobiles are a specifically defined product, and workers on the production line are easily identified.

Productivity becomes harder to define and apply as a measure of human efficiency when the product is not a physical item. Such is the case in air traffic control, where the product is an intangible -- service to airspace users. It is difficult to define a quantum of service, and even more difficult to measure the amount of service a user receives. The concept of productivity in air traffic control is further clouded when those delivering the service are not directly involved but act remotely through an automated agency. Their role becomes more like that of supervisors responsible for automobile production than that of production line workers.

The approach adopted in this study follows that which has traditionally been taken in measuring air traffic controller productivity. It involves posing the question in an inverted form. Thus, instead of asking how much service a user receives, the question is put as how many users receive service. Since it is considerably easier to count recipients than to measure the product received, the matter of productivity is at least placed on a more practical, although somewhat vaguer, footing. Hence, the unit of service used in this study is defined as all that is done to or for one aircraft as it moves from origin to destination, or through some selected part of this journey. Aside from practicality, this definition also has the advantage of allowing the findings here to be compared directly with other studies of controller productivity. For example, this definition is equivalent to that employed by MITRE (1971), where productivity is stated to be "demand serviced per controller".

As the MITRE definition suggests, productivity is a ratio of recipients (demand) to those providing the service (controllers). In AATMS the identification of those providing the service must be modified because of the high level of automation. The AATMS operator will no longer be directly involved with the routine actions required to provide most services. These tasks will be performed by machines. Man's role will be to supervise and manage the machines which perform routine operations. He will take direct action only in exceptional situations or in circumstances where a highly individualized form of service is required. Thus, the agency for "all that is done to or for one aircraft" is not just the human operator but the man-machine resource team acting in concert. To speak of productivity with regard to AATMS involves, therefore, accepting an expanded definition of both "product" and "worker". The relationship, however, remains the traditional one, whereby productivity is expressed as the product/worker ratio. For convenience of expression, this ratio will be referred to as "controller productivity", but it should be borne in mind that the "controller" is a partnership of man and machine.

4.2 PROCEDURE

Of the five operating positions envisioned for AATMS, only Position III (Flight Surveillance and Control) has a sufficient degree of involvement with individual aircraft to warrant examination of productivity. The other positions deal either with aircraft as aggregates (traffic), or they act in a support capacity to provide information to the flight surveillance and control positions. Thus, productivity estimates were calculated only for Position III.

For the purpose of computation, a number of simplifying assumptions were made about the distribution of demand across the various types of facilities. They were:

1. The duration of all flights is two hours.
2. An aircraft is under control of the departure terminal for 20 minutes, the en route portion of the system for 80 minutes, and the arrival terminal for 20 minutes.
3. The number of control actions in terminal airspace in comparison with en route airspace is in the ratio of 7 to 3 (i.e., there are 2.33 more actions per aircraft per unit time in terminal areas than in en route sectors).
4. Of the aircraft in terminal areas, one-half are at primary terminals; and one-half are at secondary terminals.
5. Aircraft at secondary terminals are distributed between manned and unmanned facilities in proportion to the number of such facilities (i.e., for every 359 aircraft at manned secondary terminals there are 227 aircraft at unmanned secondary terminals).
6. The distribution of traffic among terminal facilities of any one type is homogeneous (e.g., each primary terminal has 1/133 of the total primary terminal traffic).

The number of operators on duty at each facility was that derived in the analysis of system manning requirements. (See Chapter 3, Section 3.5.) All operators at a given facility were assumed to be equally engaged. Further, all aircraft were assumed to present an equal demand for service. To put it another way, no distinction was made for different classes of aircraft (commercial, military, general aviation) or for different degrees of control (IFR vs. VFR, PCA vs. IPC, etc.). Thus, the productivity estimates calculated here represent the simple ratio of the number of aircraft present within the jurisdiction of a facility to the number of operators on duty.

4.3 RESULTS

Operators in the Flight Surveillance and Control Position are located at four different types of AATMS facilities: Regional Control Centers (en route traffic), Primary Terminals, Manned Secondary Terminals, and Transition Hub Centers (for unmanned secondary terminals). As a result, four separate estimates of productivity were derived. Figure 4.3-1 illustrates the method of computation and the fractional distribution of demand across facilities.

In Figure 4.3-1 it can be seen that for an instantaneous airborne count of 33,750 aircraft, 22,500 will be en route and 11,250 will be in terminal areas (Assumption 2, above). Since there are 200 en route controllers per shift at each RCC (400 in all), this results in an en route productivity figure of 56.3 aircraft per controller.

Of the 11,250 aircraft in terminal areas, half (5625) will be at primary terminals (Assumption 4, above). With a total of 532 controllers on duty at all primary terminals (4 per site x 133 primary terminals), this yields a productivity estimate of 10.6 aircraft per controller.

The remaining 5625 aircraft of the instantaneous airborne count are distributed between manned and unmanned secondary terminals in proportion to the number of each type of facility. In other words, since there are 359 manned and 227 unmanned secondary terminals,

$$\frac{359}{(359 + 227)} \times 5625 = 3446 \text{ aircraft at manned secondary terminals}$$

and

$$\frac{227}{(359 + 227)} \times 5625 = 2179 \text{ aircraft at unmanned secondary terminals}$$

With 718 controllers on duty at manned secondary terminals (2 per site x 359 manned secondary terminals), the productivity is 4.8 aircraft per controller. Traffic at unmanned secondary terminals is handled through centralized facilities (Transition Hub Centers), of which there are 20. The shift size per THC is 8 (160 operators on duty in all), yielding a productivity figure of 13.6 aircraft per controller.

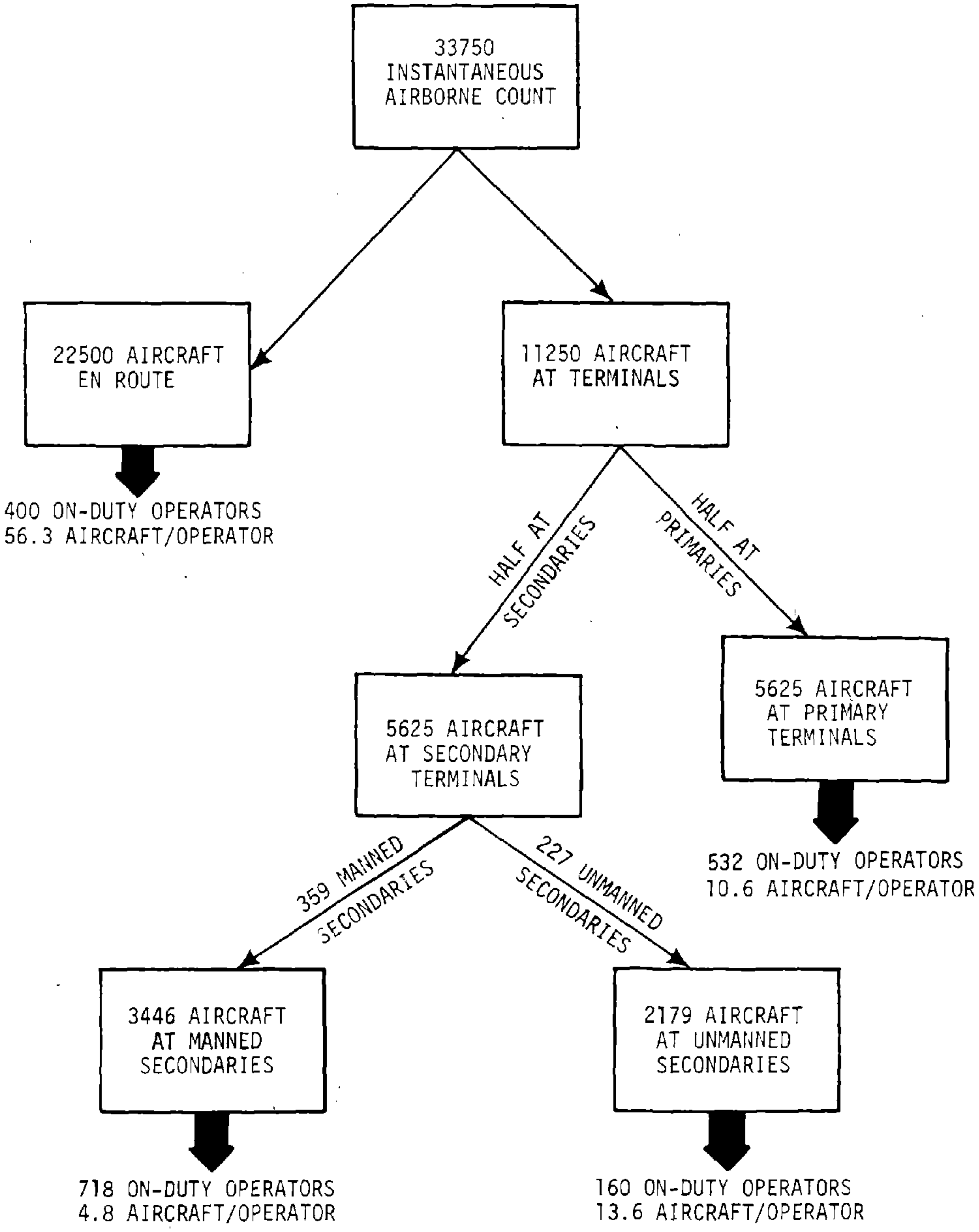

FIGURE 4.3-1 OPERATOR PRODUCTIVITY

The results of the individual productivity calculations are summarized below.

TABLE 4.3-1 SUMMARY OF PRODUCTIVITY ESTIMATES

SITE	NUMBER OF CONTROLLERS ON DUTY	NUMBER OF AIRCRAFT IN SITE AREA	PRODUCTIVITY (AIRCRAFT PER CONTROLLER)
En Route	400	22500	56.3
Primary Terminals	532	5625	10.6
Manned Secondary Terminals	718	3446	4.8
Unmanned Secondary Terminals	160	2179	13.6

The most prominent result is the large difference in productivity between en route and terminal controllers. There are several factors which account for this: centralization, demand distribution, staffing considerations, and workload.

In comparison with terminals, the RCC is a highly centralized facility. Because of its concentration of man and machine resources, the RCC tends to be much more efficient than terminals due to the distributed location of terminals. It is not surprising, therefore, that the productivity of controllers in a centralized setting is greater than that of controllers at dispersed sites dealing with small fractions of the traffic volume. This same effect shows up in a smaller way in productivity differences between controllers at manned and unmanned secondary terminals. The THC stands midway in centralization between the RCC and the manned terminal, and controllers at the THC show a corresponding intermediate level of productivity.

Another aspect of centralization which affects productivity is the size of the RCC itself. An appreciation of the size and the concentration of the RCC can be gained by considering that all en route traffic in CONUS would be handled by one of two facilities, each consisting of 100 sectors. Since the entire national en route airspace would be divided into only 200 sectors (as compared to about 550 in today's system), the average sector size in AATMS would be almost three times larger than now. The size of terminal area control zones in AATMS would, by contrast, remain about the same as today's. Thus, only part of the difference between en route and terminal productivity is attributable to the greater efficiency of the more centralized RCC. There is also an absolute increase of en route productivity due to the larger sector size of the RCC as compared to the present ARTCC sector.

Centralization and size are not the only factors influencing en route controller productivity. The distribution of demand between en route and terminal facilities also plays a part. It will be recalled that one assumption used in calculating productivity was that two-thirds of each flight, and hence two-thirds of the peak instantaneous airborne count, was in the en route portion of the system. Since productivity is the ratio of demand to operators, productivity is directly influenced by the number of aircraft assumed to be present in each jurisdiction. To some extent then, the greater productivity estimated for en route controllers is an artifact of the method of computation. The direct influence of demand on productivity also shows up in the difference between primary and secondary terminals. Primary terminals have a greater share of the traffic, and the productivity of controllers at these facilities is proportionately higher than that of controllers at the low-volume secondary airports.

Staffing considerations also affect productivity. Operators were assigned to sites in integral numbers. Thus, where 16.2 operators were needed to man a ten-sector subdivision of the RCC, 17 (plus 3 supernumeraries for relief) were assigned. Three men and a relief were assigned to primary terminals where 2.84 were needed, and so on. "Rounding up" the staff size and providing relief operators on shift had differential effects depending on the size of the facility. The RCC has a low degree of overstaffing (162 needed vs. 200 assigned, or 23.5% overstaffing). A primary terminal has 40.8% excess staffing; a manned secondary terminal slightly over 200%; and a THC the lowest of all, 21.6%. Generally speaking, the proportion of excess staff varies inversely as the size of the facility. The net effect was to lower the productivity estimates for operators at the smaller and more decentralized sites. The impact is greatest at manned secondary terminals, where productivity is estimated to be only 4.8 aircraft per controller.

If staffing were factored out of the productivity computation, a more even pattern of aircraft-to-controller ratios would result. Thus, if one were to divide demand per site not by the number of operators on duty but by the manpower required to handle the traffic, the results for the four facilities would be:

	Productivity	Adjusted Productivity
RCC	56.3	69.4
Primary Terminal	10.6	14.9
Manned Secondary Terminal	4.8	14.8
THC	13.6	14.7

This suggests that all terminal operators have essentially equal <u>potential</u> productivity, which is vitiated in the operational setting by staffing considerations. However, the adjusted productivity figure is a highly theoretical value based on fractional manpower working without relief, and so does not represent a particularly valuable or realistic index of the work which the AATMS operator can be expected to perform.

A final factor which affects productivity is workload. One assumption used in calculating both staff size and productivity was that aircraft in terminal areas require more control actions than those en route. The factor of differential workload was estimated to be 2.33 (i.e., 7 control actions for each arriving or departing aircraft vs. 3 for each aircraft en route). The workload factor was included as a recognition of the increased amount of attention required by merging and interleaving traffic around airports as compared to the more orderly flowing traffic en route. If the basic productivity figures for controllers are adjusted to account for the amount of work (i.e., frequency and amount of service) called for in the terminal traffic situation, there is a much smaller difference between terminal and en route controllers. This adjustment, which may be termed the workload-compensated productivity index, gives the results shown in Table 4.3-2.

TABLE 4.3-2 WORKLOAD-COMPENSATED PRODUCTIVITY ESTIMATES

	AIRCRAFT PER CONTROLLER	
CONTROLLER TYPE	BASIC PRODUCTIVITY	WORKLOAD COMPENSATION*
En Route (RCC)	56.3	56.3
Primary Terminal	10.6	24.7
Manned Secondary Terminal	4.8	11.2
Unmanned Secondary Terminal (THC)	13.6	31.7

*Workload compensation factor = 2.33 for terminals