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AUTOMATION APPLICATIONS IN AN ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

Volume I: Summary

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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 SUMMARY OF VOLUME I

In 1969 the Air Traffic Control Advisory Committee of the Department of Transportation published the report of its study of the projected needs of the national aviation system to the end of this century. ATCAC forecasted enormous growth in the demand for air traffic control services as a reflection of the increase in the nation's air fleet, particularly in the general aviation sector. To provide for the safe and efficient use of the national airspace and to assure an equitable distribution of services to airspace users, ATCAC offered a series of short and long range recommendations. For the short range, roughly through 1985, ATCAC recommended a program to improve the present NAS and ARTS systems, a program which came to be known as the Upgraded Third Generation System. However, ATCAC also recognized that more far-reaching solutions would be needed by the turn of the century. To this end, ATCAC recommended study of a replacement system, dubbed the Fourth Generation System, which would be operational through the period of roughly 1995 to 2020.

The long range fourth generation program recommended by ATCAC entailed a two-pronged approach, one directed at an improved surveillance, navigation, and communication system, the other at investigation of higher levels of system automation. Increased automation was seen to offer several potential advantages. Through judicious use of computers, the efficiency of airspace use could be maximized. Computers might also enhance the safety of the system by elimination of certain human errors and oversights and by increasing the speed of system response to potentially dangerous events. However, the main advantage of automation was seen to lie in the area of cost, particularly the costs of operating and maintaining the system. Air traffic control today is a labor-intensive system, where increases in demand bring about direct increases in the number of controllers needed to man the system. The costs associated with the additional workforce needed to accommodate the projected demand by the end of the century were foreseen to be of such proportions that some means had to be found to alter the demand-manpower relationship. Automation of many heretofore human functions in air traffic control offered promise as an answer.

This study was undertaken to explore the applications of automation in an advanced air traffic management system. Note that the system is characterized as a "management" rather than a "control" system, since it embraces not only the activities of directing aircraft but also the higher-order activities of traffic planning and regulation, flow control, and strategic deployment of system resources. The study involved three major work steps.

1. Development of a detailed functional description of air traffic management activities
2. Allocation of functional assignments to men and machines at successive levels of system automation and selection of a recommended level of automation
3. Evaluation of the recommended automation level in terms of its human and automated resource requirements and operational characteristics.

This volume is a recapitulation of the results of this year-long study. It begins with a chapter on the background and the general nature of the air traffic problem. This is followed by a statement of study objectives and a description of the approach. Chapter 4 contains a summary of results, presented roughly in the order in which they were derived through the three phases of the study.

As a whole, Volume I is directed to the reader who is interested in the major outcomes of the study but who does not wish to concern himself with the technical details or the methods of investigation. (This supporting material is presented in Volumes II-V.) Because it is a general document, Volume I concludes with two chapters whose intent is to provide an assessment of study outcomes. Chapter 5 is a discussion of study implications for the design of an advanced air traffic management system characterized by a high level of automation. Chapter 6 presents a suggested strategy for implementation of the system and for the supporting RDT&E activity. It was felt that placing these chapters here in Volume I, rather than amid the voluminous technical detail of Volumes II through V, would help the reader to put the study results into a better overall perspective.

2.0 INTRODUCTION

From its fledgling beginnings as an experiment seventy years ago, air travel has progressed to an everyday practicality. Travellers use the national airspace and its network of airports for business and pleasure, around the clock, in virtually all weather, throughout the year. Watching over and guiding the movement of aircraft is the air traffic control system--an array of men and machines whose purpose is to assure the safe and expeditious flow of traffic.

Just as aircraft have grown more sophisticated and more equipped with automated aids to human control, the air traffic control system has also evolved into a complex of sensors, data processors, and communication links supporting (and in some cases supplanting) the human operator. If future trends follow the past, it is expected that the air traffic control system will become even larger, more sophisticated, and more automated in the coming decades as the use of the national airspace grows.

The trend toward automation in air traffic control poses a formidable technical challenge, but it also raises a problem of a higher order. Advanced levels of automation evoke questions about the future role of man in the system. For instance, what is the most appropriate balance of contributions by man and machine? Are there tasks in the control of air traffic which should always be performed by man; and if so, is it reasonable to propose automating all the rest? Once an optimum balance of man and machine is determined, what are the guideposts for planning and implementing such a system? What will be expected of the human operator when automated features fail in the future air traffic control system?

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 users of the national airspace as civil aviation grows. This report describes one study which was undertaken as part of the AATMS program. The objective was to investigate the applications of automation in an advanced air traffic system and to examine the prospective employment of human and automated resources as air traffic control is converted from a labor-intensive to a machine-intensive activity.

At this point, AATMS is only a general concept, describing a system concept capable of operational deployment roughly twenty years hence in 1990 to 2000. The long-range and conceptual aspects of AATMS prompted, therefore, a generic approach to the question of automation. The study attempted to look beneath the specific design features of present and contemplated systems and to discern the underlying man-machine relationships which will exist if a high level of automation is achieved. This approach was taken in the interest of assuring the broadest applicability of results, regardless of the particular characteristics which emerge during the design and development of the future system.

To set the goals of this study in perspective, the report begins with a discussion of the concept of air traffic control, the role of the air traffic controller, and the evolution of air traffic control systems. This introductory material is intended primarily for the reader who is unfamiliar with air traffic control activities and controller tasks. However, those already acquainted with these subjects may still find the discussion useful in that it provides a summary of the factors which prompted this study and influenced its direction.

2.1 AUTOMATION IN AIR TRAFFIC CONTROL

An air traffic control system provides certain services to airspace users. Navigation aids, weather data, and separation assurance (keeping aircraft a safe distance apart) are examples of the kinds of services provided. Airspace users include commercial, military and general aviation aircraft. The services demanded of the air traffic control system are provided through a complex of men and machines. The combined performance output of the men and machines is the system's response to demand. To assure safe and efficient use of the airspace, the system must have sufficient machine and human resources to meet the demand.

Historically, the demand for air traffic control services has increased steadily. Because of the direct relationship between imposed demand and resources required to handle the demand, the air traffic control system has grown as well. Projections of future demand indicate continued increase. In 1972 the nation's air fleet numbered about 154,500 aircraft, of which 3500 were commercial transport, 20,000 were military, and 131,000 were general aviation. (DOT/TSC, 1973). It has been estimated that by 1995 the fleet will be about 362,000 aircraft of all kinds (7000 commercial, 20,000 military, and 335,000 general aviation). (TSC, 1973). Along with the growth of the air fleet, the number of annual operations is also expected to increase at a rapid rate. There were 139.6 million operations in 1972, and it is projected that there will be 212.6 million operations annually by 1984 and 321.2 million by 1995. (DOT/TSC, 1973). To meet the anticipated rise in demand, the resources of the air traffic control system must be expanded correspondingly.

Increasing the total capacity of a given system can be done by making the system larger or by finding ways to make it more productive for its size. Both these approaches have been applied in the development of the present-day air traffic control system. At the same time as the total numbers of men and machines in the system have grown, ways to use the skills of men and the power of machines more productively have been explored, tested, and adopted.

From the viewpoint of those using the national airspace, the quality of the air traffic control services they receive can be measured in terms of safety and efficiency. A vital aspect of ATC system performance to airspace users is that aircraft be kept a safe distance apart. In addition to separation assurance, however, users also expect the ATC system to provide for efficient utilization of the airspace. Delay of traffic, for example, may be unavoidable; but it certainly must be minimized and equitably distributed. Thus, the standards of safety and efficiency form the basis both for assessing the system as it stands and for evaluating the merits of proposed improvements. Before men and machines are added to the system to meet increased demand, there must be assurance that they will be able to perform to the standards of safety and efficiency. Before a new idea is accepted for use in the system, it must be evaluated against these yardsticks of system services.

While safety and efficiency are of paramount importance, other factors must also be taken into account in the process of system development. One such factor is the system's requirement for human resources. As the system grows to meet increasing demand, so does its workforce -- air traffic controllers and system support personnel. In 1972, a workforce of about 26,000 was required for air traffic control operations. By 1982, it is expected that 36,000 will be needed. (FAA, 1973).

Partly because there may well be a limit to the ultimate availability of human resources and hence to the growth of the system, research in air traffic control has devoted increasing attention to human productivity. The most sensitive position in the system with respect to productivity is the controller himself. Ways are being sought to increase, without any sacrifice in standards of service, the number of airspace users that can be served by each controller.

Of various approaches to increasing productivity, one that holds promise is automation. An air traffic controller performs tasks involving collecting and analyzing information, making decisions, and taking actions. Through automation, the productivity of an air traffic controller can be increased by allocating some of these tasks to machines. One way of thinking about the problem is to visualize a typical flight of an aircraft going from one airport to another. During this flight, a set of transactions take place which involve adjustments in response to effects of weather, terrain, other flights, and so on. Insofar as a machine can take on some part of of the set of transactions, the controller can work with more flights doing only those things that require human judgment. Thus, fewer human resources are required to achieve a given total system output; and the problems and costs of recruiting, training, and deploying a larger and larger human workforce can be ameliorated.

Since its beginning, the air traffic control system has relied on machines for the performance of certain tasks. Radios have always been essential to air-ground communications. Radars -- and more recently radar beacon transponders -- have been incorporated into air traffic surveillance. Automatic teleprinting equipment is used to transmit weather data, and so on. Thus, a certain degree or level of automation is already established for air traffic control. This established underpinning of system automation is the point of departure for design studies of future systems which could lead to still higher automation levels.

It is important to note, however, that these increasing levels of automation affect human productivity not so much by numbers of machines as by what machines do. Machines have been used so far mostly for one or another mode of communications; the scope of automation technology now extends to include information processing and decision making functions.

An overriding obligation for those who must decide on implementing automation in air traffic control is to balance costs. Some information processing, decision, and action tasks in air traffic control operations can be performed either by humans or machines. Allocating these tasks to machines results in conservation in human resources on the one hand, but requires additional machine resources on the other. The question is whether, when all the costs have been identified and assessed, the increase in human productivity obtained by implementing any given degree of automation is worth the price of additional machines.

Testing the practicality of automation is not always easy. And once practicality is established, there remains the necessity for further testing of automation with respect to safety and effectiveness. The introduction of new areas of automation must have the effect of maintaining or improving the quality of service offered by the ATC system. Despite the difficulties, and despite the technological complexities, the benefits of automation realized to date and envisioned for the future have stimulated continuing investigation. This report describes a major effort along such lines conducted within the AATMS program.

2.2 THE JOB OF THE CONTROLLER

Automation in air traffic control is most directly concerned with the tasks presently performed by human air traffic controllers. To form a basis for discussion of future levels of automation, a brief examination of the controller's role today is in order.

Air traffic controllers work in three kinds of facilities: flight service stations, en route traffic control centers, and terminals. Flight service stations provide information services to airspace users. So do en route centers and terminal facilities, which also provide services related to control of traffic movement. Therefore, the discussion which follows deals with controller activities in the latter two kinds of facilities since they perform the broadest and most representative range of ATC services.

Terminal and en route facilities are sited and linked together in such a way as to provide appropriate service capability to airspace users. The airspace itself is structured in a reflection of user needs and use patterns, i.e., surveillance coverage, air route structures, and navigation aid installations are generally concentrated according to air travel patterns.

Users request and receive services from the system according to their eligibility, capability, purpose or intent, and the situation or phase of flight. For example, there are two basic kinds of agreement between the system and its users in terms of flight rules to be followed. Under Visual Flight Rules (VFR), the pilot assumes the responsibility for maintaining a safe distance from other aircraft, operating under the rule of "see and avoid". For VFR traffic, separation assurance is not ordinarily provided by the ATC system. The other salient feature of VFR is that the pilot navigates and guides the aircraft by visual reference, i.e., without necessarily relying on instruments. Under VFR only a basic set of instruments and minimum pilot qualifications are required. A pilot flying under Instrument Flight Rules (IFR), on the other hand, must be more highly qualified (trained) and have on board his aircraft certain navigation and communication devices. Table 2.2-1 shows a comparison of requirements for VFR and IFR flight.

TABLE 2.2-1 PILOT AND AIRBORNE EQUIPMENT REQUIREMENTS FOR VFR AND IFR FLIGHT

TYPE OF AIRSPACE	FLIGHT CONDITION	PILOT REQUIREMENTS		
		Current Pilot Certificate	Appropriate Rating	Current Medical
Uncontrolled	VFR (day)	1. Student 2. Private 3. Commerical 4. ATR	1. Single-Eng. 2. Multi-Eng. 3. Land 4. Sea 5. Instructor 6. Instrument 7. Helicopter 8. Glider	1st, 2nd (FAR 61.3)
Uncontrolled	VFR (night)	Same as VFR (day)		
Uncontrolled	IFR	Same as VFR plus: Pilot Certificate: Private or higher with 200 hours	Rating: Instrument	
Controlled (nonpositive)	VFR	Same as uncontrolled VFR plus: Pilot Certificate: Private or higher		
Controlled (nonpositive)	IFR	Same as uncontrolled IFR plus: FCC radio-telephone rating		
Positive control	VFR	Not authorized		
	IFR	Same as controlled nonpositive IFR		

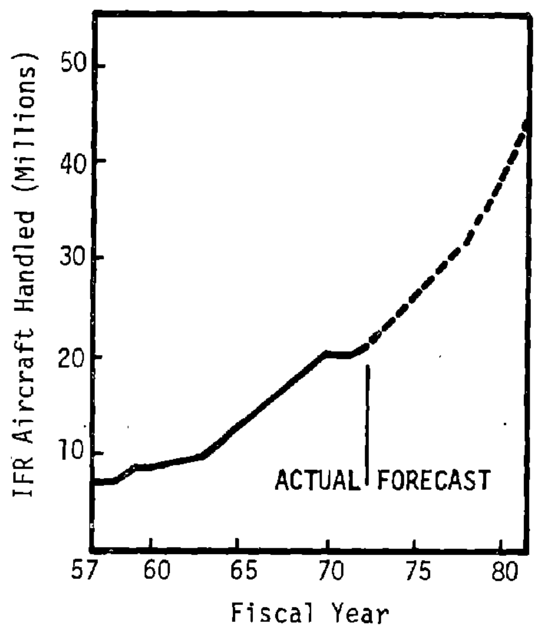
(Adapted from FAA, 1973)

TABLE 2.2-1 PILOT AND AIRBORNE EQUIPMENT REQUIREMENTS FOR VFR AND IFR FLIGHT (cont'd)

TYPE OF AIRSPACE	FLIGHT CONDITION	AIRBORNE EQUIPMENT REQUIREMENTS
Uncontrolled	VFR (day)	1. Airspeed 2. Altimeter 3. Compass 4. Tachometer 5. Oil temperature 6. Manifold pressure 7. Fuel gauge 8. Landing gear 9. Belts (FAR 91.33)
Uncontrolled	VFR (night)	All above plus: 1. Position lights 2. Anti-collision light 3. Landing light (if for hire) 4. Electrical source
Uncontrolled	IFR	Same as VFR plus: 1. Two-way radio 2. Navigation system 3. Gyro turn/bank 4. Sensitive altimeter adjustable for barometer pressure 5. Clock with sweep second hand 6. Artificial horizon 7. Directional gyro or equivalent 8. Generator
Controlled (nonpositive)	VFR	Same as uncontrolled VFR
Controlled (nonpositive)	IFR	Same as uncontrolled IFR
Positive control	VFR	Not authorized
	IFR	Same as uncontrolled IFR plus: 1. DME 2. Transponder 3. VOR (in TCA's)

(Adapted from FAA, 1973)

Aircraft flying IFR (air carriers, military, business or executive general aviation, and a growing segment of private general aviation) receive the highest order of system services, including, for example, separation assurance. Figure 2.2-1 shows the growth of demand for IFR services over several years. IFR demand is partly a function of weather, i.e., when conditions are below the minima necessary for VFR "see and avoid" flying, the user must follow the instrument flight rules. However, especially in the case of air carriers and military, IFR is frequently the basis of flight whatever the weather or visibility conditions*. IFR demand is also influenced in part by airspace structure. Certain portions of the airspace have been set aside for IFR flying only; users whose path traverses that airspace must always follow instrument rules, at least during that portion of their flight.



Fiscal Year	Aircraft (in millions)
1957	8.0
1960	9.4
1965	12.9
1967	15.1
1968	18.1
1969	20.6
1970	21.6
1971	21.3
1972**	22.0
1973**	23.2
1974**	24.4
1975**	24.8
1976**	26.1
1977**	27.5
1978**	29.3
1982**	38.7

**Forecast

(Adapted from FAA, 1973)

FIGURE 2.2-1 DEMAND FOR IFR SERVICES, 1957-1982

*This trend toward IFR utilization comes, in part, from advances in aircraft performance characteristics. Aircraft closing speeds have reached the point where human reaction times are not adequate to achieve the avoidance response after another aircraft on a collision course has been detected. Thus, additional means of separation assurance beyond "see and avoid" are required.

Figure 2.2-2 is an illustration of an IFR flight involving two terminals and an en route center. The aircraft departs from terminal A, cruises through the jurisdiction of an en route center, and arrives at terminal B. The airspace in each facility's jurisdiction is further subdivided into sectors. A controller or controller team is responsible for each sector. Thus, as the aircraft moves along the ground, takes off, cruises, lands, and moves to its parking spot, the responsibility for providing control services passes from sector to sector and from facility to facility. Each transfer of responsibility is called a "handoff"; the dots and arrows on the figure illustrate the handoffs involved in the hypothetical flight.

The circled numbers on the figure indicate selected points in the flight at which controller services are provided, as follows:

> The aircraft pilot notifies the system of his intentions by filing a flight plan. In this case, the flight plan is IFR. (The data to support planning of the flight might be provided to the pilot by a flight service station.) The preliminary flight plan prepared by the pilot is amended (if required) and approved by an agent of the ATC system.
>
> The mechanism for implementing the plan is a clearance. Clearances may be given for the entire flight; or, more frequently, clearance is given to an intermediate point or "fix". When the pilot is ready to depart, he calls the ground controller (1) and receives a departure taxi clearance including instructions on taxiway and runway use, place in line for departure, and radio frequency of the local controller (2). The local controller issues clearance to take off, provides further clearance data as appropriate, and gives directions for contacting departure control.
>
> When the aircraft becomes airborne, the departure time and appropriate flight plan data (e.g., estimated arrival times at various points, or revised estimates) are passed on to other facilities and jurisdictions involved. The departure controller (3) next assumes responsibility for control, providing the guidance instructions (vectors) required for separation assurance, avoidance of weather phenomena such as turbulence or thunderstorms, navigation assistance, and clearing the aircraft to successively higher altitudes as it climbs away from the departure point.

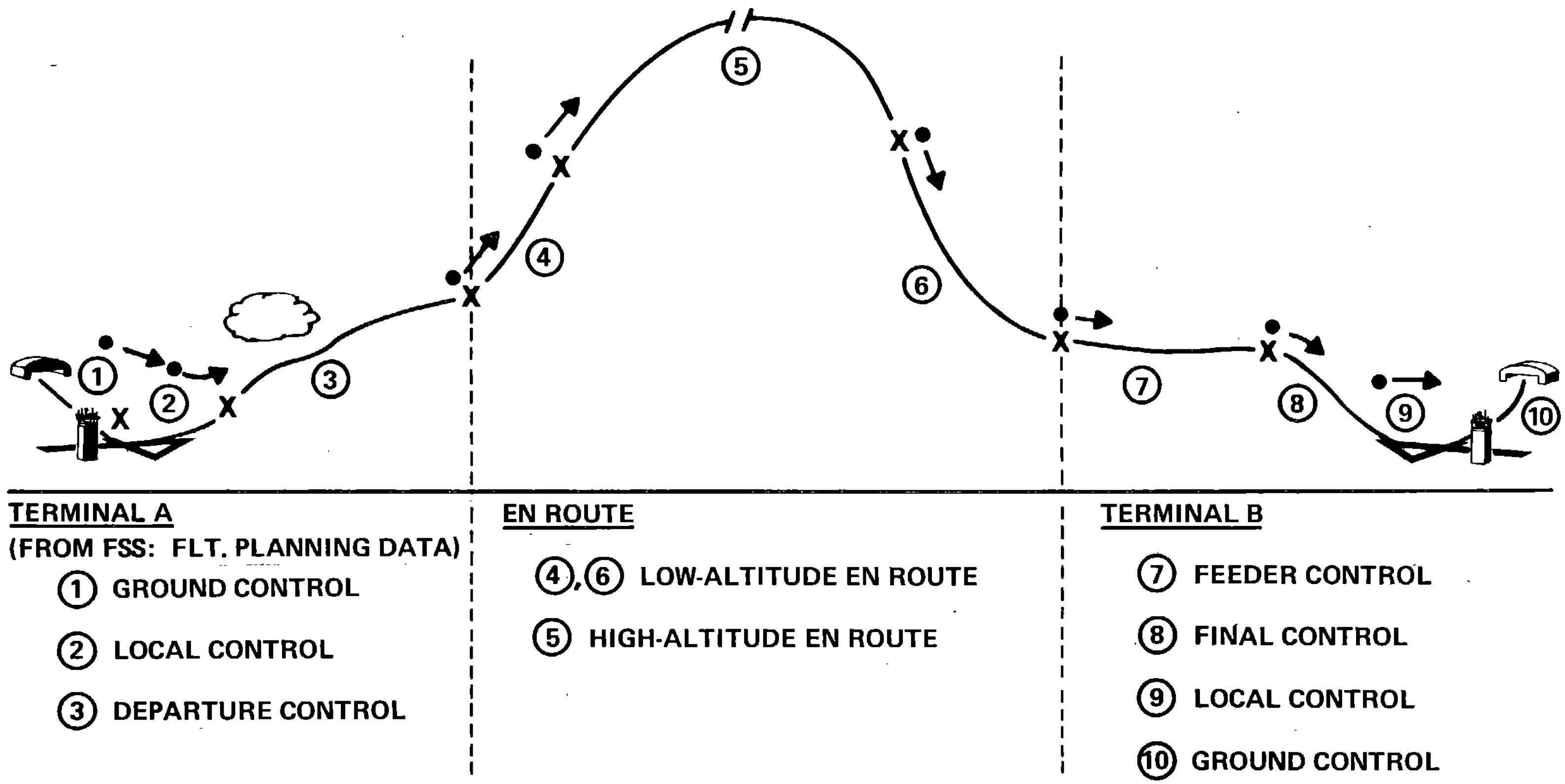


FIGURE 2.2-2 SIMPLIFIED SCHEMATIC REPRESENTATION OF CONTROLLER FUNCTIONS IN AN IFR FLIGHT

The hypothetical flight next passes from the terminal area into the jurisdiction of an en route center. Responsibility for control is transferred, in the example, to a low-altitude en route sector (4). The controller continues the process of clearance to higher altitudes (and intermediate locations further along the route of flight as appropriate), and continues to provide vectors as necessary.

The example flight of Figure 2.2-2 shows that sectorization within a facility can be vertical as well as horizontal. The aircraft, having entered the jurisdiction of the en route center, climbs through a low sector and is handed off to a high-altitude sector for its cruise. The sector controller (5), having assumed responsibility, continues to provide direction, speed, or altitude vectors as appropriate for navigation, weather avoidance, and separation assurance.

At the appropriate point, the aircraft is cleared to begin a descent. The descent takes it back into a low-altitude sector (6), with the responsible controller continuing the provision of service as necessary. The aircraft is next handed off to the jurisdiction of its destination terminal facility.

Controller (7) at the destination terminal is a feeder controller. In addition to vectors for traffic, weather, or navigation, the feeder controller issues guidance instructions that begin the process of arranging arriving aircraft in an orderly procession. He arranges for aircraft to arrive at an appropriate rate, in initial sequence for landing, and with correct spacing for hand-off to the final controller (8).

The final controller completes the process of sequencing and spacing, issuing the instructions necessary for the aircraft's approach for landing.

Local control (9) gives clearance to land and landing instructions, handing over the arriving aircraft to ground control (10), who provides the arrival taxi clearance and directions, completing a hypothetical IFR flight.

Figure 2.2-2 illustrates, in a simplified way, the general nature of controller positions and duties at terminal and en route center facilities. It should be kept in mind that at peak travel hours in heavily used parts of the airspace, the controllers may be responsible for many aircraft in their sectors at the same time. Indeed, one reason for sectorization is to help provide sufficient controller manpower to handle these simultaneous responsibilities.

While the special responsibilities of a controller may differ according to his position (e.g., ground control, high altitude en route, feeder control), the ways in which he collects and analyzes information, makes decisions, and takes action are sufficiently common across all positions to allow summarization in a relatively small number of task categories. Table 2.2-2 is one such categorization, originally developed by Davis (1961) through observation of air traffic controller activities at en route centers.

GIVES CONTROL INSTRUCTIONS
OBTAINS INFORMATION
GIVES INFORMATION
PERFORMS MANUAL TASKS
COORDINATES
NO OBSERVABLE CONTROLLER ACTIVITY

(after Davis, 1961)

TABLE 2.2-2 CONTROLLER ACTIVITY CATEGORIES

Except for the activity of decision-making, which is essentially internal and not directly observable, these categories embrace all information-related and action-related tasks associated with air traffic control.* For example, consider this selected list of controller actions identified by Davis as part of the category of control instructions.

Control Instructions
Vectors Aircraft
Changes Altitude
Changes Route

Vectors, it will be recalled, may be given to direct an aircraft around weather or other air traffic. Altitude changes may be given in the process of climb or descent, to avoid turbulence or weather, or for

*In the Davis categorization scheme, decision-making is partially subsumed under the heading of "No Observable Controller Activity", which also includes pauses between other activities and periods when the controller is not performing any activity.

purposes of separation assurance. Aircraft fly along air routes; route changes are given in response to changed intentions or to assist in controlling traffic flow.

Some of the information-related tasks listed by Davis are:

<u>Obtains Information</u>
Receives Handoff
Receives Change Estimate (Pilot)
Receives Request for Altitude Change

<u>Gives Information</u>
Altimeter Setting
Handoff to Sector
Notes Possible Conflict

Most of these tasks titles are self-explanatory. Two are especially noteworthy -- changes of estimate and conflict prediction. For various reasons, the planned path of an aircraft from one point to another is not always made good. For example, an aircraft expecting to reach the intersection of two airways at a certain time might encounter unexpected headwinds and be late. Thus, the pattern of air traffic is not only moving, but also shifting in relation to original intentions as unforeseen factors are encountered.

Because of such emerging shifts and for other reasons, such as navigational error, aircraft may begin to move too close together. This condition is a "conflict". The ATC service of separation assurance involves predicting and resolving conflicts -- hence, the task "notes possible conflict".

In general, automation is seen as a means to raise the productivity of the air traffic control system by increasing its efficiency and by bringing about savings in human resources. Proponents of automation contend that the greater speed, accuracy, consistency, and reliability of machines will enable the system to handle more aircraft, while at the same time preserving (and perhaps even enhancing) the safety and quality of service provided to airspace users. Those who favor automation also suggest that allocation of more tasks to machines will have an additional favorable influence on productivity in that it will "unburden" the human operator of routine and time-consuming tasks.

"Unburdening", however, should be considered in a context less restricted than the task level. For example, Corson et. al. (1970) looked at the air traffic controller this way:

> "The successful controller appears to require -- at least -- the following special talents and aptitudes:
>
> - A highly developed capacity for spatial perception
> - A keenly developed, quick, and retentive memory
> - A capacity for articulate and decisive voice communication
> - A capacity for rapid decision making, combined with mature judgment
>
> There is compelling evidence that many controllers work for varying periods of time under great stress. They are confronted with the necessity of making successive life and death decisions within very short time frames -- decisions requiring constant standards of perfection.
>
> The operations schedule in most facilities requires that the personnel work on a 24-hour, multi-shift basis 365 days a year. This schedule adds to the day-in-day-out wear and tear on the individual and to the disruption of normal family and social relationships. The controller is convinced that the job is unique in that he will "burn out" between ages 40-50 and will not be able to continue controlling traffic."

Some evidence has been reported to support the assertion that air traffic control is a stressful job. For example, in a medical comparison between air traffic controllers and pilots, Catterson (1970) found an earlier and more frequent manifestation of such problems as hypertension and peptic ulcers among air traffic controllers than among pilots. A series of studies by the FAA Civil Aeromedical Institute begun in 1968 found differences in heart rates as a function of traffic load and further differences as a function of the nature of traffic (i.e., arriving vs. departing).

It is not presently clear which of the information, decision, and action tasks performed by air traffic controllers induce stress, or even if the tasks can be differentiated in terms of stress effects. Older and Cameron (1972) had controllers rank tasks and task groups in terms of how demanding they felt the tasks to be. Table 2.2-3 is an example of the results.

Older and Cameron's rankings must be interpreted with caution because they are based on subjective data obtained from a rather small sample of controllers. Still, they suggest the possibility that those tasks directly connected with the control of aircraft may be a principal source of stress in the controller's job. If so, it seems likely that the decision-making requirement may be a key component. That is, deciding whether a given pair of aircraft will have a conflict or deciding which way to turn aircraft so as to resolve one conflict without creating another are stressful elements of the job not only because of the need for promptness but also because of the consequences of a wrong decision.

Ratner and others (1972), in studies of the controller's contribution to capacity in manual and automated settings, were able to distinguish between the two decision types. They found that a greater proportion of time was spent in making the predictive-anticipative decision than in making the "which-path" decision.

Most automation concepts envision the ultimate allocation of both kinds of decision-making to machines. Implementing automation in air traffic control may possibly, therefore, have the corollary benefit (so long as the automated system is operating normally) of reducing some of the stressful aspects of the controller's job. It should be noted, however, that because man is to be a monitor of the machine, he must still decide on the correctness of machine-generated actions and intervene if required. One set of problems with respect to stress may, in essence, be traded for another.

TABLE 2.2-3 TERMINAL AIR TRAFFIC CONTROLLER ACTIVITIES RANKED IN TERMS OF TASK DEMANDINGNESS

1.* Determine and Issue Landing Sequence and Traffic Information

2. Determine and Issue Instructions Relative to the Flight Path of an Aircraft

3. On-The-Job Training

4. Issue Clearances or Approval for Special Operations (Low Approaches, Contact Approaches, Visual Approaches, Simulated Instrument Approaches, etc.)

5. Issue Landing Clearances and Related Information

6. Issue Takeoff Clearances

7. Issue Control Instructions and/or Advisories to Departing Aircraft

8. Assign Runways

9. Instruct Pilots to Change Radio Frequencies/Radar Beacon Codes

10. Observe and Report Weather Changes

11. Operate Airport Light Systems and Visual Aids

12. Monitor Navigation Aids and Operate Monitor Control Panels

* The rank order is from most to least demanding

(Older & Cameron, 1972)

2.3 THIRD GENERATION AIR TRAFFIC CONTROL

While research workers analyzed controller activities in the system as configured for operation in the early 1960's, others were at work on the design concept for a new generation of the air traffic control system. In 1962, the first edition of a design for the National Airspace Utilization System (NAUS) was published. The design not only incorporated advances in the sensor/effector and communication portions of the system (for example, it envisioned the use of beacon transponders to provide surveillance and identity information), it also addressed the use of automation as a means for increasing controller productivity. (FAA/SRDS, 1962)

The NAUS design documentation included, in a section on data processing functional requirements, a description of an automation "ladder" with rungs or steps of successively higher system automation:

1. Completely manual (machines used only as sensors/effectors)
2. Data processor introduced in flight planning and flight plan updating
3. Display alphanumeric capability introduced
4. Data processor/display subsystems connected; display of flight plan extrapolations
5. Automatic tracking (association of actual and planned positions)
6. Action prompting (handoff pending, conflict detected)
7. Decision aiding (route/altitude change recommendations, tentative sequencing, conflict resolutions).
8. Flow control (long-range traffic planning to prevent overloads)

The concept of a ladder of automation is useful in several ways. It permits, for example, the making of comparisons among successive generations of the ATC system. The ATC system operational in the early 1960's was largely a manual system, situated approximately at Steps 1 and 2 on the ladder -- limited use of automated devices for information processing tasks. The NAUS concept, in comparison, proposed by 1975 to extend automation up to Step 6 -- automatic alerting and prompting of controllers.

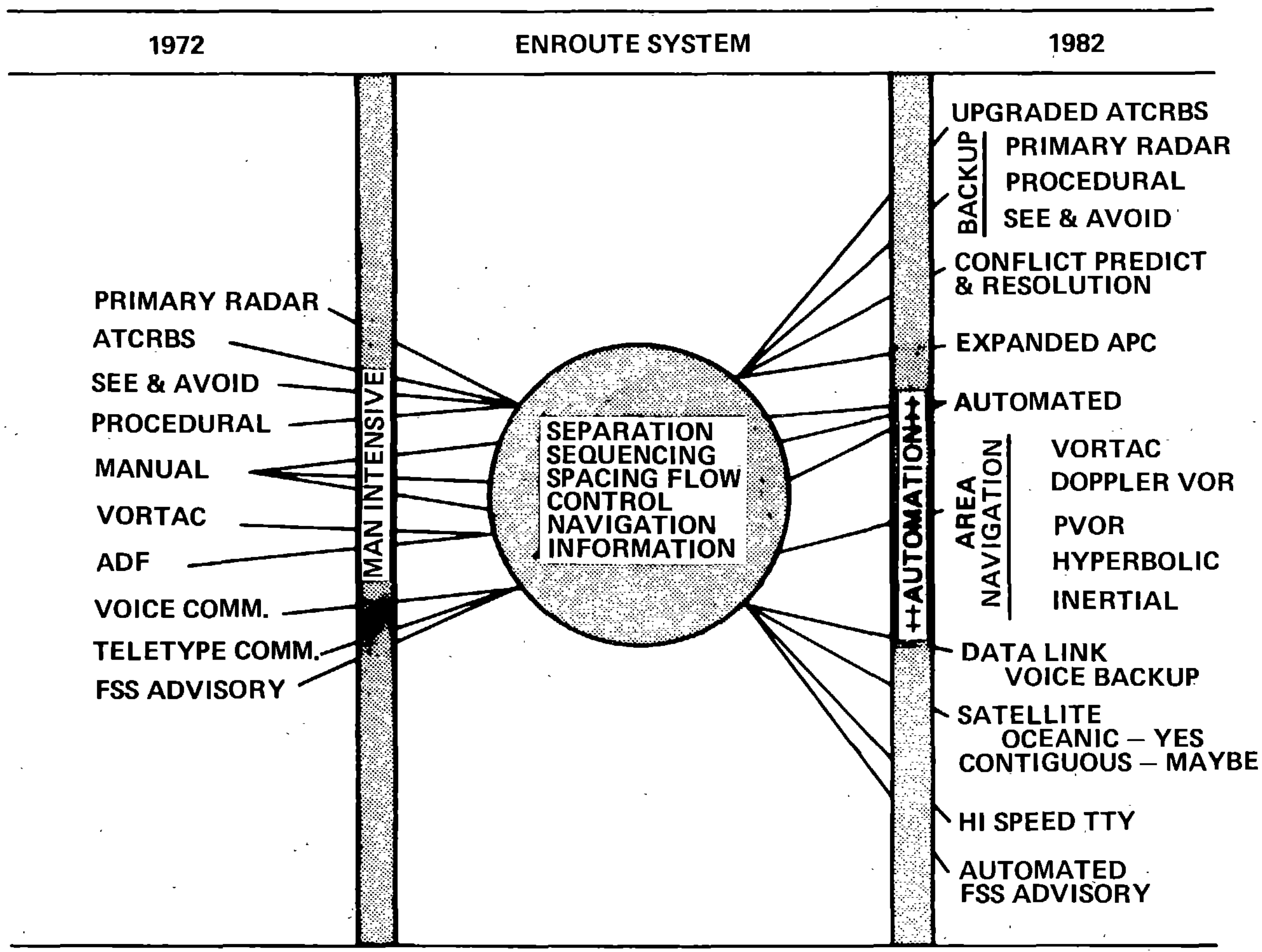
The automation ladder concept is also helpful in organizing thought about the system. For instance, because some parts of the airspace are much more crowded than others, there may not be a need for uniform level of automation. A busy complex of airports serving major population centers might be brought up to automation Step 7 or 8, while facilities responsible for less crowded airspace might be held at Step 5*.

Finally, if the levels or rungs of an automation ladder are considered as increments, the concept can be used in constructing and analyzing plans and timetables for automation. Later in this report, in Chapter 6, the technique of incremental automation is discussed in connection with implementation strategy.

In the intervening ten years, several of the automation concepts proposed in the NAUS design have evolved into firm plans and physical reality. This is reflected in the current FAA policy summary and ten-year plan for the air traffic control system, which describes the on-going program of automation in en route centers and terminals, known generally as the Third Generation ATC System (FAA, 1973). The automation of en route centers, called NAS Stage A, is illustrated in Figures 2.3-1 and 2.3-2. For terminals, the program of automation is known as Automated Radar Terminal System (ARTS). For smaller airports a system called ARTS II is being installed. Major terminals have a more sophisticated version, ARTS III. ARTS is depicted in Figures 2.3-3 and 2.3-4.

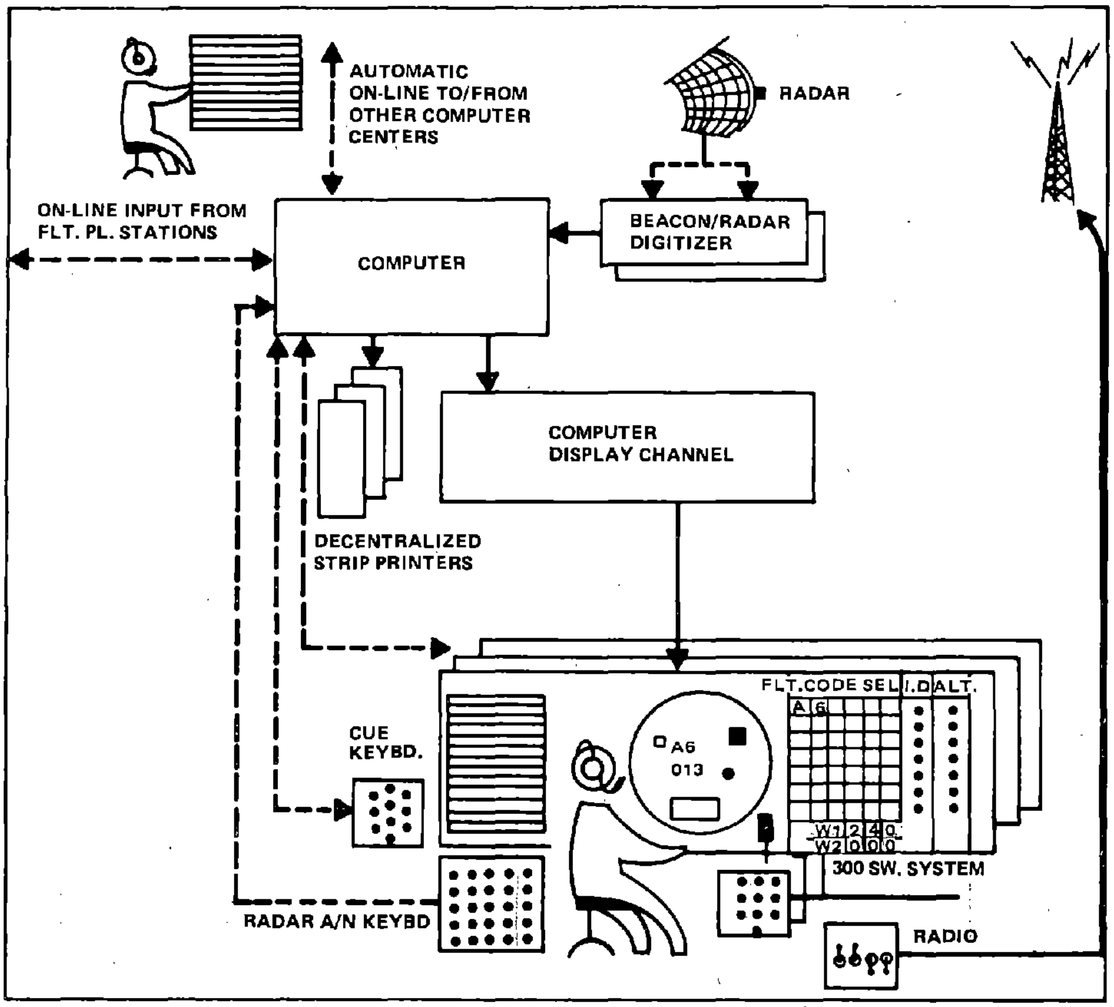
Although planning and implementation of automation in air traffic control are currently under way, continued examination of future needs has raised further questions about the ultimate requirement for automation. At the same time, the press of events impacting on the operational system has had other repercussions. In late 1969, the report of the Department

*Having parts of the system at different automation levels might have the favorable effect of holding down the machine resource requirements for the total system, but such a posture might also pose problems of compatibility and create the need for different levels of controller training.



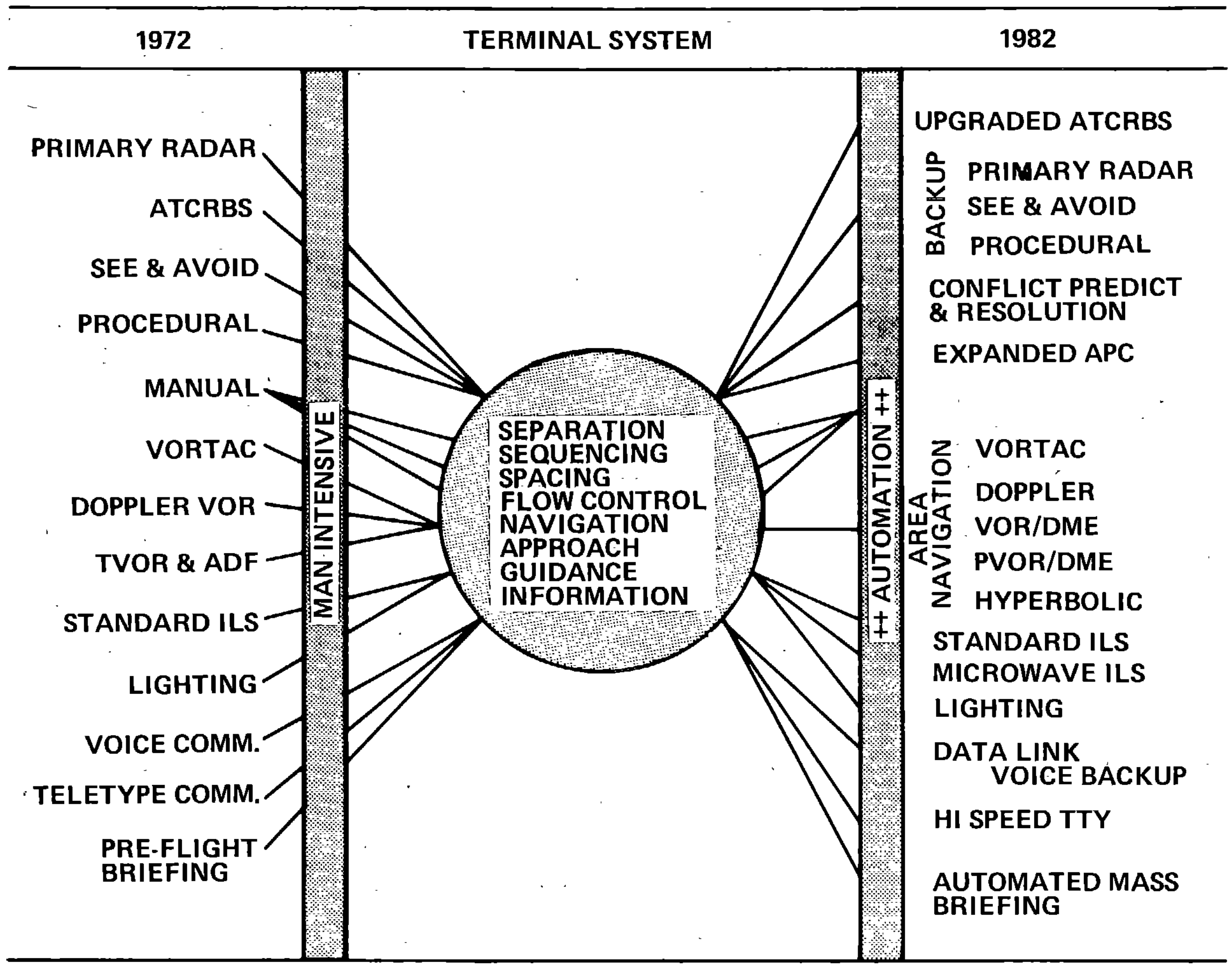
(ADAPTED FROM FAA, 1973)

FIGURE 2.3-1 NAS STAGE A EN ROUTE SYSTEM



(ADAPTED FROM FAA, 1973)

FIGURE 2.3-2 NAS STAGE A AIR ROUTE TRAFFIC CONTROL CENTER



(ADAPTED FROM FAA, 1973)

FIGURE 2.3-3 AUTOMATED RADAR TERMINAL SYSTEM (ARTS)

TYPICAL ARTS III DISPLAY

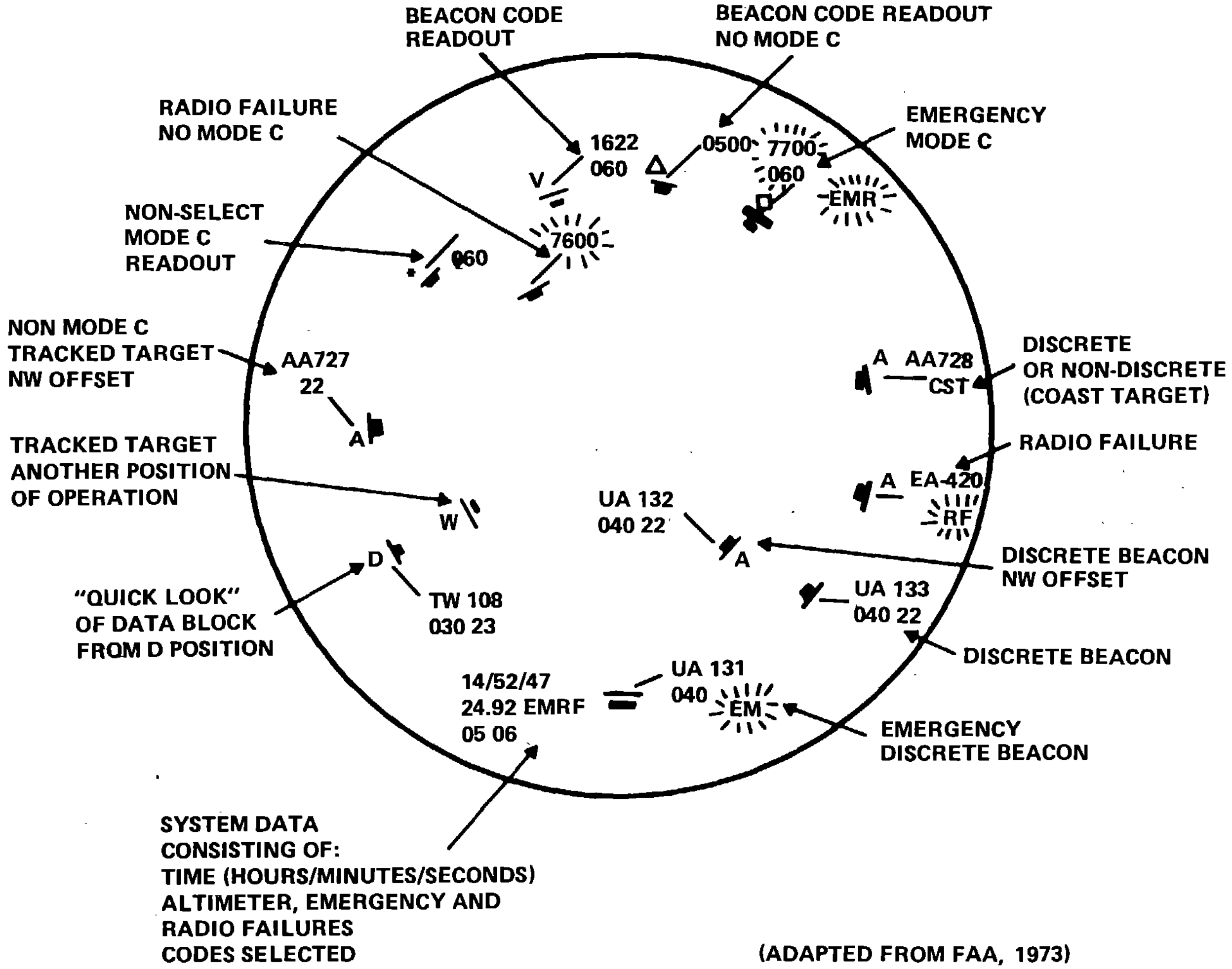


FIGURE 2.3-4 AIRPORT SURVEILLANCE RADAR (ASR) WITH AIR TRAFFIC CONTROL RADAR BEACON SYSTEM (ATCRBS).

of Transportation's Air Traffic Control Advisory Committee (ATCAC) was published. The report began:

> "Air traffic is in crisis. The crisis now manifest at a few high density hubs is the direct result of the failure of airports and air traffic control capacity to keep up with the growth of the aviation industry. With proper leadership, funds, a sense of common purpose in the aviation community, and steps taken to promote coexistence between airports and their neighbors, this deficit can be eliminated through intelligent application of recent advances in aeronautics, electronics, and computer science. Unless strong measures are taken, forces presently in motion will blight the growth of American Aviation." (ATCAC, 1969)

The ATCAC report pointed out that unforeseen growth in demand, coupled with the slow pace of implementing plans for automation, appeared to render the third generation system obsolescent before it could even be completely installed. The committee proposed the upgrading of the third generation system so that, when operational, it could meet the anticipated needs of the near-term future. This program of extension of the present ATC system, the so-called Upgraded Third Generation Air Traffic Control System, is currently under intensive study by the FAA. The current FAA ten-year plan contemplates completion of an "upgraded third generation" system by roughly 1982. The key features of each of these ATC system generations are summarized in Table 2.3-1.

TABLE 2.3-1 AIR TRAFFIC CONTROL SYSTEM GENERATIONS

GENERATION	TIME PERIOD	KEY FEATURES
First	1936-1960	• Limited control, mostly by radio • Procedural control by Flight Progress Strip
Second	1960-1970	• Radar control • Introduction of Air Traffic Control Radar Beacon System (ATCRBS) • 2D fix navigation • Voice communications (Air-Ground, Ground-Ground)
Third	1970-1980	• National Airspace System (NAS) En Route • Automated Radar Terminal System (ARTS) • Greater use of ATCRBS • Centralized flow control • Automated aids to radar control • 2D-3D area navigation • Some data link replacement of voice communications
Upgraded Third	1980-?	• Increased automation of flow control and scheduling • Discrete Address Beacon System (DABS) • Microwave Landing System (MLS) • 2D-4D area navigation • Automated separation assurance • Automated metering, sequencing, and spacing • Increased digital data link communications

2.4 NEXT GENERATION OF AIR TRAFFIC CONTROL

The report of the Air Traffic Control Advisory Commission also directed attention to the need to examine long-range system concepts, which were collectively designated as a fourth generation ATC system.

> "While the upgraded Third Generation System appears to be able to handle the traffic estimated into the 1990's, it is likely to exhibit significant deficiencies before the end of the century .... While ad hoc fixes could be used to overcome some of these deficiencies, the Committee feels a Fourth Generation System should be in orderly development which can supplant the upgraded Third Generation System .... (The) Committee recommends the prompt initation of a system study that determines whether the higher levels of automation achieved by the incremental additions to NAS/ARTS would be fundamentally different from a automation program that was derived from basic considerations of air traffic flow capacity and safety." (ATCAC, 1969)

ATCAC foresaw the fourth generation system study as two parallel efforts, one directed toward examination of higher levels of automation and the other directed toward evaluation of a cluster of synchronous satellites as the base for a data acquisition, navigation, and communication system for aircraft in the continental United States. By 1971 the definition of a satellite-based system was under way, and from these studies there emerged a system concept known as the Advanced Air Traffic Management System (AATMS). (Boeing, 1972; Autonetics, 1972) AATMS concept definition and refinement are still in progress. About a year later, the second part of the study program recommended by ATCAC, examination of higher levels of automation, was undertaken. This report on automation applications in an advanced air traffic management system is a part of this ongoing study program.

3.0 THE STUDY

3.1 OBJECTIVES

The aim of this study was to extend the conceptual definition of a future, highly automated air traffic management system by re-examining the fundamental relationships of men and machines. Specifically, the study was addressed to the following major objectives:

1. Providing a functional description of a highly automated system which will meet the air traffic demands projected for the 1990's;
2. Defining the most suitable roles of man and machine in such a highly automated air traffic management system;
3. Defining the functional effectiveness and practicability of achieving high levels or degrees of automation in the design of future ATM systems;
4. Identifying areas in which projected computer technology may be most effectively applied;
5. Providing the plans for required RDT&E activities that should be conducted to develop and validate a highly automated air traffic management system; and
6. Identifying influences and constraints imposed by automation on other parts of the system.

The principal outcome of the study was envisaged to be a recommended level of automation which would be appropriate to the requirements of 1990 and beyond, effective in that it would have inherent high productivity, and acceptable in terms of safety to those using and manning the system. The specific study products contributing to this outcome are itemized below.

1. Analysis of generic air traffic management activities to the level of individual tasks,
2. Allocation of tasks to men and machines according to their respective performance capabilities,
3. Estimation of the workforce and computer resources required to operate the system at the recommended level of automation,
4. Specification of qualitative and quantitative system manning requirements,

5. Estimation of the operator productivity inherent in the recommended system automation level,

6. Assessment of the capability of the system to withstand failure of automated resources without compromise of safety and capacity,

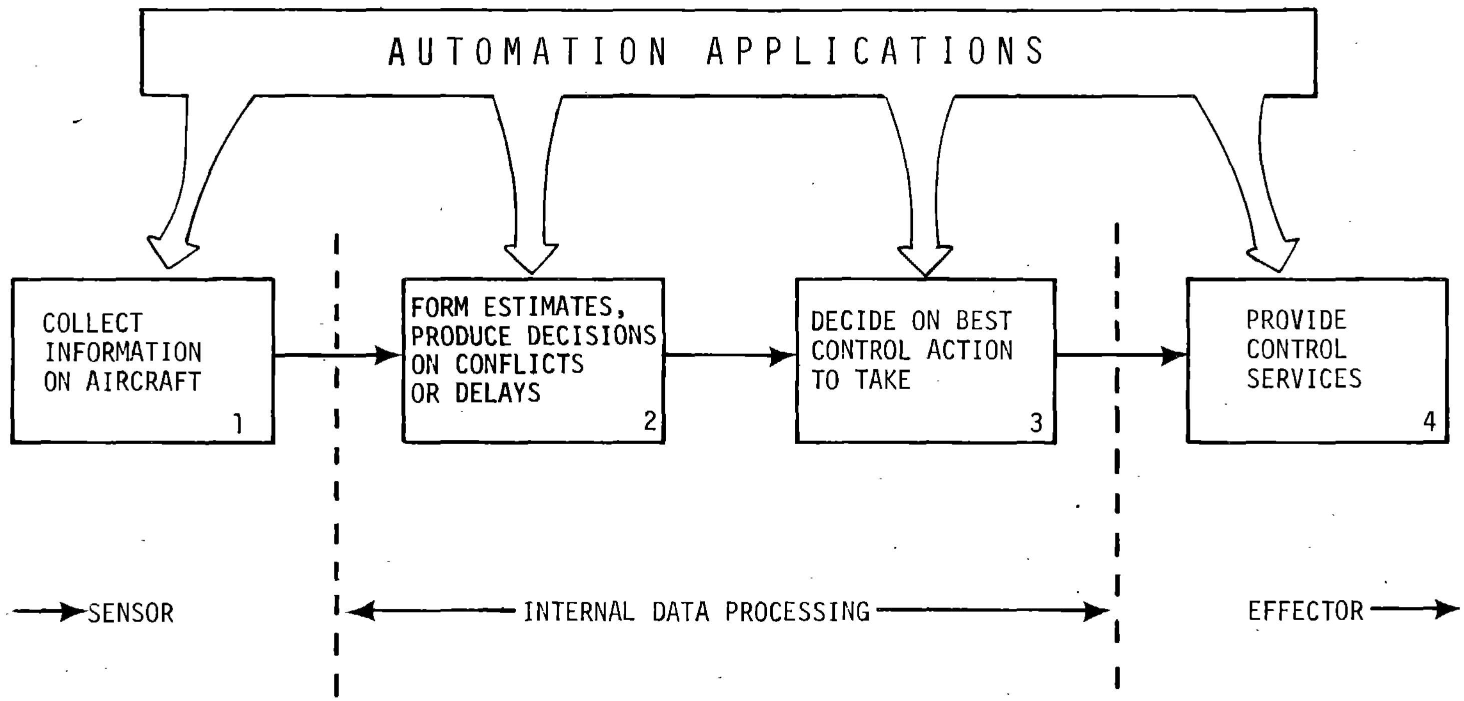
7. Definition of the man-machine interface and delineation of control and display requirements,

8. Outline of a time-phased RDT&E plan and a strategy for implementing higher levels of automation.

The concept of levels or degrees of system automation is not an innovation; it has substantial historical precedent in the study of air traffic control. As pointed out in the introduction to this report, the NAUS design team envisioned an "automation ladder", made up of eight steps or levels of automation in air traffic control systems. (FAA, 1962) In another study, Buckley and Green (1962) outlined thirteen categories of man-machine function allocation in ATC, each corresponding to a progressively higher level of system automation. The concept of generations of ATC systems outlined by ATCAC (1969) and incorporated in current FAA planning documents carries the implicit notion of successively greater degrees of automation in the evolution from the Second, to the Third, to the Upgraded Third Generation systems. Thus, in formulating the objectives of this study and in specifying a recommended level of automation, the work was guided by the concept of incremental and evolutionary growth of the system through levels of automation, spanning the range from a wholly manual system to one in which there is minimal human involvement.

It should be kept in mind that the emphasis in this study was on the internal processes of the system, rather than on sensors and effectors. Figure 3.1-1, which uses the system model of Buckley and Green (1962) as a basis, depicts this area of concentration.

In the box numbered (1), information is collected on aircraft. In boxes (2) and (3), the information is processed and used to make control decisions. In box (4), the decisions are implemented. While consideration was given to the tasks implied in boxes (1) and (4) (e.g., receiving information manually by listening, transmitting information manually by speaking,



(After Buckley & Green, 1962)

FIGURE 3.1-1 ATC PROCESS FLOW

or automating the process through the use of data link), most of the air traffic controller activities dealt with in the study fell in the process areas of boxes (2) and (3).

This concentration on the "internal" portions of the system (information processing and decision making) was motivated by two concerns. First was the intent to focus on those aspects of air traffic control where automated devices could be used not as simple extensions of man (i.e., not as enhancements of his ability to sense information or to take action) but as aids or surrogates to man in managing and directing the flow of air traffic. To put it another way, it was felt that the phrase "higher levels of automation" implied the participation of machines in actually controlling aircraft and not just in conveying information to and from aircraft. The second reason for directing attention to internal processes was to isolate the study of automation applications, insofar as possible, from any particular system design concept. Thus, the study attempted to deal with the question of automation in such a way that the outcomes would have meaning regardless of the ultimate choice of the means to accomplish surveillance, navigation and communication.

Given the objective to select a level of automation which would be appropriate to the requirements of the 1990-2020 era and of inherently high productivity, it seemed reasonable to expect at the outset of the study that the automation level of choice would be an extension of that envisioned for the near-term future, in the sense that more tasks would be allocated to machines. The ATCAC report alluded to such a higher level:

> "Adding the functions of conflict prediction and resolution, spacing, sequencing, and metering with ground-air-ground data link to the semi-automatic NAS Stage A and ARTS III, automates all normal ATC functions. But this is not the limit to automation possibilities. A higher level of automation would have the controller provide system status inputs such as weather and wind shifts, blocked runways, aircraft emergencies, and ATC equipment failures, so that the ATC system automatically accommodates to these inputs in directing traffic." (Underlining added)
>
> (ATCAC, 1969)

As mentioned earlier, it also seemed reasonable to assume that the chosen level of automation would be reached by steps or increments, rather than in a single jump. Such an evolutionary development would allow, for instance, the matching of system automation to technological progress. Further, it would permit the spreading of implementation costs over time. Finally, it would result in a gradual transition from one generation to the next, maximizing the potential for acceptance by system users and operators.

In performing this study, there was no arbitrary selection of a baseline from which to measure the level of automation. Thus, instead of taking the automation level of today's ATC system or that of the Upgraded Third Generation System as a point of departure, the scope of the study encompassed all controller tasks, including those now automated as well as those performed manually. This was done in the belief that the statement of study objectives implied taking a fresh look at the entire spectrum of air traffic control activities and reassessing their potential for automation without restriction. It was felt that such an approach would assure the utility of study results both in evaluating long-range and near-term system concepts and in helping to formulate guidelines for evolutionary development of the ATC system over the next twenty years.

3.2 APPROACH

The approach adopted for this study involved the following major steps:

1. Analysis of air traffic control activities
2. Development of a method for man-machine allocation
3. Synthesis of a generic system description
4. Selection of a preferred level of automation
5. Determination of system requirements and design implications.

Figure 3.2-1 is a schematic representation of the study approach, in which the numbered boxes correspond to the five steps above. The relative size of the boxes illustrate increasing levels of detail in system definition as the study progressed. Figure 3.2-1 also indicates the division of the study into three phases, characterized as analysis, synthesis, and evaluation. The activities carried out in each study phase are outlined below.

Phase A - Analysis and Definition

The first phase of the study involved analysis and definition of air traffic control functions. Concurrently, the man-machine interface was defined; and a method for allocating tasks to men and machines was developed. Phase A also involved specification of functional system performance measures and development of the requirements for a computer simulation model (DELTA, for Determine Effective Level of Task Automation) for use later in the study in estimation of resource requirements.

Phase B - Synthesis of System Description

In Phase B, the ATC function analysis was refined and extended to a level of detail where each unit of activity (task) could be integrally assigned to man or machine resources. Through application of the allocation methodology, a quantitative expression of task automatability (called the Automation Index) was derived; and on this basis, all ATC tasks were allocated to men or machines to form five incremental levels of system automation.

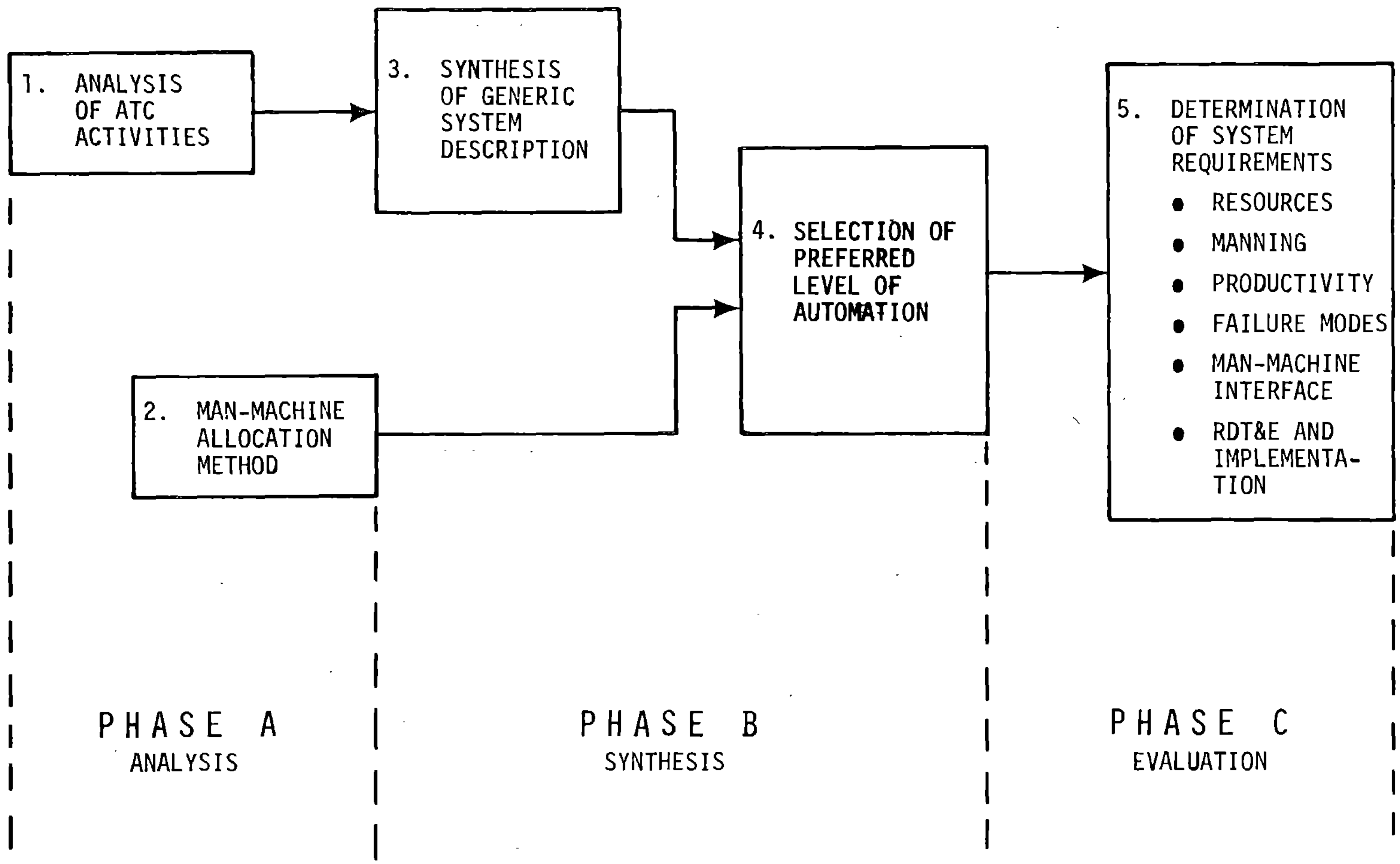


FIGURE 3.2-1 STUDY APPROACH AND WORK PHASES

Phase C - Evaluation of System Requirements

The system description resulting from the Phase B effort formed the basis for estimates of human and computer resource requirements at successive levels of automation and then for selection and refinement of the level which provided an optimum man-machine mix. This, in turn, was used as the point of departure for derivation of system manning requirements, estimation of productivity, analysis of failure effects, and specification of man-machine interface characteristics. As a final step, a plan for RDT&E activities was prepared; and a strategy for implementing the recommended level of automation was outlined.

4.0 RESULTS

While the study was self-sustaining, in the sense that interim products developed in one phase were the basis for the next, continuous input from many organizations and individuals in the aviation community was sought and received throughout the project. The interactions not only fed the study but also helped to modify, refine, and validate the work as it progressed. The results obtained in each study phase are summarized below. A detailed exposition of the results and the methods to obtain them is presented in Volumes II through V of this report.

4.1 PHASE A RESULTS

Phase A, which was nine weeks in duration, produced five major products:

- Preliminary Function Analysis
- Man-Machine Interface Definition,
- Methodology for Man-Machine Allocation,
- System Performance Measures,
- Model and Simulation Requirements.

4.1.1 Preliminary Function Analysis

To provide services to airspace users, an air traffic control system must perform certain activities or functions. Depending on the service required, functions are carried out singly or in combinations. Thus, it is possible to describe the system as a network of functional components (as distinct from physical components) whose operation results in services to airspace users. The function analysis of air traffic control carried out in Phase A had two salient features:

- the functional structure of the system was described in such a way that it was extensible to whatever level of detail that might be necessary to allocate activities wholly and uniquely to men or machines.

- the function analysis was made as free as possible of system concepts and equipment considerations by defining air traffic control in terms of what activities were to be performed rather than in terms of the agents of accomplishment.

Thus, the function analysis was cast in a form which allowed great specificity of system definition in terms of activities and outcomes but without the need to identify the means by which they were effected.

Figure 4.1-1 is an extension of the basic air traffic system model given earlier in Figure 3.1-1 (page 3.1-3). In addition to the four activities shown previously, two more are depicted to illustrate in a simplified way the extended scope of thought about system automation required by this study. The additional boxes (5) and (6) also symbolize the extension of thought about air traffic control itself. The system is now thought of as "management" system carrying out functions beyond real-time control of aircraft and including the activities of traffic planning and flow control, hence the use of the term "air traffic management system".

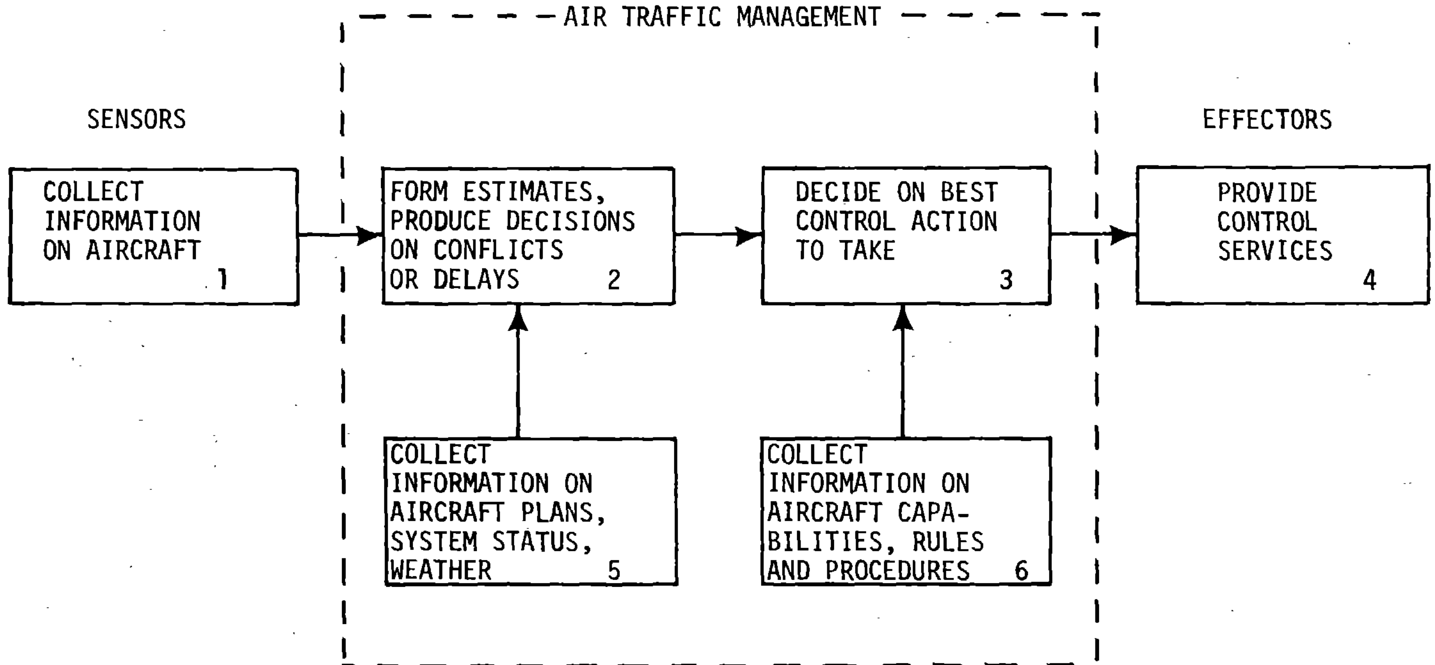


FIGURE 4.1-1 AIR TRAFFIC MANAGEMENT PROCESS FLOW

The function analysis included not only the control activities implied in boxes (2) and (3) of the diagram, but also the management activities of boxes (5) and (6). The sensor and effector portions of the system, boxes (1) and (4), were not treated in the function analysis because they were considered to be highly influenced by the specifics of system concept and mechanization. However, in the interest of providing as complete a functional description as possible, the boundaries of the analysis were broadened to include the zones of interface with sensors on the input side and with effectors on the output side.

To serve the ends of the study, it was anticipated that the function analysis would need to be carried out to at least three levels of detail. For ease of reference, these levels were designated as functions, subfunctions, and tasks and assigned a number code as follows:

1.0 Function

1.1 Subfunction

1.1.1 Task

This allowed each functional component of the system to be described and defined iteratively and to be fitted into place in the overall functional network.

At the same time, however, it was important that the analysis be generic in nature. "Generic", as used here, means independent of hardware implementation and, to the extent possible, independent of system concept. Such a concept-free approach would at the same time allow the greatest latitude for ultimate system configuration choices and eliminate confusion or ambiguities between tasks genuinely required for the management of air traffic and tasks whose performance requirement is induced by a specific system concept or mechanism.

The function analysis performed for this study was not unique; there have been several previous investigations which produced functional descriptions of air traffic control at various levels of detail and to various degrees of system specificity. To take full advantage of this earlier work and to avoid duplication of effort, these previous studies were reviewed and abstracted to serve as inputs for the present effort. A second valuable source of data was handbooks, manuals, instructional materials, and other such official publications describing controller activities and duties. While this material was not expressly formatted as functions, subfunctions and tasks, it proved to be an extremely useful catalog of the work that controllers do and, hence, easily translatable into functional terms.

A master list of all ATC activities from all the input sources was compiled and indexed. At that time, no effort was made to distinguish among different levels of detail or variations in terminology. This effort produced almost two thousand separate activity items, which were then sorted according to the phase(s) of flight in which they occurred. The flight phases were:

Preflight planning
Preflight taxi
Takeoff
Departure
Transition to en route (later merged into the en route phase)
En route
Transition to arrival (later merged into the arrival phase)
Arrival
Final approach and landing
Missed approach
Post-flight taxi

The activity items for each phase of flight were then grouped into categories reflecting similarity of activity or similarity of outcomes. The classification system was entirely emergent and empirical, in the sense that no attempt was made at that point to force the activity items into predetermined categories or to develop a set of categories which, on logical grounds, were complete and exhaustive. The activity categories reflected only the functional similarities which emerged when all the items for a given flight phase were considered as a whole.

Meanwhile, a flow chart of an "IFR flight" was prepared to show the interactions between pilot and controller, the activities carried out by each, and the inputs required for those activities. Thus, both those activities within the main flow of pilot-controller interaction and those that, although not a part of the main flow, must be performed to provide required inputs were identified. The activity categories by flight phase were then mapped onto the flow chart. They were carefully crosschecked; and activity categories were added or modified where, on logical grounds, it appeared necessary for the functional completeness of the system. The result was a list of functions to be performed during each phase of flight. These were then compiled into the list of generic air traffic management functions extending across all phases of flight.

The preliminary definition of system functions conducted in Phase A was subsequently refined and extended to the subfunction and task levels as part of the Phase B effort. Lists and examples are therefore given later in this report, under Phase B results.

4.1.2 Man-Machine Interface Definition

A central question in establishing an automation level for air traffic management is how to choose between men and machines for the performance of tasks. The choice can be made on many grounds; those used in this study centered around the relative performance capabilities of human and automated resources. Thus, in Phase A, definition of the man-machine interface involved collecting information on the performance capabilities of men and machines, developing a framework of criteria for choosing between them, and arraying the results for later use in making allocation decisions.

An extensive review was made of the literature pertaining to man and machine performance. In all, nearly two hundred primary sources were identified. In addition, the review turned up three excellent summaries of the literature on man-machine performance capabilities, incorporating many citations of the primary sources. These compendium documents not only saved a great deal of research drudgery, but also afforded the benefit of the thoughtful analysis performed by the authors of these summary reports.

The findings of the literature review were classified according to specific performance capabilities and then aggregated into clusters of capabilities which, on the basis of internal evidence and logical analysis, appeared to be related. These clusters or categories of performance were assigned a descriptive title which was indicative of the nature of the performance and consistent with the general usage found in the literature. Similarly, the constituents of these categories -- the specific types of performance -- were given designations which were both descriptive and compatible with the terminology of the literature. The results are presented in Table 4.1-1 which contains a listing of performance categories and types, a brief definition of each category, and examples of this performance in the field of air traffic control.

In connection with Table 4.1-1, it should be noted that the titles and descriptions are intended to apply equally to man or machine as a performance mechanism. That is, both man and machine are assumed to have all of these performance capabilities to some degree. Note also that the list in Table 4.1-1 is limited to those categories and types of performance which were deemed relevant to air traffic control. No attempt was made to provide an exhaustive inventory of performance capability. Thus, areas of performance such as the capability to exert force or to withstand weightlessness were excluded since they have no bearing on man-machine functional allocations in air traffic control.

As a final observation, it should be recognized that the performance classification scheme employed here was prompted by essentially pragmatic concerns. While there is logical consistency in the list, there may be some overlap between categories and some artificial distinctions. In view of the short time available in Phase A to complete the work, airtight mutually exclusive categories were felt to be a nicety that should be foregone in the interest of providing a workable rubric of performance classifications. In other words, the main concern was not the organization *per se*, but the utility of the classification scheme in locating the criteria which apply to man-machine allocations with respect to a given kind of performance.

Having determined the essential framework of performance requirements in air traffic control, the next step was to collect and organize information

TABLE 4.1-1 CLASSIFICATION OF MAN-MACHINE CAPABILITIES

MONITORING

To maintain a state of readiness or preparation for receipt of input signals pertaining to an operation or condition.

Monitoring includes:	Examples:
Search	Listening for messages
Surveillance	Vigilance for warning signals
Vigilance	Observation of displays
Watch-keeping	Surveillance of traffic patterns

SENSING

To perceive external stimuli, to recognize a change of external state, to acquire data from the environment.

Sensing includes:	Examples:
Perception	Sensing aircraft position
Signal Detection	Signal/noise discrimination
Signal Recognition	Recognition of movement
Discrimination	Detection of alarm signal
Recognition of discrete change	
Recognition of dynamic change	

INFORMATION PROCESSING

To transform, to organize, to break down, to combine, or to operate on input data or signals.

Information processing includes:	Examples:
Encoding/Decoding	Encoding flight data
Sorting	Solving navigation equations
Filtering	Calculating flight path
Ordering	Estimating demand or load
Merging	
Analysis	
Calculation	

TABLE 4.1-1 CLASSIFICATION OF MAN-MACHINE CAPABILITIES (cont'd)

INTERPRETING

To construe, to derive, to translate, or to assign meaning to information, data, or signals.

Interpreting includes:	Examples:
Pattern recognition Interpolation Extrapolation Prediction Association Classification	Reading flight plans Estimating ETA Conflict prediction Weather forecasting

DECISION MAKING

To select among alternatives, to determine a course of action, or to assess the validity of a proposition.

Decision making includes:	Examples:
Hypothesis formulation Induction/inference Probability/contingency estimation Identification of alternatives Comparison of alternatives Comparison of temporally different states Comparison with standard (criterion reference) Selection/choice	Flight plan approval Path selection Conflict resolution Clearance change

STORING AND RETRIEVING INFORMATION

To retain or to remain aware of information and conversely to recall or to bring forth previously acquired information.

Storing and retrieving information includes:	Examples:
Short-term memory Long-term memory Total retrieval/recall Selective retrieval/recall Purging	Retention of instructions Accumulation of flight history Remembering call sign Recall of procedures/rules

about the relative capabilities of men and machines in each category. The findings of the literature review were abstracted to produce about two hundred statements, which were then grouped in the relevant performance capability categories under three headings:

Human Capabilities and Limitations
Machine Capabilities and Limitations
Man-Machine Performance Comparisons

These data formed the basis for development of the task allocation criteria used to make man-machine assignments in the Phase B effort. A full listing of the literature citations is presented in Volume III, Appendix A.

4.1.3 Methodology for Man-Machine Allocation

The basic concern in the man-machine allocation area of the study was to generate specific configurations of man and machine functional components which would serve as definitions of levels of system automation. Three elements were needed to generate these configurations: a listing of the tasks, a set of criteria for task allocation, and a method for applying the criteria in making specific allocation decisions. Work on all three items was initiated simultaneously in Phase A of the study. The functional analysis and man-machine performance criteria have been described in preceding paragraphs; this discussion concerns the method for applying them to task allocation decisions.

Most previous work in the area of man-machine task allocation has suffered from a major deficiency. Thus, while the definition of tasks has been generally good and the criteria for allocation have been carefully formulated, the specific procedure for applying the criteria in making task allocations has been left somewhat vague. As a result, there has been considerable latitude for interpretation and selectivity (and for individual differences of opinion) in the decision process. The methodology developed for this study sought to remedy the problem by placing man-machine allocation on a more objective basis through specification of a systematic decision-making procedure.

The approach rested on two major premises. First was that the operation of the air traffic system could be described as a finite series of tasks and that each task could be defined in terms of specific performance capabilities necessary for its accomplishment. Given a catalog of man-machine performance characteristics, allocation thus became a question of determining which type of resource was best suited to the task. In other words, it was decided to use the performance requirements inherent in the task to determine its assignment to man or machine resources.

The second premise was that man and machine performance characteristics could be arrayed on a continuum, with uniquely human performance at one extreme and uniquely machine performance at the other. Description of a task in terms of the type of performance required allowed it to be placed at some position along this continuum. Since the position could be described quantitatively, tasks could be directly compared to determine their relative automatability.

Note that the intent was to obtain an index of relative not absolute automatability. There was no attempt to ascertain that any given task should or must be assigned to machines or men. Rather, the intent was to determine the order in which tasks should be considered for automation, i.e., to obtain a numerical index of automation priority.

The method selected for making the judgments of task automatability was an adaptation of the ratio scaling technique originally developed by Stevens (1966). In its classic application, ratio scaling is used to obtain a relationship between the physical and psychological dimensions of a series of events. Obviously, man-machine task allocation is not such a case because there is no overt, physical dimension of the task with which to correlate subjective magnitude estimates. However, later work by Stevens in the area of purely judgmental ratings demonstrated the validity of subjective ratings for which there are no physical coordinates at all. Thus, the selection of the Stevens method was predicated upon the hypothesis that individual judges had (or could, with appropriate instructions, acquire) an internal scale of values relating to task performance requirements. Further, it was hypothesized that such a scale could be used by raters as a yardstick to produce reliable quantitative judgments about the amenability of tasks to performance by human or automated resources.

Man-machine task allocation is a complex judgment, involving an interplay of several factors. Rather than ask individuals to combine all these factors into a single, global judgment, it was decided to construct multiple rating scales which, by statistical processes, could be aggregated to form a unidimensional automation index. This procedure offered several advantages. First, it facilitated more precise discriminations by judges because it allowed them to concentrate on one aspect of the task at a time. Second, it promoted greater factorial purity of the constituents of the automation index; variations of the judges (either individually or collectively) across rating dimensions could be more easily isolated and analyzed. Third, the use of multiple scales helped minimize judges' bias; it was felt that judgments of greater objectivity could be obtained by disassembling the judges' decisions into a series of separate component judgments. A final advantage of multiple scales related to the subject of the judgments themselves, i.e., man-machine performance capabilities. It is overly simplistic to perceive task allocation as some sort of competition between humans and automata. A more accurate view is to think in terms of performance capabilities which are shared to some degree by men and machines but manifested in different ways. Thus, by seeking judgments on a series of particulate aspects of the task and by casting the question in terms of the type of performance required (rather than the type of resource to be assigned), it was believed that more pertinent and valid judgments could be obtained.

The Phase A effort was limited to formulation of the man-machine allocation methodology and to design of the protocol for making task allocation judgments. The application of the method and the assignment of tasks to men and machines were performed in Phase B of the study. See Section 4.2.2 below.

4.1.4 System Performance Measures

System performance measures are the parameters of system operation by which it is possible to evaluate the extent to which a particular level of system automation responds to given goals and constraints. The fundamental parameters of system performance are safety, effectiveness, and cost. Only the first two were of direct interest in this study, with cost treated indirectly by estimating the man and machine resources needed to operate the system. As system parameters, safety and effectiveness are complex and mutually related. Effectiveness is a function of resources and demand and can be measured generally in terms of traffic volume and delay. However, volume also has an influence on safety, which can be treated as a combination of collision/accident risk and traffic conflicts. Conflicts, in turn, produce delay, which suggests that a given level of safety produces consequences in terms of effectiveness. The purpose here is not to analyze the safety-effectiveness relationships in detail, but simply to recognize that they exist. Their interdependency should be borne in mind in the following analysis of system performance measures where, for clarity and simplicity, safety and effectiveness are treated as if they were independent.

Analysis of the system performance measures related to safety and effectiveness indicates there is a hierarchical relationship among system parameters, performance measures, and specific quanta of measurement. The listing given in Table 4.1-2 shows this relationship by placing the orders of measurement at three successive levels of indentation, thus:

I PARAMETER

A. MEASURE

1. Quantum of Measurement

4.1.5 Model and Simulation Requirements

The large number of tasks associated with air traffic management and the complexity of their relationships posed a serious problem in analyzing the system and assessing the implications of various levels of automation. Therefore, it was decided at the outset of the study to construct a large scale digital computer simulation, designated DELTA (Determine Effective Level of Task Automation). In Phase A of the study, the design guidelines, concepts, and specifications of the DELTA model were prepared. The goal was to create a model capable of simulating each task as being performed either in a manual or automated mode, allowing different levels of automation to be tested and evaluated.

TABLE 4.1-2 SYSTEM PERFORMANCE MEASURES

I. SAFETY

A. COLLISION RISK - The probability of collision experienced by an aircraft during its transit through a unit of airspace.

1. Frequency of Collision - the number of aircraft whose collision risk probability equals 1 for an airspace-time sampling unit.

2. Mean Peak Collision Risk - the mean value of the peak collision risk probabilities for all aircraft in an airspace-time sampling unit.

B. CONFLICT - A conflict exists when a violation of minimum separation standards occurs. Separation standards are defined in terms of the maximum acceptable collision probability (MACP).

1. Conflict Rate - the proportion of aircraft which exceeds the MACP for an airspace-time sampling unit.

2. Conflict Duration - the amount of time the aircraft exceeds the MACP.

3. Conflict Frequency (Unadjusted) - the number of pairs of aircraft which exceed the MACP in an airspace-time sampling unit.

4. Conflict Frequency (Adjusted) - the number of different aircraft which exceed the MACP in an airspace-time sampling unit.

II. EFFECTIVENESS

A. DELAY - The failure of an aircraft to transit any point in the system at or prior to its original ETA/ETD. Points in the system are understood to extend from gate to gate.

1. Number of Aircraft Delayed - the number of aircraft which encounter delays in a traffic sample.

2. Delay Frequency - the distribution and variability of the number of aircraft delayed as estimated from multiple traffic samples.

TABLE 4.1-2 SYSTEM PERFORMANCE MEASURES (Cont'd)

3. Average Net Delay Time Per Aircraft - the mean net delay for a given traffic sample, where net delay is the excess of actual transit time over estimated transit time as calculated from the actual time of departure from point of origin.

4. Net Delay Time Frequency - the distribution and variability of net delay time in a given traffic sample.

5. Mean Segment Delay Time Per Aircraft - the mean of the individual segment delays (ISD), where ISD is the excess of actual time of arrival over estimated time of arrival at the end of a flight segment and where ETA is estimated from the actual time of departure from the previous segment end point.

6. Segment Delay Time Frequency - the distribution and variability of mean segment delay time in a given traffic sample.

B. VOLUME - the number of aircraft entering, leaving, and passing through an airspace unit during a specified time frame.

1. Instantaneous Peak - the largest number of aircraft observed at any point in a specified time frame.

2. Peak Volume - the largest mean number of aircraft observed during any interval within a specified time frame.

3. Minimum Volume - the smallest mean number of aircraft observed during any interval with a specified time frame.

4. Average Volume - the mean number of aircraft observed throughout the specified time frame.

5. Volume Frequency - the distribution and variability of volume over intervals within the specified time frame.

The general guidelines for design of the model were:

- The model structure was to be based on a generic (concept-free) functional analysis of an air traffic management system. Use of the term concept-free meant that the functional analysis was not tied to specific hardware or software concepts. Functions were, however, to be tied to resources defined in terms of their output performance characteristics.
- Output from the simulation was to support analyses of man/machine requirements.
- Simulation of each subject area of air traffic management was to be at a level of detail proportional to its relative influence on controller workload and control system effectiveness. The subject areas were 1) Air Traffic Management System, 2) Air Traffic, 3) Airport System, 4) Environment, 5) Airspace Structure.

The specification called for an event-stepped model, with input control to provide time-stepped sequencing in those elements which were critical to the operation of the system. The model was driven by the generation of tasks, created either externally (exogenous) or internally by the simulation itself (endogenous). The movement of aircraft through the system created the need for tasks to be performed. These tasks (and not the aircraft movement) were the driving function for the model.

The model was driven by a tape that listed the exogenous events in the order of their occurrence. Each event was stored together with the associated time of the event. When the simulation time clock reached the time of the event, the event was stimulated. The main exogenous events were filing of a flight plan by an aircraft prior to takeoff and requests by an aircraft to amend a flight plan in flight.

Each flight plan consisted of a series of straight line segments with associated speeds, altitudes, and route numbers. Additional data such as a response time, equipment performance, and route structure were also input. The processing of tasks for each of the functions was defined by appropriate flow chart coding or by a Logic Control Chain. Each Logic Control Chain (LCC) had a summary sheet which specified all files required for the LCC.

4.2 PHASE B RESULTS

The end products of the first phase of the study were the starting point for the work performed in Phase B, where the generic functional analysis of an advanced air traffic management system was extended and refined to produce a final listing and description of each task. Numeric rating data on a scale of performance capabilities were collected and processed to produce a single dimension of the relative amenability of each task to automation -- termed an Automation Index. Five preliminary levels of system automation were defined in preparation for evaluation and selection of a recommended automation level. These activities are described below.

4.2.1 Function Analysis

Phase A had resulted in a preliminary definition of the generic functions of air traffic management. The list was reviewed internally and against comments solicited from knowledgeable members of the air traffic community. The result was a final listing of 17 generic air traffic management system functions. They are listed in Table 4.2-1.

It will be recalled that system functions, carried out singly or in combination, account for the services provided by the air traffic management system to its users. A method for refining and testing the initial set of functions was to derive a list of services and to determine the relationship of a function or functions to each service. The list used in this project was derived with participation from the study team, the MITRE Corporation, TSC and FAA (OSEM). Ten categories of service were defined. They are:

1. Airport/Airspace Use Planning - This is the strategic or long-range control service concerned with the establishment and modification of plans for airspace and airport use. It is related to both safety and efficiency, and involves an agreement between the user and the control authority. It includes such things as:

   - The flight planning process
   - Flow control, both national and local
   - Conflict prevention by planning
   - Promotion of efficiency by planning
   - The clearance process

   The outputs to the user are clearances and advisories.

TABLE 4.2-1 GENERIC AIR TRAFFIC MANAGEMENT FUNCTIONS

FUNCTION	DESCRIPTION
1.0 Provide Flight Planning Information	Provides information to the pilot for use in the preliminary planning of a flight. (Similar information is also provided during the development of a flight plan; see Function 3.0)
2.0 Control Traffic Flow	Matches system demand to system capacity and resolves capacity overload situations.
3.0 Prepare Flight Plan	Accepts a preliminary flight plan from the pilot, assists him in assessing the effects of current operational, environmental and regulatory factors on his intentions, and assists him in compiling a flight plan to submit for approval.
4.0 Process Flight Plan	Reviews the flight plan developed in Function 3.0 and accepts, rejects, or modifies it appropriately.
5.0 Issue Clearance and Clearance Changes	Issues appropriate clearances and clearance changes to controlled aircraft.
6.0 Monitor Aircraft Progress	Maintains a continuous record of aircraft position and capability; predicts future positions and ETA's of the aircraft.
7.0 Maintain Conformance with Flight Plan	Checks for actual and predicted deviations from flight plan and resolves them; detects and resolves long-term conflicts among flight plans.
8.0 Assure Separation of Aircraft	Predicts and resolves short-term conflicts between aircraft.
9.0 Control Spacing of Aircraft	Provides sequencing and scheduling of aircraft to promote efficient use of airspace and facilities.
10.0 Provide Airborne, Landing, and Ground Navigation Capability	Provides signals or other detectable phenomena that can be used onboard for determination of the aircraft's position.
11.0 Provide Aircraft Guidance	Vectors the aircraft to some intended position.
12.0 Provide Flight Advisories and Instructions	Provides information to the pilot during all flight phases except preflight planning.
13.0 Handoff	Effects transfers of responsibility for the performance of ATM functions between ATM jurisdictions or between an ATM jurisdiction and an aircraft.
14.0 Maintain System Records	Compiles and stores system records; prepares operational, statistical and special reports.
15.0 Provide Ancillary and Special Services	Provides non-routine or special services, such as those presently listed in the controller's manuals.
16.0 Provide Emergency Services	Provides appropriate services in response to air failures.
17.0 Maintain System Capability and Status Information	Maintains, for use by other system functions, an up-to-date body of information regarding the status of the airspace and the capability and status of the ATM system.

2. Flight Plan Conformance - This is the strategic or long-range service that promotes implementation of the plans developed above. It includes:

   - Monitoring to determine deviations from plan
   - Corrections back to plan, or
   - Modifications to the plan
   - Monitoring for conflicts within the plan
   - Resolution of those conflicts

   The outputs to the user are corrections to keep him on flight plan and changes to his flight plan.

3. Separation Assurance - This is a short-term service related to safety. It consists of both short-term conflict prevention (tactical conflict detection and resolution) and tactical collision prevention.

   Short-term conflict prevention includes:

   - Monitoring for predicted violations of the airspace volume reserved about an aircraft
   - Resolution of predicted violations

   Tactical collision prevention includes:

   - Monitoring for actual violation of reserved airspace volume
   - Resolution of actual violations

   In either case the output to the user is instructions to resolve the conflict. The resolution instructions do not represent a flight plan change but may generate the need for a flight plan change after resolution has been effected.

4. Spacing Control - This is a short-term service related to efficiency. It includes:

   - Runway configuration scheduling -- allocation of "slots" of runway time for takeoff and landing traffic
   - Sequencing -- ordering of aircraft en route as well as into the takeoff and landing slots provided by scheduling
   - Spacing -- adjustment of inter-aircraft spacing to promote efficiency

5. Airborne, Landing, and Ground Navigation - This is the service that provides position location capability. As defined, it does not include the process of getting from present position to a desired position. Therefore, vectoring and GCA are not a part of this service.

6. Flight Advisory Services - This is the service that provides information to the pilot during all flight phases except preflight planning. It provides weather and traffic information and includes the present Automatic Terminal Information Service.

7. Information Services - This service is similar to the preceding one except that the information is provided during the preflight planning phase. It provides information about weather, traffic, facilities, routes, obstructions, regulations, and procedures.

8. Record Services - This service provides the required "permanent records" of operations and events.

9. Ancillary Services - This service provides the special services listed in the present controller's manuals. It includes such things as:
   - Weather observation
   - Military flight handling
   - Transborder flight handling
   - Search and rescue coordination

10. Emergency Services - These are services provided in response to air failures. The services are provided in the event of either:
    - Controllable emergencies -- those during which the aircraft can respond to control instructions, or can carry out established procedures applicable to the emergency situation.
    - Uncontrollable emergencies -- those during which neither control instructions nor established procedures can be implemented.

In some cases there is a direct, one-to-one, relationship between a function and a service. For example, Function 1, Provide Flight Planning Information, is directly related to Service 7, Information Services. Likewise, Function 14, Maintain System Records corresponds to Service 8, Record Services.

The relationships between services and functions is shown in Table 4.2-2. Services are listed along the abscissa of the matrix and functions

TABLE 4.2-2 FUNCTION PERFORMANCE REQUIRED TO PROVIDE AIR TRAFFIC SERVICES

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

I = Information
D = Decision
A = Action

along the ordinate. If a function supports a service, this fact is indicated by one or more of the following symbols in the appropriate cell.

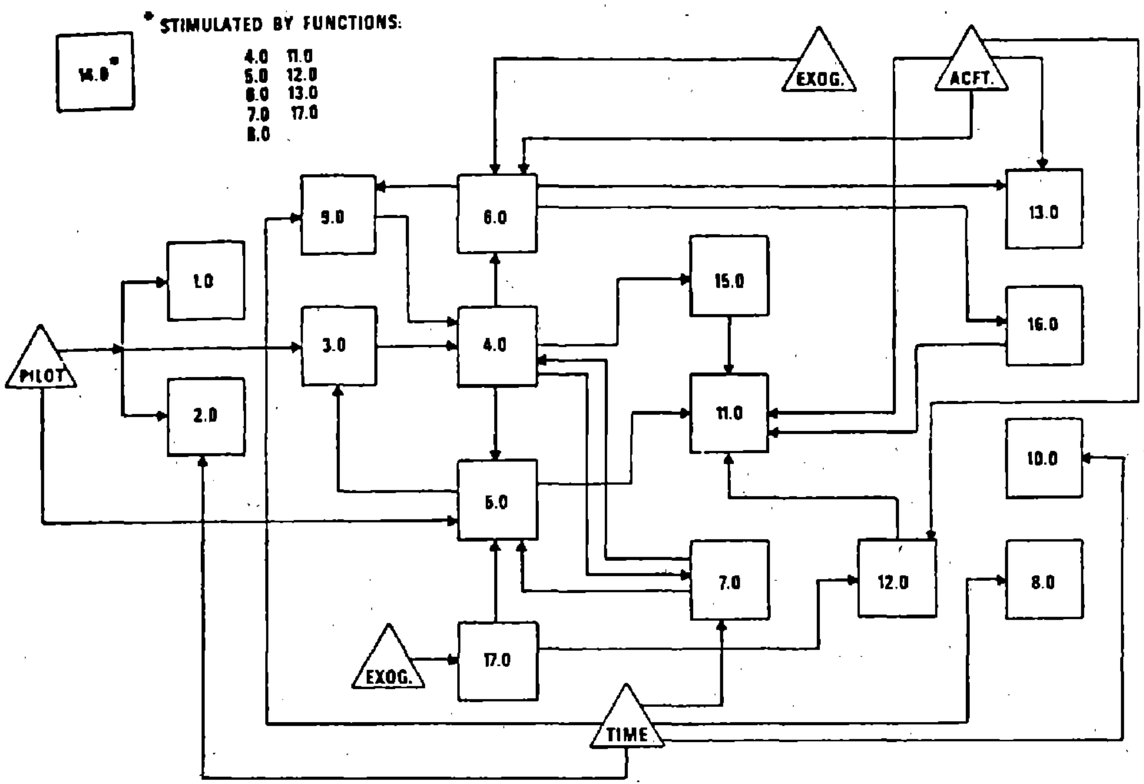
- I - the function produces information outputs needed to provide the service
- D - the function produces decisions associated with the service
- A - the function produces actions by which the service is implemented.

Air traffic management functions, or course, do not stand alone. They are interrelated to form a network of inputs, processes, and outputs which result in services being performed for users of the airspace. The overall relationships among system functions are shown in Figure 4.2-1.

Figure 4.2-1 is a top-level diagram showing the stimulus relationships among functions. It should be emphasized that the diagram does not represent how information flows within the system. Instead, the lines between functions indicate how activities within one functional component stimulate (or trigger) activities within other components. The diagram is intended to provide only a simplified overview of the system at the function level. Detailed diagrams and descriptions of system operation are presented in Volume II of this report.

In Phase B each function was elaborated to the task level of detail, and the information flow and stimulus relationships were thoroughly traced. This resulted in the identification and description of 17 functions, which consisted of 60 subfunctions, and -- at the next level of detail -- 265 tasks. Two techniques were employed as study aids and documentation tools in the function analysis: flowcharting and descriptive files. Functions, subfunctions, and tasks were represented symbolically in flowchart form and by word descriptions in file documents. About 200 flowcharts and 700 pages of descriptive files were required to document the system at the task level of detail.

Figure 4.2-2 is a representative flowchart, showing a portion of the separation assurance function. This diagram depicts the flow of information inputs and outputs among tasks. The general direction of the flow is from



1.0: PROVIDE FLIGHT PLANNING INFORMATION
2.0: CONTROL TRAFFIC FLOW
3.0: PREPARE FLIGHT PLAN
4.0: PROCESS FLIGHT PLAN
5.0: ISSUE CLEARANCES AND CLEARANCE CHANGES
6.0: MONITOR AIRCRAFT PROGRESS
7.0: MAINTAIN CONFORMANCE WITH FLIGHT PLAN
8.0: ASSURE SEPARATION OF AIRCRAFT
9.0: CONTROL SPACING OF AIRCRAFT
10.0: PROVIDE AIRBORNE, LANDING AND GROUND NAVIGATION CAPABILITY
11.0: PROVIDE AIRCRAFT GUIDANCE
12.0: ISSUE FLIGHT ADVISORIES AND INSTRUCTIONS
13.0: HANDOFF
14.0: MAINTAIN SYSTEM RECORDS
15.0: PROVIDE ANCILLARY AND SPECIAL SERVICES
16.0: PROVIDE EMERGENCY SERVICES
17.0: MAINTAIN SYSTEM CAPABILITY AND STATUS INFORMATION

FIGURE 4.2-1 SYSTEM DIAGRAM SHOWING FUNCTION STIMULI left to right. The ovals indicate information inputs or outputs; the rectangles represent tasks. Triangles represent information inputs from (or outputs to) other functions/tasks. The arrows indicate the path of information flow, with the small circles enclosing a dot or a plus sign to denote logical relationships. A dot (•) means "either"; a plus (+) means "both".

On the page following Figure 4.2-2 is an example of the descriptive file which was prepared for each task. Note that, in addition to information on the nature of the task, there is a listing of the performance capabilities required to carry it out. Performance capabilities were the characteristics chosen as criteria for allocating tasks to man or machine. Once the functional analysis had reached this level of detail, work on establishing a task automation index could begin. That work is described in the next section.

4.2.2 Automation Index

The man-machine allocation methodology developed for this study was intended to provide a direct way of bridging the gap between principles and application. The aim was to devise an explicit procedure by which criteria could be applied to make decisions about the assignment of tasks to human or automated resources. To put it another way, the objective was to go beyond the usual collation of research findings and design principles and to give the system engineer a clearly defined and objective method for applying these rules to the question of man-machine allocation.

The approach involved construction of a quantitative and objectively derived rating scale of task automatability, called the Automation Index. The foundation of the Automation Index was an analysis of air traffic control operations, carried out to a level of detail where each unit of activity (task) was allocatable as a whole to man or machine resources. The Automation Index itself was a multi-dimensional scale made up of a set of performance characteristics extracted from the research literature on man and machine capabilities. The fundamental assumption was that, while men and machines have certain basic capabilities in common, the manner in which they manifest these capabilities and the characteristics of performance are different. These performance differences formed dimensions which

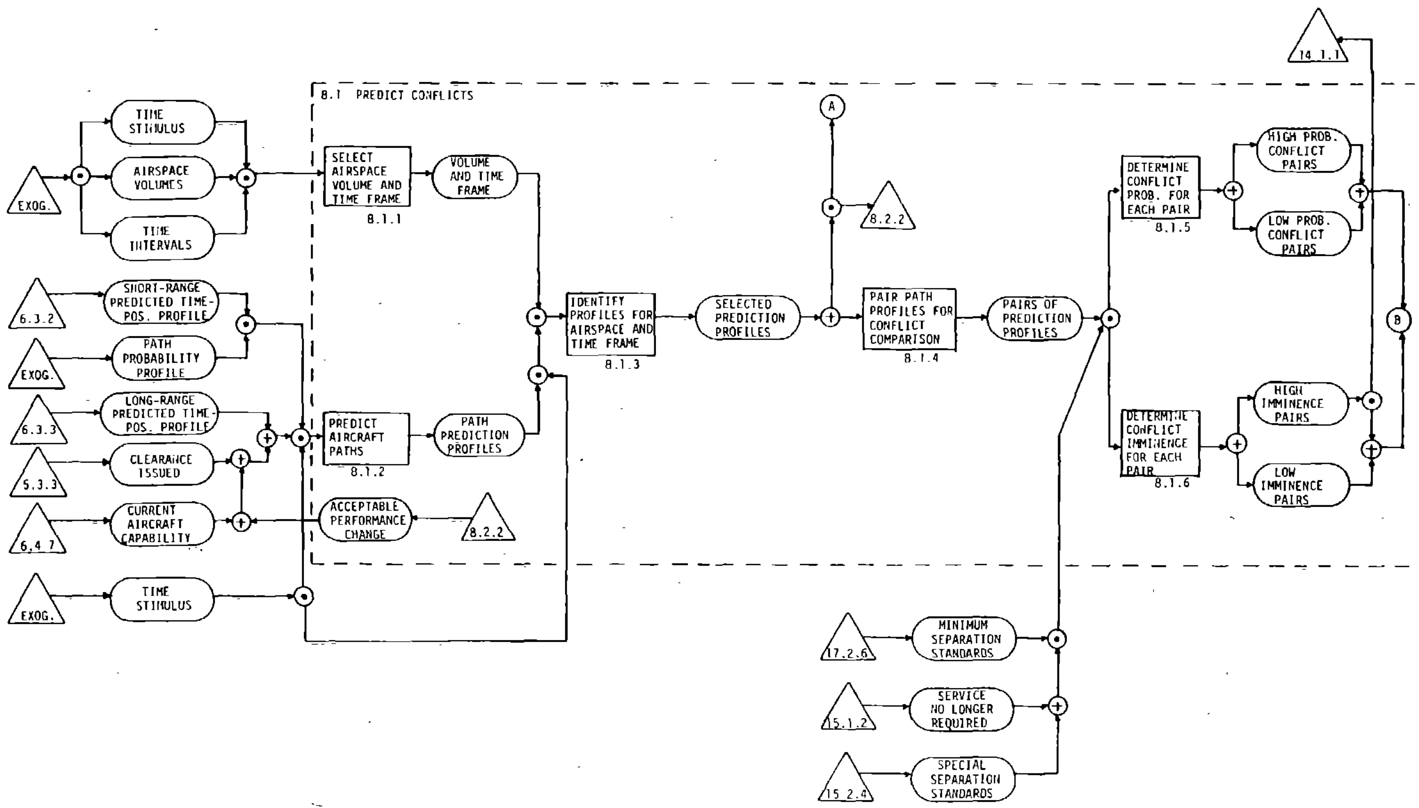


FIGURE 4.2-2 EXAMPLE OF FUNCTIONAL FLOWCHART (FUNCTION 8.0 - ASSURE SEPARATION OF AIRCRAFT)

B

TASK DESCRIPTION

FILE: 2.2.2
TASK: Process and Store Reservations
SUBFUNCTION: Determine System Demand
FUNCTION: Control Traffic Flow

OUTPUTS:

(1) Confirmed reservations

(2) Disapproved reservation request with suggested alternate available reservation times

(3) Deleted reservation

DESCRIPTION:

Purpose: To process and store reservations for use of high traffic density terminals

Stimulus: Event-stimulated by a request for a reservation from the user (exogenous), or by receipt of commercial schedules (exogenous)

Decisions and Actions:

(1) Determine if time requested is available

(2) Determine alternate available time, if requested time is not available

(3) Record reservation, if requested time is available

(4) Issue reservation confirmation (to include informing user) or

(5) Inform user of reservation disapproval with alternate times, or

(6) Delete existing reservation and inform user of deletion

Phase of Flight:

Preflight phase only

Critical Performance Parameters:

Flexibility

Performance Capability Required:

(1) Decision making:

- Comparison of alternatives
- Selection/choice

(2) Information processing:

- Filtering

(3) Storing/retrieving:

- Short-term memory

External Constraints:

Allocation Sensitivities:

INPUTS: (1) From the pilot:

- Request to establish or cancel reservations

(2) From exogenous source:

- Commercial schedules

could be used to rate the suitability of man and machine resources for carrying out task assignments. It is important to note that the rating process did not involve a direct judgment about automation per se, but rather a matching of task requirements and the performance characteristics of resources which might be assigned to the task. Putting the question in this form served both to minimize the influence of preconceptions about automation and to focus attention on the evaluation of resource capabilities in light of task requirements.

The work of obtaining and processing the rating data was accomplished as follows. First, the statements comparing men and machines obtained from the literature in Phase A were combined and condensed into a series of axioms about each performance capability. For example, one axiom about monitoring was: "Machines excel at monitoring which requires continuous attention or detection of random, infrequent events; in the same situation man is easily distracted and unreliable." Next, these axioms were reduced to unipolar statements about machines, so that the comparative statement above became "monitoring of infrequent events". Each statement provided an explicit guide to the kinds of things machines do well. Thus, the "machine-like" end of the continuum was defined explicitly while the "man-like" end was defined inferentially. The statements about all six performance capabilities were then assembled into a rating scale. Each task was ratable upon six dimensions, and within each dimension there were between five and nine aspects of performance to be considered. Taken together, this gave the rater about forty potential factors to take into account in making attributions for each task.

The grounds for selection of raters were that the participant had to have experience in systems engineering, human factors, computer applications, or air traffic control. A group of thirty-two persons, drawn from contractor personnel and representatives from DOT/TSC and FAA/NAFEC were selected as raters. Ratings were obtained in two sessions for each organization group. Each session consumed between eight and twelve hours over a two-day period. The reference materials used by the raters consisted of:

- Detailed task descriptions
- A schematic system block diagram

- Performance capability descriptions
- A task-capability matrix, with spaces provided for recording the ratings.

The procedure for making man-machine performance ratings involved the following steps for each task.

1. The rater examined the task description to familiarize himself with the functional details.
2. The rater consulted the task-capability matrix which designated the basic capabilities required to perform the task.
3. For each capability relevant to the task, the rater reviewed the criterion statements of resource characteristics.
4. The rater made a comparison between the criterion statements and his own estimate of the performance characteristics required for the task.
5. The rater expressed the comparison as a number, whose magnitude indicated the degree of correspondence between the criterion statements and his own estimate of the required performance characteristics.
6. The rater repeated steps 3, 4 and 5 until the task had been rated on all the relevant performance dimensions.

The rating procedure had the effect of reducing the question of man-machine task allocation to a series of particulate, quantified judgments about performance capabilities in relation to functional requirements. The rater was not expected to make a global decision about the level of automation in the system. In fact, he was not expected to make any explicit judgment at all about automation. Instead, he was asked to characterize (task by task along each performance dimension) the appropriate resource to be assigned, without ever specifically identifying that resource as a man or a machine. By atomizing the task allocation process in this way and by reducing it to a systematic procedure, rater bias and the intrusion of extraneous considerations were minimized.

Of the 32 raters, 27 completed ratings of the 265 tasks*. The ratings constituted a data base with three dimensions: tasks, performance capabilities, and raters. Arraying the data orthogonally along these dimensions

*Five were unable to complete the ratings because other assignments or illness.

produced a matrix with 42,930 cells (265 tasks x 6 performance capabilities x 27 raters). However, about half of the cells were empty because not all the task-capability conjunctions were relevant and so had not been assigned ratings. Deleting the empty cells left a matrix with approximately 21,000 data points (770 task-capability conjunctions x 27 raters).

Analysis of the findings indicated that the aggregation of rating scores produced an Automation Index of high validity and internal consistency. Interrater agreement, as tested by the Spearman-Brown reliability coefficient, was 0.822 in a circumstance where a value greater than 0.60 would be considered acceptable. Additional tests of the rating results by standard analysis of variance revealed that there was no discernible rater bias attributable either to occupational specialty or group affiliation. The internal variability of task Automation Indices, due either to lack of consensus among raters or inconsistency of ratings across performance capabilities within given tasks, was generally low. Over 80% of the task indices, when tested by four separate statistical confidence measures, proved to be reliable. The variability of the remaining task indices (52 of a total of 265) turned out to be a useful symptom for identifying areas of controversy about automation and for isolating conceptual and procedural problems in the task descriptions and the rating protocol. In other words, there was a built-in quality control element in the rating procedure.

Apart from internal statistical reliability, the task rankings by Automation Index also gave evidence of validity when tested by external criteria. One such test was a comparison with the present ATC system. An examination was made of 22 generic tasks which could be closely identified with tasks presently automated in the NAS Stage A and ARTS III systems. The Automation Indices for 20 of these tasks indicated that the raters also considered them highly suitable for automation. Thus, taking the existing system as a standard, the Automation Index produced task allocations that were highly consistent with the engineering judgment which led to the automation of these tasks in NAS Stage A and ARTS III.

A second, and perhaps more significant, indication of the external validity of the findings was found by examining the common characteristics of tasks which lay within any given level of automation. Tasks which, on logical grounds, had common performance requirements or functional similarity tended also to have equivalent Automation Indices. This finding suggested strongly that raters, regardless of their background and experience and despite any general bias they may have had about automation, were inclined to have a highly uniform and logically consistent view of performance requirements in relation to tasks. Thus, it seemed legitimate to conclude that the rating process did, in fact, tap an underlying and common conception of resource-task compatibility.

On the whole, the positive features of the Automation Index methodology appeared to outweigh its disadvantages. The method was conceptually simple and practical to use. In comparison with other methods for determining man-machine task allocation, it was rapid and fairly economical of manpower. The resulting rater estimates, because they were expressed in numerical form, were readily processed by machines and simple to manipulate mathematically. The Automation Index, derived by straightforward computational techniques, was both statistically reliable and logically coherent. The method is easy to replicate and verify. And, highly important, the method yielded pertinent and detailed answers with regard to assignment of tasks to human and automated resources. There were some negative attributes. The method called for a high level of rater cooperation. Extensive task analysis and preparation of a detailed rating protocol were required before the rating process could begin. The results, because they are expressed as numbers, could be subject to misinterpretation and even abuse. That is, the task rankings are valid only as relative indices of automatability, yet they are prone to interpretation in an absolute sense by those not fully conversant with the method and the rationale of the rating procedure. However, as stated above, these disadvantages were far from overwhelming, and there appeared to be much more on the positive side of the ledger.

4.2.3 Automation Levels

On the basis of the Automation Index, each task could be assigned a position along a man-machine performance continuum. It had been expected that the ratings would yield a distribution of sufficient variability to discriminate the relative "automatability" of tasks (i.e., to determine how machine-like" they were in relation to other tasks). Such a characteristic was obtained. Further, the task array tended to be subdivided into clusters, in that there were some scale intervals with few or no members. Since confidence could be placed in the relative locations of tasks falling above and below these empty places on the scale, the "holes" in the distribution were convenient places to draw preliminary bounds for automation levels.

Four such boundaries were chosen, dividing the distribution into five subsets of tasks. Each subset corresponded to an incremental step or level of system automation. The lowest (level I) contained those tasks rated most "machine-like"; the highest (level V) contained those adjudged least "machine-like" (in other words, most "man-like").

Figure 4.2-3 is a schematic representation of how the tasks ranked by Automation Index were segregated into levels of automation. Figure 4.2-3 also illustrates the concept of incremental automation, where each successively higher level builds upon those below it.

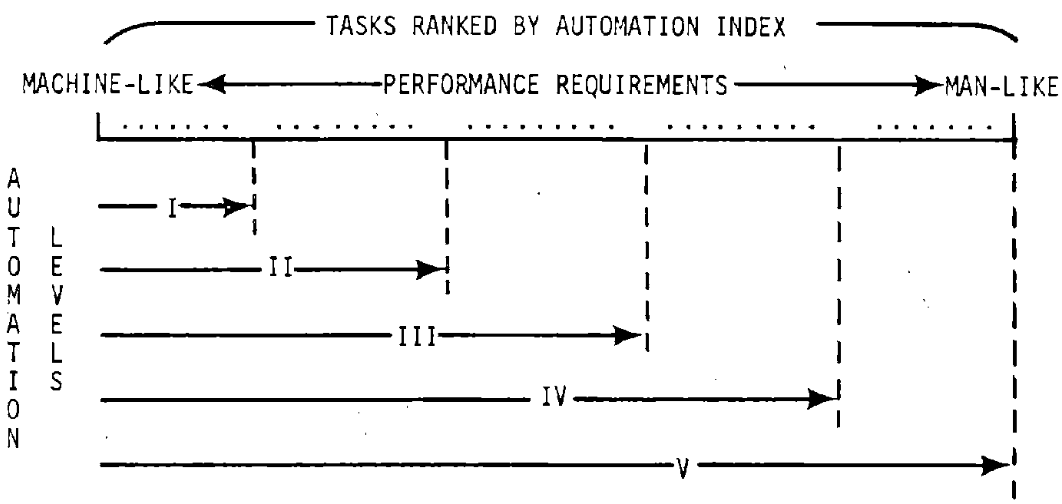


FIGURE 4.2-3 LEVELS OF SYSTEM AUTOMATION

The next step was to examine the tasks found in each of the five subsets. The concept was that all were equally automatable as an increment of system automation and that a characterization of the automation levels could be drawn from the logical/functional implications of automating each successive subset, with the tasks at higher levels remaining allocated to manual performance. Examination of the tasks grouped at each automation level revealed that there were common characteristics which indicated the effects of progressive automation of the system. These shared characteristics showed both an internal consistency within levels and a logical relationship between levels, lending further credence to the validity of methodology of ranking tasks by Automation Index. The following is a summary of the five incremental levels of automation which resulted.

Level I - Automation of Computational Aids

Tasks allocated to machines at the lowest order of automation are those involving repetitive computation and routine data processing, primarily in the areas of active control of aircraft (surveillance and vectoring) and maintenance of the system data base.

Level II - Automation of Aids to Decision Making

Automated resources are assigned to tasks such as detection of flight plan deviations and conflicts and formulation of possible solutions. Machines are also assigned to more sophisticated data processing tasks. Thus, the machine begins to function as a means of alerting man to the need for a decision and of providing him with data to assist his decision making.

Level III - Automation of Decision Making

At this level many decision-making tasks, particularly those of a routine and repetitive nature, are assigned to machines. Level III is also characterized by essentially complete automation of records keeping and maintenance of the operational data base.

Level IV - Automation of Communications

At level IV the machine replaces man in air-ground communication loop for routine relay of information, e.g., vectors, clearances, and flight advisories. Man is still assigned responsibility for communication of a special or emergency nature. Thus, the system passes from voice communication to two-way data link for normal modes of operation. At this level, virtually all strategic planning and regulation of traffic flow is also delegated to automated resources.

Level V - Full Automation

This level represents a hypothetical system in which man has no direct responsibility for regulation and control of air traffic. All planning, all surveillance, all intervention,

> and all communication have been automated. Man's role has become that of a system monitor and manager. Thus, man controls not aircraft, but a complex of automated resources which, in turn, control aircraft.

Another way to appreciate the effects of progressive automation of the system is to look at the percentage of tasks assigned to machines at each incremental level. Table 4.2-3 shows the proportion of machine tasks within each function at automation Levels I through V.*

The table illustrates the point that the nature of the tasks, as seen by the raters, differs markedly from function to function. The effect is that some functions are automated at lower levels than others. For example, Functions 7, 8 and 11 have a sizeable proportion of tasks automated at Level I, while automation of Functions 4, 15 and 16 does not begin until Level II or higher.

A second effect shown in the table is that the size of the automation increment from one automation level to the next higher level also differs markedly from function to function. For example, in Function 2, the percent difference between Level I and II is 40 while Function 1 has only a 13 percent change between the same two automation levels.

It should be noted that these two effects stem mainly from the manner in which the raters placed the tasks along the automation continuum, i.e., the effects would persist if the automation level boundary locations were different than those chosen for this discussion.

A second, and simpler, illustration of the progressive effects of system automation can be obtained by examining how the transfer of tasks from men to machines occurs within groups of related functions. The 17 generic air traffic management functions can be placed in metafunctional families as follows:

*Note that Function 10, Provide Airborne, Landing and Ground Navigation Capability, has been eliminated. It was felt that automation of this function was almost exclusively dependent on system concept and implementation. Thus, no ratings of this function were obtained because it would have called for the judges to make highly specific hypotheses about equipment design.

TABLE 4.2-3 PERCENT OF AUTOMATION BY FUNCTION AND AUTOMATION LEVEL

FUNCTION	PERCENT AUTOMATED AUTOMATION LEVEL				
	I COMPUTATION AID	II DECISION AID	III DECISION MAKING	IV COMMUNICATION	V FULL AUTOMATION
1.0 Provide Flight Planning Information	0	13	38	75	100
2.0 Control Traffic Flow	7	47	67	93	100
3.0 Develop Preliminary Flight Plan	0	0	11	44	100
4.0 Process Flight Plan	0	0	17	48	100
5.0 Issue Clearances and Clearance Changes	0	50	60	70	100
6.0 Monitor Flight Progress	24	53	82	94	100
7.0 Maintain Conformance with Flight Plan	29	57	79	93	100
8.0 Assure Separation of Aircraft	50	79	93	100	100
9.0 Control Spacing of Aircraft	0	47	75	88	100
11.0 Provide Aircraft Guidance	31	81	94	100	100
12.0 Issue Flight Advisories and Instructions	0	17	56	72	100
13.0 Handoff	0	10	50	90	100
14.0 Maintain System Records	6	38	88	100	100
15.0 Provide Ancillary and Special Services	0	0	0	63	100
16.0 Provide Emergency Services	0	15	54	92	100
17.0 Maintain System Capability and Status Information	29	41	76	98	100
All Functions	15	37	64	86	100

ACTIVE CONTROL

6.0 - Monitor Flight Progress
7.0 - Maintain Conformance with Flight Plan
8.0 - Assure Separation of Aircraft
11.0 - Provide Aircraft Guidance

HOUSEKEEPING

14.0 - Maintain System Records
17.0 - Maintain System Capability and Status Information

TRAFFIC PLANNING AND REGULATION

2.0 - Control Traffic Flow
5.0 - Issue Clearances and Clearance Changes
9.0 - Control Spacing of Aircraft
13.0 - Handoff

EMERGENCY AND SPECIAL

15.0 - Provide Ancillary and Special Services
16.0 - Provide Emergency Services

DATA SERVICES

1.0 - Provide Flight Planning Information
3.0 - Develop Preliminary Flight Plan
4.0 - Process Flight Plan
12.0 - Issue Flight Advisories and Instructions

Figure 4.2-4 shows the percentage of tasks automated in each of these metafunctions at each successive automation level. Note that the tasks from Active Control generally lead the way, with Housekeeping, Traffic Planning and Regulation, Emergency and Special, and Data Services following more or less in that order at each automation level. The sequence of automation by metafunction suggests an interesting feature of the task allocation scheme. As one passes from left to right across the metafunctional families ordered in terms of their degree of automation as they are in Figure 4.2-4,

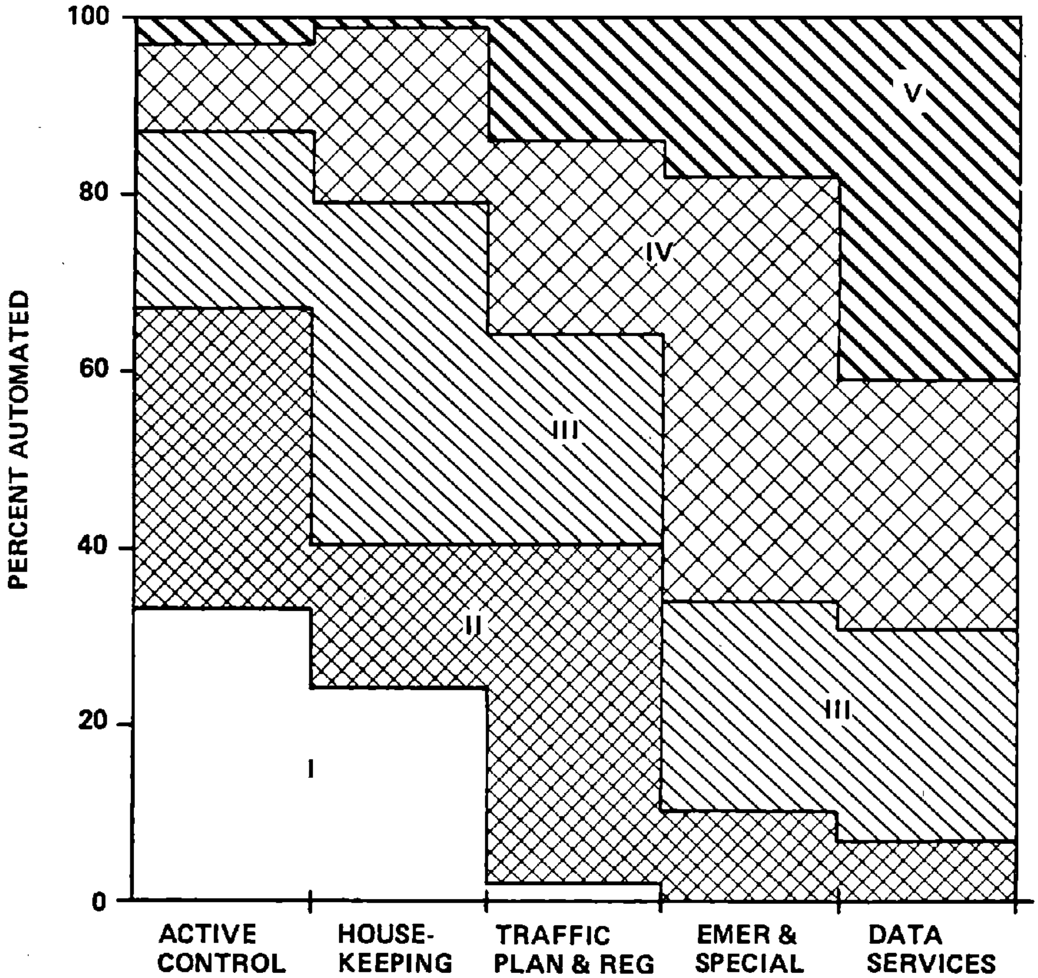


FIGURE 4.2-4 PERCENT OF AUTOMATION BY METAFUNCTION

there is also in general a progression from those functional activities calling for routine, repetitive tasks to those which entail more specialized and individual services. This is consistent with a general concept of incremental system automation in which the former kind of tasks are adjudged more machine-like, and the latter more man-like.

4.3 PHASE C RESULTS

Phase C was the concluding phase of the study, where the function analysis, man-machine allocations, and other products derived in preceding phases were put to use in the generation of the remaining study products. The Phase C products included:

1. A finalized system description
2. A recommended automation level with its associated
    a. man-machine resource requirements
    b. human operator productivity estimates
    c. display/control requirements
    d. an analysis of failure modes requirements
3. An exploration of such related topics as the implications of the study and recommended strategies for implementing automation in air traffic management.

Study implications and implementation strategy are given as later chapters in this volume. The other study outcomes are set forth in summary form below. Detailed discussion of each of these topics can be found in Volume IV of the study report.

4.3.1 System Description

The first elements of a system description were generated in earlier study phases. They included the enumeration of each of ten services that the air traffic management system must provide and the identification of the seventeen generic functions required to perform these services. To permit a meaningful extrapolation of system resource requirements, a necessary first step in Phase C was to extend the description to include:

- Refinement of the system operational concepts, to the extent that they would affect resource allocations
- Facilities, by type, number, and operational purpose
- Operator positions, tasks, and duties
- Refinement of the estimated demand by its apportionment across system facilities and jurisdictions.

The general approach to the system description work done in Phase C was to derive specifications only to the extent necessary for estimating resource requirements and establishing guidelines for system design. The intent of the study was not to design a system but to delineate the design goals and estimate the man-machine requirements arising from a high level of automation.

The function services relationships were the basis for definition of the way in which key management functions (e.g., flow control, flight plan conformance) relate to safety and efficiency. Figure 4.3-1 represents the relationship schematically.

The functions given in the figure are termed "key management functions" because they are the functions in which decisions about strategy and tactics are made. For example, "flight plan conformance" is included because deviations from flight plan are detected and resolved in this function, but "monitor aircraft progress" is not included as a key management function since decisions about system interventions are not made in that function. Also shown in the figure is the time frame of system decisions and actions ranging from seconds in providing separation assurance to days in flow control. The concept is that of a layering of system functions. Note that high contributors to safety, such as separation assurance, are conversely low contributors to efficiency. In the same way, high contributors to efficiency (like flow control) are low contributors to safety.

In addition to the conceptual refinement of the role of key management functions, a method was devised whereby all system functions could be related to the class of service they perform. The ten system services were classified into categories of safety, capacity/efficiency, and support. The relative criticality of each function was established, by defining its contribution to services in each class. The key management function relationships and the functional criticality data formed a base for carrying out and verifying operator position responsibility allocations and failure mode analyses, discussed later in this section.

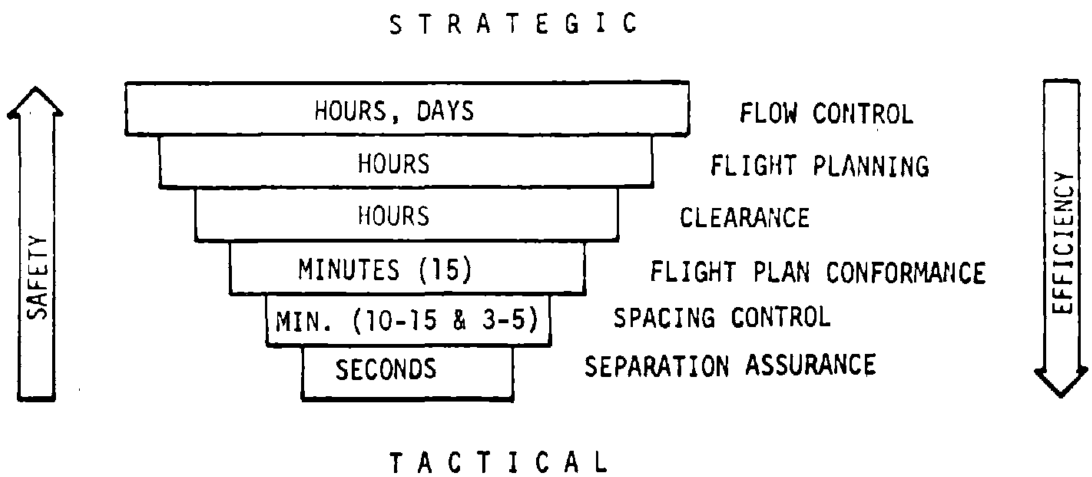


FIGURE 4.3-1 SYSTEM FUNCTIONS IN RELATION TO SAFETY AND EFFICIENCY

The study team was supplied with a facilities plan for AATMS by DOT/TSC. This plan was used in the preparation of system manpower and data processing resource requirement estimates. The following facilities were defined, with responsibilities as shown:

Air Traffic Management Facilities

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 functions:
   - 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

- o Serve as a backup to the Transition/Hub Centers and Airport Control Centers to which they are connected

- o Coordinate with their respective Regional Flight Service Station 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:

   - o Conduct terminal area operations for secondary terminals with unmanned towers

   - o Manage the transition of aircraft control assignments between the associated Regional Control Center and secondary terminals with unmanned towers

   - o Manage the traffic within the largest major hubs but outside of airport control zones (e.g., provide services similar to those of today's Common IFR Room for the New York City Hub area)

   - o Coordinate with their respective Hub Flight Service Stations to obtain weather data as required

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

   - o Primary Terminals - 133

   - o Secondary Terminals (manned towers) - 359

   - o 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.

Flight Service Facilities

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

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 distributed 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

Figure 4.3-2 is a schematic representation of the air traffic management facilities configuration, showing air traffic management facilities, flight service facilities, and their points of interface.

In addition to the facilities plan, another necessary dimension of the system description was definition of operator positions and distribution of operators among system facilities. The basic operator categories (options) as defined in the study based on natural groupings of the 17 functions were of three types, two of which had subdivisions (positions). They are:

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

The operator position responsibilities are purely functional. That is, each option and position is assigned responsibility for performing one or more of the seventeen generic system functions. Table 4.3-1 shows the allocation of functions to positions.

Note that only one position, IIB (Flow Control), is allocated one system function. All others have multiple assignments, with Position III (Flight Surveillance and Control) having responsibility for eight generic functions. A position was defined to consist of a man, a machine, and an input/output device so that the two can interact. It will be seen later that, although Position III has a large number of functions to perform, many tasks are allocated to the machine resource included in the position. Note also that two generic functions were omitted, Function 3 because it is performed by pilots and Function 10 because it relates to system sensors and effectors rather than to operator positions performing internal processes.

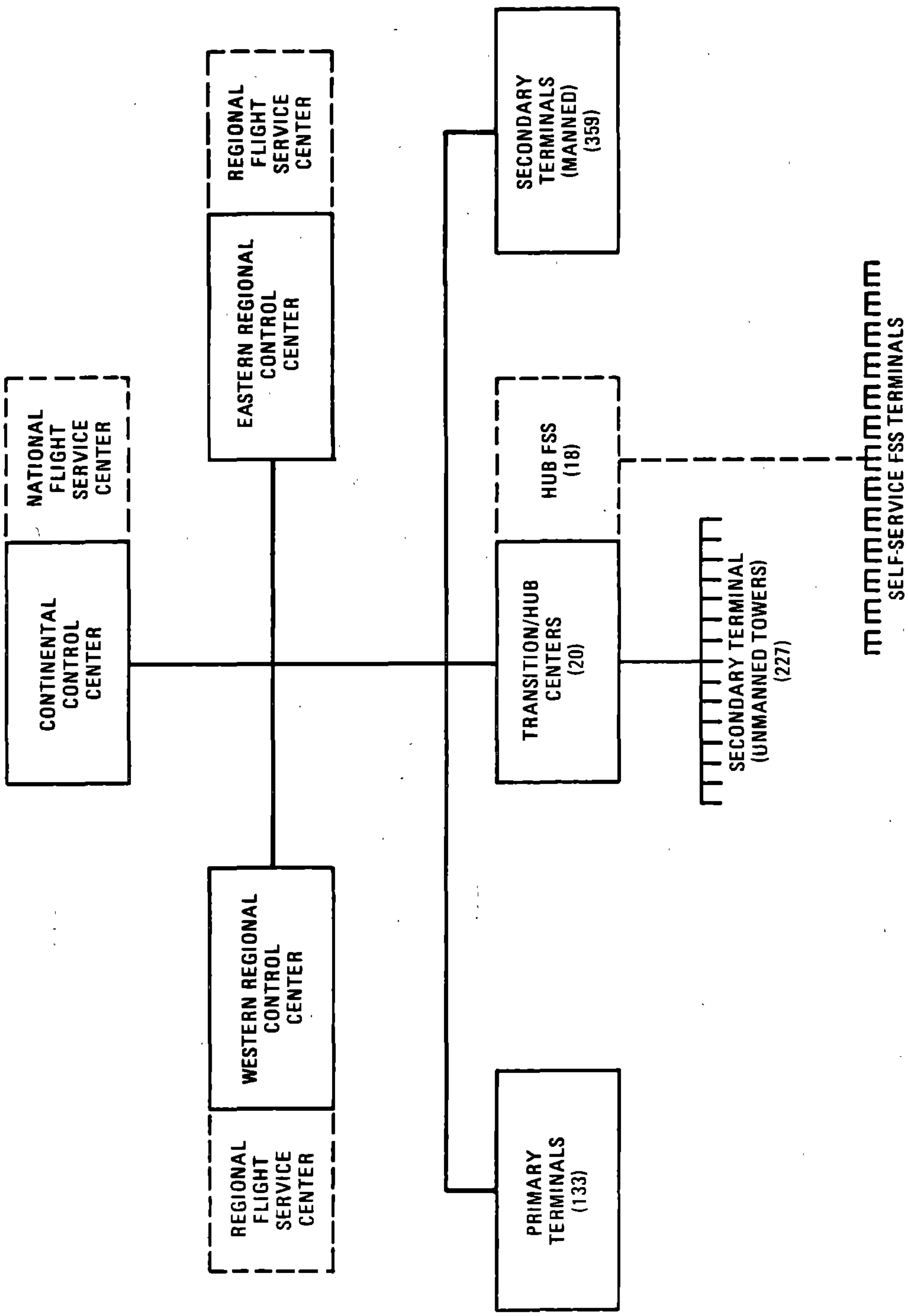


FIGURE 4.3-2 AATMS FACILITIES CONFIGURATION

TABLE 4.3-1 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 Advisories 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

Since the functional assignments describe both operator positions and system facilities, it was possible to relate the two. Table 4.3-3 on page 4.3-10 shows the distribution of AATMS operating positions among facilities. The final step in extending the system description was to relate the anticipated demand figure to the system by apportioning it among the various en route and terminal facilities. Two simplifying assumptions were made:

1. Demand would be homogenous. Each primary terminal would have an equal share of traffic, each en route facility would be apportioned one-half the total en route traffic, and so on. Further, the mixture of air carrier, general aviation, and military traffic would be uniform throughout the system airspace.

2. Capacity would equal demand. Sufficient runways, navigation routes, runways, terminal gates and so on would exist to account for the peak instantaneous demand figure given. In this way, demand was allowed to drive resource requirements without other factors constraining the relationship.

Peak instantaneous airborne count (IAC) was the expression of assumed demand derived from data supplied by DOT/TSC. Allowing for uncontrolled aircraft and rounding for ease of computation, a peak IAC of 33,750 was reached. It was assumed that of this total, 22,500 would be en route and 11,250 in terminal areas. To account for the higher activity at primary terminals, half of all aircraft in the terminal portion of the system were assigned to 133 primary airports, and the other half to the 586 secondary airports. Table 4.3-2 shows the resulting distribution of demand across facilities.

TABLE 4.3-2 DISTRIBUTION OF ASSUMED 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

TABLE 4.3-3 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

4.3.2 Recommended Automation Level

The recommended automation level was reached by carrying out a series of computations, in which demand was held constant at the given peak IAC and the resources required to meet the demand at various automation levels were determined. When a generally acceptable automation level was reached, i.e., one at which required manpower and machines fell within given limits, it was further studied and refined; and final computations were carried out to determine man and machine resource requirements. The selection of the appropriate level on the rank ordered automation index was then further substantiated by a limited exercising of the DELTA (Determine Effective Level of Task Allocation) simulation. (See Appendix C of Volume IV.)

To perform the computations, three elements of data about each of the 256 applicable tasks were derived. They were:

1. Manual Task Performance Time
2. Automated Task Computer Instruction Requirement
3. Frequency of Task Performance

Manual task performance time was based wherever possible on empirical data, taken from studies of manual task performance in the air traffic system. Where no empirical data could be found, estimates were used. Machine instruction requirements and task performance frequency requirements were also derived by estimation.

In general terms, the computation process proceeded as follows:

- Manual task performance time multiplied by task performance frequency equals man-hours, the basic unit of human resource requirements,
- Machine instructions required multiplied by task performance frequency equals instruction execution rate, a rough measure of computer resource requirements.

Thus the basic form of each equation was a summation. Summations were computed for each way in which the stimulus for performing a given task could occur. As an example, the manpower calculation was:

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

where P_{OU} = total number of operating personnel

T_{MD} = per aircraft flight, demand stimulated

T_{MT} = per system terminal, time stimulated

T_{MF} = per system facility, time stimulated

T_{MJ} = per system jurisdiction, time stimulated

T_{MM} = per month, time stimulated

Appropriate sums for man and machine resources were computed and multiplied by a calibration factor at each automation level to arrive at totals for manpower and machine requirements.

The computation for each automation level also took into account the effect of the requirement to perform "induced tasks", which had a material effect on resource requirements. An "induced task" was defined to occur whenever:

- A machine must communicate information to a man (thus creating the induced tasks of "generate display" for the machine and "read display" for the man);
- A man must control a machine (thus, "enter data" for the man, "receive data entry" for the machine);
- A man must coordinate with another man at a different system position (thus, "talk/listen" for one man, "listen/talk" for the other).

It can be seen that machine resources had to be provided to generate displays and receive data entries, and similarly men had to be given time to read displays, enter data, listen and talk. At relatively low automation levels, there is a large requirement for induced task resources because there is a relatively large amount of interaction between man and machine. As the automation level rises, so that a majority of tasks are performed by machines, the interaction requirement is reduced.

The total manpower and machine resources required to service a constant peak IAC were computed for five theoretical automation levels. Separate subtotals of induced task requirements were also made at some of the five levels, so that the relative impact of induced tasks on total resource requirements could be evaluated. Table 4.3-4 shows the results of the computations.

TABLE 4.3-4 MAN/MACHINE RESOURCE REQUIREMENTS BY AUTOMATION LEVEL

AUTOMATION LEVEL	MANPOWER REQUIREMENTS (Number of Operators)			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 needed to perform Subfunction 14.2 (System Records).

Table 4.3-4 which was computed for the 1995 nominal demand indicates that total manpower resource requirements decrease markedly as system automation is increased, but that there is not a corresponding increase in machine requirement in terms of instruction execution rate. The small increases in machine resources with automation level is attributed to the fact that the data processing requirements are dominated by the resources required to automate elements of the active control metafunction level I. The purpose of the theoretical automation levels was to find, by rough approximation, a level at which total system resource requirements were near a minimum level when considering both men and machines. The indication was that the level of choice would be somewhere between III and IV and fairly close to III. The next step was to study more closely the level so approximated.

The additional study of the automation level was done in order to take into account two factors not incorporated in the Automation Index method for ranking tasks. The first 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. For example, although the rating data provided a clear indication as to the relative automatability of a single task considered in isolation, no similar 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 linkage among tasks is such that when one task in a cluster is performed, all are performed. Clusters, therefore, had to be taken into account in order to recognize the need for performance continuity in chain performance situations and to reduce the incidence of induced tasks.

In addition to accounting for cluster effects, it was also necessary to formulate rules to take into account the nature and the similarity of tasks, unusual performance frequency requirements, and automated data system software complexity. These rules were applied as tests in each case where a question existed about a task allocation. The net effect was that adjustments were made to the preliminary man-machine allocation to reach a final recommended automation level for the system -- a complete allocation of the 256 generic tasks either to man or machine, and a complete catalog of the number and nature of the induced tasks associated with the basic allocation.

At the recommended automation level, 70 percent of the generic tasks are automated. The system is composed, in other words, of 77 manual tasks and 179 automated tasks. In the following paragraphs, the recommended automation level is briefly discussed in terms of the system 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 not concerned 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 -- either 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 (estimated time over/estimated time of arrival) are automated tasks.

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.

Once specification of the recommended automation level was complete, final computations of system resource requirements could be made. This was accomplished in two steps. First, a raw total of the manpower and machine requirements was computed. Next, this single pool of resources was distributed across the system facilities, adding to and rounding off the manpower requirement as necessary to achieve a shift staff size and a workforce total including administrative personnel and overhead.

The results of the first step, calculation of the undistributed man and machine resource requirements associated with each system position, are given in Tables 4.3-5 and 4.3-6. Raw manpower is the dimension of human resources, KIPS (thousand of instructions per second) is the unit of machine resources.

The most striking result in the manpower table is that, even at the relatively high automation level recommended, induced tasks ("read display", "enter data", "coordinate") account for 60 percent of the human operator workload. A second noteworthy result is that Position III, Flight Surveillance and Control, accounts for only 30 percent of the human manpower requirements; but the functions associated with this position are highly automated, so that 21446 of 23777 KIPS in the system are accounted for by Position III needs.

TABLE 4.3-5 UNDISTRIBUTED MANPOWER BASE REQUIREMENTS BY POSITION AT THE RECOMMENDED AUTOMATION LEVEL

POSITION	MANPOWER REQUIREMENTS				
	MANPOWER	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

*Percents may not add to 100 because of rounding.

TABLE 4.3-6 UNDISTRIBUTED DATA PROCESSING REQUIREMENTS BY POSITION AT THE RECOMMENDED AUTOMATION LEVEL

POSITION	DATA PROCESSING REQUIREMENTS			
	TOTAL KIPS	PERCENT OF TOTAL DUE TO:		
		GENERIC TASKS	INDUCED TASKS	
			CREATE DISPLAY	ACCEPT DATA
FLIGHT SURVEILLANCE AND CONTROL	21446	99.5	0.4	0.1
DATA BASE	657	100	*	*
FLIGHT INFORMATION SERVICES	240	81	13	6
FLIGHT PLANS	1003	83	15	2
FLOW CONTROL	31	93.0	6.2	0.8
ALL POSITIONS	23377	99	1	*

*Less than .1 percent

The second step in defining human resource requirements was to distribute the raw manpower resource totals associated with the recommended automation level across the various system facilities. In so doing, a number of adjustment factors were applied. They included rounding up to integral numbers of men and application of a "busy" factor to account for relief needs, operator-operator interaction outside the "coordination" tasks, operator-supervisor interactions, and operator administrative time. The effect of the adjustments was to convert a basic manpower per site allocation into a recommended shift size per site, and ultimately into a total system workforce requirement. Table 4.3-7 presents the system staffing requirements.

The effects of system automation on manpower requirements can be assessed by examination of Table 4.3-8*. The data source for the 1972 and 1982 figures was the National Aviation System Ten Year Plan (FAA, 1972). The figure of interest is the total staff size since the 1995 operator positions and options are different from those of today. It should also be noted that the figures for 1982 and 1995 are both extrapolations and should, in consequence, be interpreted with caution.

Another aspect by which the manpower resource requirements can be assessed is operator productivity. "Productivity", as used here, means the number of aircraft handled per operator at a specific system facility, given the peak IAC of 33,750 aircraft of all kinds and the demand distribution by facility discussed earlier in this section. Figure 4.3-3 is a schematic representation of operator productivity by facilities.

A prominent factor of the productivity results is the large difference between the en route portion and manned secondary airports. Two factors are involved in the difference. The first is that a greater proportion of activity (task performance workload) was assumed at terminals than in the en route environment. This was done to allow for more system interventions as the traffic converges around terminals and more precise management is required. The other factor is the difference in rounding effects when the various adjustment factors are applied to smaller dispersed facilities and

*Note that the manpower in Figure 4.3-8 does not include computer operators since computer staff requirements are highly dependent on centralized/decentralized details of the final computer architecture decisions. In any case the computer staff should be less than 2 to 3,000 operators and maintenance.

TABLE 4.3-7 SITE MANNING

SITE	NO. OF SITES	MANNED BY POSITION	REQUIRED SHIFT SIZE/SITE	RECOMMENDED SHIFT SIZE/SITE	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	162.0	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

TABLE 4.3-8 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	(4700)** 8002	9606*	DATA BASE, FLIGHT INFORMATION SERVICES, FLIGHT PLANS, FLOW CONTROL
TOTAL	24708	(31758)** 35060	16651	TOTAL

*The 9606 staff size is associated with the 1995 position which provides a much larger range of services than the 1972 and 1982 FSS position.

**Reduced FSS force of less than 4700 as projected by - A Proposal for the Future of FSS - DOT August 1973.

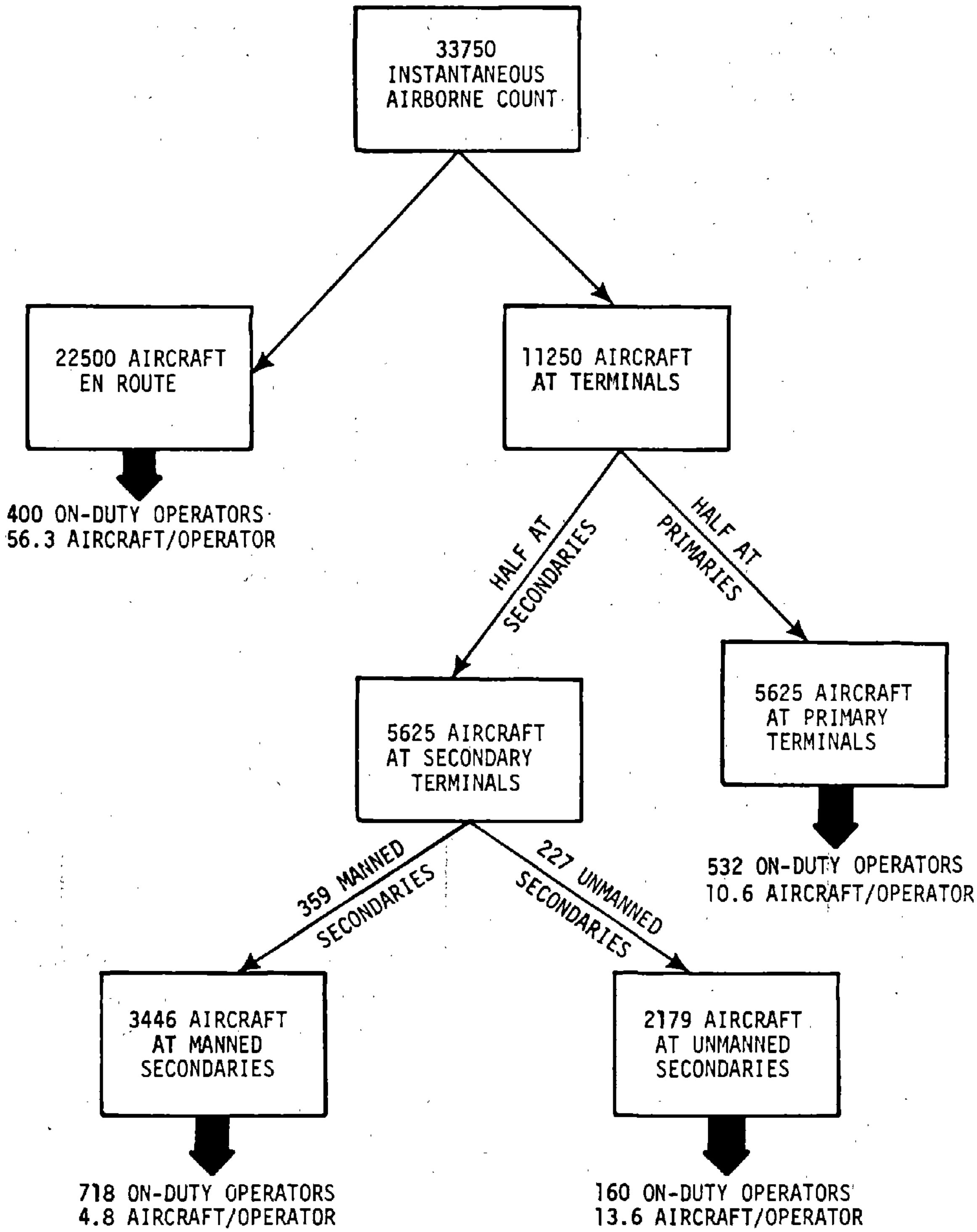


FIGURE 4.3-3 OPERATOR PRODUCTIVITY

larger centralized facilities. In effect, for every one operator initially allocated to the en route facilities, these factors resulted in a shift size increase by a factor of 1.23. By contrast, the factor of increase at manned terminal facilities was 3.08 operators for every one initially allocated.

Considered as a whole, however, the system productivity reflects a situation engendered by the effects of system automation. A system workforce estimated at 1810 Position III operators has sufficient power to service a demand of 33,750 aircraft when the system is automated to the recommended level.

4.3.3 Failure Mode Requirements

A major Phase C activity was an analysis of failure modes in the advanced air traffic management system. The objectives of the analysis were:

1. To determine the effects of functional component failure, measured in terms of loss of service to airspace users;
2. To identify remedial strategies which could be employed in system design to ameliorate the effects of failure;
3. To evaluate the degree to which these remedial features could serve to restore the system to its original operating state.

The assumption underlying the failure mode analysis was that, whatever physical configuration the system might ultimately employ, the system could be considered to consist of functional entities, each of which would be the locus of activities whose end result was a service to airspace users. Therefore, a loss of functional activity through failure of a task or subfunction could be expressed in terms of a loss of service to users. Since services to users could be classified in terms of safety and capacity-efficiency, functional failure states could be expressed as degradations of capacity-efficiency, safety, or both.

The method employed in the failure modes analysis was to identify the various ways in which functional failure can occur, assess the effects of the failure, devise a set of strategies for coping with failures, and relate failure strategies to failure situations. The results, as is the case in other study products, are useful in two ways:

1. As an approach and method that can be verified and reapplied in the course of subsequent system design activities, and

2. As an example of how the approach can be applied to define functional requirements and guidelines for near-term engineering and development investigations.

Assessing the effects of a given failure was done by identifying the degree of criticality inherent in the performance of the activity. The criticality was established by relating, at the subfunction level, system activities to system services. The activities were categorized as the production of information, decisions, or actions. Services, it will be recalled, had been classified as safety-related, capacity/efficiency related, and supporting services.

Five classes of criticality of activity to service were established. The classes of criticality are given below in the order of most to least critical.

Class 1 - The subfunction produces decisions or actions related to any of the four safety-related services.

Class 2 - The subfunction produces information for two or more safety-related services.

Class 3 - The subfunction produces decisions or actions related to any of the four capacity/efficiency-related services.

Class 4 - The subfunction produces information for one safety-related service or two or more capacity/efficiency-related services.

Class 5 - The subfunction produces information, decisions, or actions only for supporting services or for one capacity/efficiency-related service.

System operating positions had been derived by allocating functional performance responsibility to position type. Positions were defined to consist of a man, a machine, and an input/output device; the failure analysis considered only the failure of the machine resource. Given the recommended automation level, the tasks and subfunctions performed by machines at each operator position may be enumerated, and expressed in terms of their criticality class. Table 4.3-9 below is such an expression of failure criticality.

TABLE 4.3-9 FAILURE CRITICALITY OF SUBFUNCTIONS BY POSITION

POSITION	ASSIGNED SUBFUNCTIONS						
	AUTOMATED OR SEMI-AUTOMATED						ENTIRELY MANUAL
	FAILURE CLASS					TOTAL BY POSITION	
	1	2	3	4	5		
IA Data Base	0	6 (4/2)*	0	4 (4/0)	4 (2/2)	14 (10/4)	0
IB Flight Info.	0	0	5 (1/4)	0	1 (0/1)	6 (1/5)	0
IIA Flight Plans	0	0	3 (0/3)	0	0	3 (0/3)	3
IIB Flow Control	0	0	2 (2/0)	0	0	2 (2/0)	1
III Flight Surveil. and Control	16 (12/4)	8 (6/2)	2 (1/1)	0	0	26 (19/7)	2
TOTAL BY FAILURE CLASS	16	14	12	4	5	51	6 / 57

*Figures in parenthesis indicate, respectively, the number of automated and semi-automated subfunctions.

Next, a unit or module of data processing capability was defined, and all facility data processing capabilities were expressed as multiples of the modular unit. Failure of one or more modules was postulated, and the resulting effects on facility operations examined. The examination resulted in a statement as to the effects of failure in terms of one of three system conditions:

- Fail-operational - neither system capacity/efficiency nor safety are affected for reasonable lengths of time
- Fail-safe - some degree of loss of capacity/efficiency is encountered, but no loss in safety
- Fail-soft - some degree of loss of capacity/efficiency and of safety.

To reach this specification of the end point effects of failure modes, the results included recommendations on reconfiguration strategies appropriate for each failure condition studied. In all, seven strategies were defined; they are described in Table 4.3-10.

As strategy selections were derived, the number of modules of data processing capability for each facility was redefined as necessary, so that the final data processing volume recommended for each facility included any additional amount needed to enable reconfiguring in failure modes to implement the strategy or strategies recommended. Table 4.3-11 shows the data processing resource distribution derived in the analysis.

In general, the results of the analysis indicate that the system is highly resistant to the effects of individual failures. In all cases but two, which will be examined below, the system can be restored to a fail-operational state after loss of a single component. In all but 13 of the 126 cases considered, the fail-operational state can be attained without resorting to redundancy, manual backup, or elimination of services.* The most commonly applied strategies are drawing on internal reserves (66) and lateral borrowing (39). The vertical borrowing strategy is not required to deal with any instance of single-component failure. These findings suggest that the allocation and configuration of resources within facilities is such that the facilities are entirely self-sufficient in overcoming individual failures. In 8 cases (all in Position IA at the CCC) failures cause the system to cut back to essentials by eliminating supporting services (suspending the preparation of statistical and special reports), but this is not regarded as a significant weakness in the resource allocation for the CCC.

*There are three additional cases (Subfunction 7.1, 7.2 and 8.1) in Position III at RCC en route sectors where redundancy is a possible second-choice strategy; but these are not included in the 13 cases referred to above.

TABLE 4.3-10 STRATEGIES FOR RESPONSE TO FAILURE

STRATEGY	DESCRIPTION	CRITERIA FOR ADOPTION
Draw on Internal Reserves	Excess capacity within the data processing module where the failure has occurred is put to use to perform automated tasks.	The module must have sufficient excess to handle all automated tasks of the failed component and all its associated display generation and control input processing tasks.
Reduce to Essentials	Subfunctions resulting in outputs to low priority services are no longer performed and the excess capacity thus generated is put to use in restoring the outputs of the failed component.	a) Services of criticality Class 5 <u>must</u> be sacrificed to restore services of a higher class (1-4). b) If no services of criticality Class 5 are performed at the position, services of Class 3 or 4 <u>may</u> be sacrificed to restore Class 1 and 2 services. c) Under no circumstances can a higher class service be sacrificed for a lower.
Lateral Borrowing	Excess capacity from functionally similar modules at adjacent positions in the same facility is put to use in performing automated tasks associated with the failed component.	Modules must have sufficient excess, either singly or in combination, to handle all automated tasks of the failed component and all its associated display generation and control input processing tasks. (This strategy may be used in combination with "Draw on Internal Reserves".)

TABLE 4.3-10 STRATEGIES FOR RESPONSE TO FAILURE (Cont'd)

STRATEGY	DESCRIPTION	CRITERIA FOR ADOPTION
Manual Backup	The operator intervenes to perform manually those tasks which were performed by the automated resource prior to failure.	If a) the Automation Index shows that the tasks are suitable for human performance (i.e., the task ranks in automation levels III, IV or V), And if b) the frequency of task performance is low (i.e., not more than twice per flight or 40 times per hour per facility), And if c) the manual performance time is brief (i.e., 10 seconds or less), the tasks of the failed module may be reallocated to the human operator.
Vertical Borrowing	Excess capacity at a facility of equal or higher centralization is put to use in performing automated tasks associated with the failed component.	a) The loaning facility must have functionally similar modules in reserve with sufficient capacity to carry out the automated tasks and the induced display and control tasks of the failed component. b) If not, modules with dissimilar functional assignments but with sufficient capacity may be used. c) Modules associated with more critical services may not be loaned to perform less critical services. d) More centralized facilities may not borrow from less centralized facilities.

TABLE 4.3-10 STRATEGIES FOR RESPONSE TO FAILURE (Cont'd)

STRATEGY	DESCRIPTION	CRITERIA FOR ADOPTION
Redundancy	A spare module, unused in normal operating modes, is provided to restore service.	a) If none of the preceding strategies is adequate, spares may be provided at the facility so long as they do not exceed 20% of the capacity required for normal operations. b) If the 20% limit would be exceeded, spares should be provided at a more centralized location.
Do Without	No attempt is made to compensate for the loss of outputs from the failed component, and services associated with these outputs are allowed to degrade.	This strategy is appropriate only for failures affecting services of Critical Class 5 and should be adopted only when manual backup is not feasible.

TABLE 4.3-11 DATA PROCESSING MODULE REQUIREMENTS BY POSITION AND FACILITY

POSITION	MACHINE MODULES REQUIRED[1]					NO. MEN SERVED BY EACH PROCESSOR	CAPACITY (IPS) REQUIRED BY EACH MAN	EXCESS PER MODULE	TOTAL IPS EXCESS PER SITE 3
	SITE	NO.[2]	SPARES	TOTAL PER SITE	TOTAL FOR SYSTEM				
IA DATA BASE	CCC	91	9	100	100	1	7,231	-	64,800
IB FLIGHT INFORMATION	THC	2	0	2	40	17	353	1,200	2,400
IIA FLIGHT PLANS	THC	7	1	8	160	12	593	-	7,200
IIB FLOW CONTROL	CCC	5	0	5	5	5	1,2 1	800	5,200[6]
III FLIGHT SURVEILLANCE AND CONTROL	RCC	1000	10	1010	2020	.2[4]	35,140	178	250,000
	PRI.TERM.	4	0	4	532	1	6,725	425	1,900
	SEC.TERM.	1	0	1	359	2	3,046	1,100	1,100
	THC	10	0	10	200	.9[5]	7,812	-	1,700

1. Each module has a processing rate of 7,200 ips.
2. Number required for normal operations per site.
3. Includes excess for all modules and capacity of spares.
4. Each operator requires 5 7,200 ips modules for normal operations.
5. Each of the 9 operators requires more capacity than that available in a single module. Therefore, each operator must share part of the tenth module.
6. Includes 4,000 excess (5 modules x 800 excess each) plus 1,280 excess because there are modules sufficient for 25 operators but only 24 are assigned per shift.

There are two failures where the remedial strategy reduces the system to a fail-safe state, i.e., where capacity/efficiency are sacrificed in order to continue operations. One is in connection with failure of Subfunction 7.1 (Detect Long-term Conflicts Among Flight Plans) at a primary terminal. Failure of 7.1 can be resolved by lateral borrowing, but to do so would use up half of the total reserve of the facility, and this may not be prudent in view of the high safety-related criticality of other functions performed by Position III. Subfunction 7.1 (along with 9.1) has the lowest failure class rating in Position III; all others are failure Class 1 or 2. Therefore, the strategy of reducing to essentials by eliminating Subfunction 7.1 is suggested as a second choice, even though it entails some sacrifice of capacity and efficiency. This sacrifice, however, is not complete since 7.1 is backed up functionally by 7.3, 8.1 and 8.2. Still, it may be argued that the second-choice strategy represents a needless penalty in capacity/efficiency. If this is the prevailing view, then the first choice of lateral borrowing can be adopted, but at a serious cost in the total available reserve of the facility.

Failure of Subfunction 7.3 (Predict Deviations from Flight Plan) at a Transition Hub Center is a more clear-cut case. The reserves of the THC are not sufficient to remedy the failure by lateral borrowing. Subfunction 7.3 requires 2052 ips, and a reserve of only 1700 ips is available. Since 7.3 is a subfunction of failure class 2, it must be restored if the system is to continue to operate safely, i.e., if the system is not to fail weak. The only subfunction in Position III with a lower failure class and with a sufficient instruction rate is 7.1 (Class 3, 1101 ips). Therefore, the recommended strategy is a combination of drawing on internal reserves (which provides 1700 ips) and reducing to essentials by eliminating 7.1 (which makes an additional 1101 ips available). This results in a fail-safe condition. However, as noted above in the discussion of failure of 7.1 at a primary terminal, functional back-up is provided by Subfunction 7.3 (here restored to service), 8.1 and 8.2 -- so there is only a partial sacrifice of capacity and efficiency.

The discussion above summarizes the effect of failing any individual system activity at the subfunction level. The failure effect analysis also considered more massive failure modes, where the entire data processing capability of a given terminal or centralized facility was lost. The analysis indicated that even if an entire facility must thus be "closed", the system will still fail operational insofar as the functions performed by Position IA, IB, IIA, and IIB are concerned. There are two reasons for this degree of system resiliency. One is the backup structure given in the system concept, e.g., the CCC backs up THC's for Position IB and IIA activities. The other reason is that reserve operating capabilities are centralized, so that relatively large blocks of data processing volume can easily be reassigned or reconfigured.

The situation with respect to Position III in the event of massive failures is somewhat more complex. In the en route portion of the system, the worst case studied was failure of Position III functions in an entire subdivision of an RCC. In such a case, 10 percent of the total RCC data processing capability is lost. (Each RCC is made up of 10 major subdivisions.) The result is "fail-safe" for the affected subdivision and "fail-operational" for other RCC subdivisions. To achieve these states, all the data processing reserves of the RCC in question, its companion RCC, and the CCC would have to be committed.

In the terminal portion of the system, complete failure at the facility level was considered. In terms of assessing its effect on Position III activities, the failure was considered to make it necessary to shut down the terminal, handing over all aircraft to the appropriate RCC for rerouting. For the aircraft involved, the situation begins in a "fail-soft" operational state, with loss of safety-related services occurring until the RCC assumes responsibility for performance. It should be noted that if total redundancy at each terminal had been postulated, the fail-soft operational state would not result, but the option of total redundancy at terminals was not considered because it would entail uneconomically large data processing equipment requirements.

4.3.4 Display and Control Requirements

A significant Phase C project activity was to analyze the requirements for displays and controls in the advanced system. Display and control requirements were derived by examination of the number and nature of the "induced tasks" created for each operator and associated machine resource at the recommended system automation level. The logic whereby tasks are interrelated produces three kinds of induced tasks:

- Display
- Control
- Coordinate

A display task is induced whenever a machine must pass information to a man. A control task is induced whenever a man must pass information or instructions to a machine. A coordinate task is induced whenever two human operators must interact.

The objective of the analysis was to develop a generic statement of requirements for displays and controls. "Display" as used here means one or more information items, presented to a human operator at a given time for a specific purpose. The term does not mean a physical form such as a CRT. In other words, a human operator in the advanced system will have certain devices for information presentation at his work station. On these devices he will receive arrays of information items, presented to him for carrying out some particular task. Thus, the term "display" refers to the information item and not to the device. The purpose of the analysis was to derive the nature and content of the information items, not to create physical display and control designs.

This enumeration of information items constitutes a statement of functional requirements that can be used in subsequent system design and development activities to produce display and control consoles. Perhaps more importantly, the function analysis, the automation level, and the display/control characterization scheme developed in this study represents a method whereby display/control requirements can be expeditiously derived for any future system concept. The requirements analysis given here is, in that sense, an example of the application of the method.

The first step in defining display/control requirements was to review the man-machine task allocations against the system logic. The result was a list of all "display", "control", and "coordinate" tasks induced at the recommended automation level. The information items required for displays and the data entry items required for controls were collected, categorized, and formatted by operator position. A rubric was devised whereby format attributions could be made for each display. It is represented schematically in Figure 4.3-4.

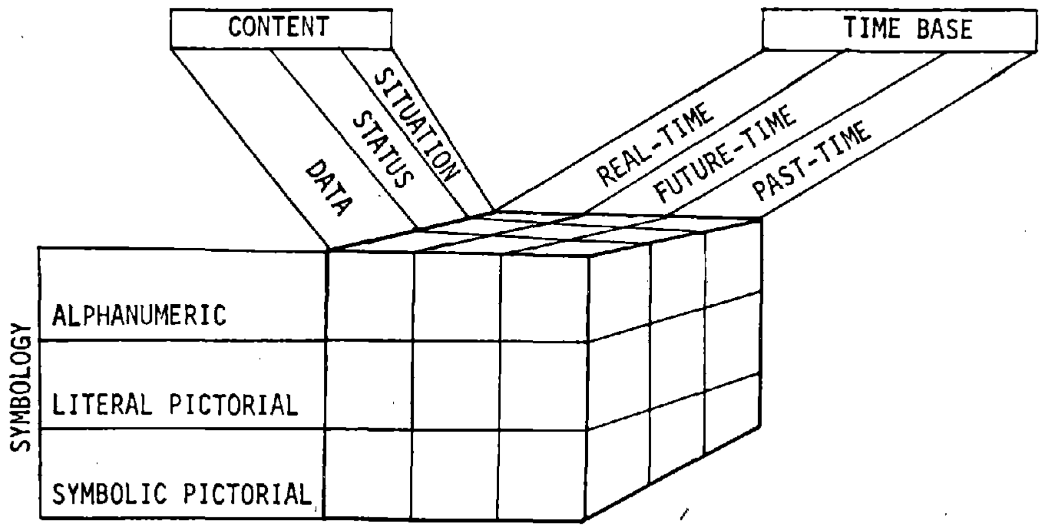


FIGURE 4.3-4 DISPLAY FORMAT ATTRIBUTIONS

As each display was identified, it was characterized by making appropriate attributions as to format. Thus:

- "Correlated aircraft position and identification" is a hybrid pictorial data display, containing literal pictorial and symbolic pictorial information. It is displayed on a real-time basis

- "Ground facilities status" is an alphanumeric status display, presented on a real-time basis
- "Traffic and other flight plans" is an alphanumeric/pictorial display, presented in a real-time mode, future-time mode, or both.

A total of 86 discrete information items are used within the system. When these were mapped across operator positions, it was found that the items are repeated at positions, shared across positions, and recombined in such a way as to generate 114 displays, each display consisting of one or more information items. Table 4.3-12 is a distribution of displays, indicating the number of displays at each position used only by that position (unique) and the number of displays shared across positions (common).

TABLE 4.3-12 DISTRIBUTION OF DISPLAYS SERVING AATMS OPERATOR POSITIONS

OPERATOR	POSITION	INFORMATION DISPLAYS		
		UNIQUE	COMMON	TOTAL
Data Base	IA	13	3	16
Flight Information, Flight Advisories	IB	12	11	23
Flight Planning and Special Services	IIA	15	12	27
Flow Control	IIB	2	8	10
Flight Surveillance and Control	III	29	9	38
TOTALS		71	43	114

Display format attributions were similarly analyzed. Table 4.3-13 is a summary of the formats.

TABLE 4.3-13 SYSTEM DISPLAY ATTRIBUTES

ATTRIBUTION	NUMBER OF DISPLAYS
Display Content	
Situational Information	27
Status Information	5
Data	12
Display Time Base	
Real Time	55
Future Time	17
Real/Future Time Modes	8
Real/Past Time Modes	3
All Time Base Modes	3
Display Encoding	
Alphanumeric	44
Alphanumeric/Symbolic Pictorial	4
Symbolic/Literal Pictorial Hybrid	10
Literal Pictorial (i.e., Surveillance)	1
Alpha/Literal/Symbolic Hybrid	27

System controls were identified and classified by a similar method, but with a different scheme of attribution. A control entry made by a human operator falls basically into two categories: data (the value of some parameter) and instructions (a command to perform some processing routine). In a few cases, an entry may be both data and instruction. The form of a control may be alphanumeric, (i.e., a keyboard), discrete (i.e., a switch), or dynamic/analog (i.e., a light pen or joystick).

While many display items are common to more than one situation and hence appear across operator positions, control entries are nearly always unique to the task in question. The single exception is the entry "description of guidance required", which is made both by the flight information position (IA) and by the flight planning position (IIA). However, most control entry items are alphanumerically encoded. The implication is that some standard keyboard will, therefore, suffice at all positions.

The manual tasks to be performed are such that several opportunities were found to take advantage of discrete or dynamic/analog input methods. Discrete controls might be appropriate, for example, in cases like "operational report required". The control could be a two-position switch (yes/no) that also enables a keyboard mode when the switch is set to "yes", allowing the keyboard to function as a video switcher, channeling information from some operational activity to a data storage device. Another case where a discrete control seems appropriate is "ID code assignment not required/required". Given that some sort of discrete-address beacon system is to be the primary surveillance mode, the identification of aircraft will normally be automatic. Indeed, if the performance of future beacon systems justifies it, the task of identification might be altogether eliminated. However, such basic assumptions inferred from specific hardware were, it will be recalled, outside the scope of the study. Therefore, the task exists as a generic task, normally automated at the recommended level. The manual performance is to determine if an identification code assignment is required, and normally it would not be. A control is provided to account for any exceptions. However, it seems unlikely for a failure to occur in such a way that it would disable only the identity-sending portion of an aircraft's transponder, or only the identity-sensing portion of the system's surveillance device. Therefore, it would be appropriate to investigate the concept of a "yes/no" control set normally at "no".

Discrete controls involving multiple rather than dual settings could be used in tasks like "select category of information", or "specify time period to be checked." Such controls could also be used to advantage in an application like "prefers new approach". This is the branch of the "missed approach" situation in which the pilot elects to go around and try again. The assumption here is that at a given terminal there might be several possible paths the pilot could follow in order to return to and be merged with the stream of incoming aircraft. Suppose the "prefers new approach" control to have two "new approach" settings: "standard" and "other". Setting the control to "standard" would result in a display of the procedural (that is, previously defined and agreed) vectors appropriate for the original runway, the weather, and the traffic situation, with the merge point selected by the computer. Setting the control to "other" would allow the operator to see several merge points and, by changing the aircraft's landing sequence priority, to select one.

It can be seen from the examples given that the recommendations for discrete control methods constitute guidelines for study in the process of selecting physical means for the performance of the generic induced tasks. The same intent can be inferred where a "dynamic/analog" recommendation is made for a particular control entry item. For example, "identifying area of restriction" could be done expediently if a keyboard entry alerted the machine that an area of restriction is to be defined, then a pointer or light pen type of device were used to draw the area on a pictorial display. The same combination of keyboard/light pen might be used to present "proposed modifications to flight plan" or to indicate to the machine a "description of guidance required". (For example, to avoid clear-air turbulence, the operator could indicate that he would like the aircraft to be vectored in thus and such a fashion from this point to that.)

After displays and controls had been considered separately, they were combined to develop a general characterization of the man-machine interface. Figure 4.3-5 is a simplified schematic representation of the interface, with positions and processes identified.

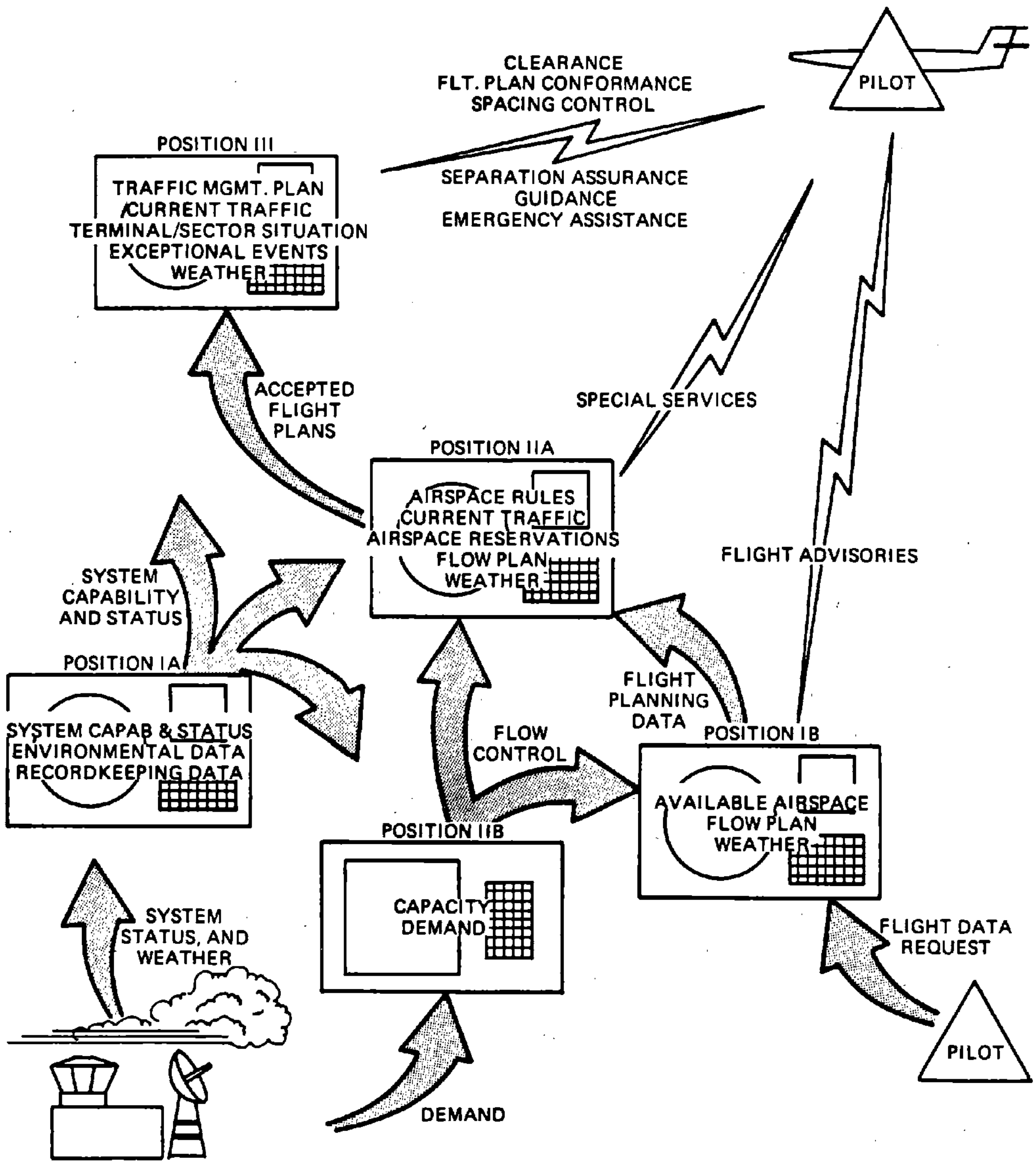


FIGURE 4.3-5 AATMS MAN-MACHINE INTERFACE

As the figure shows, the system data base is maintained through the activities of Position IA. The processes that are carried out involve recording and updating information on the status and capabilities of the system -- for example, the ground facilities, the communication and navigation subsystems, and user characteristics. Position IA also deals with environmental data, specifically with weather sensor data, weather observation schedules and reports, and with other sources of weather information like pilot reports (PIREPS). The data base position is also the keeper of system records. For that purpose, Position IA can receive on his pictorial display all current, predicted, or historical traffic data that relates to making reports. In addition, there are tabular displays such as traffic count, summaries of operations, and facilities downtime.

Position IIB (flow control) deals basically with demand for services and with predicted system capacity as affected by weather, facilities status, and other factors impinging on nominal values. He derives, according to an overall paradigm, the match between capacity and demand over time, called in the figure the system "flow plan".

Flight information and flight plan preparation services are provided by Position IB. The operator at this position deals with available airspace on given routes between points of origin and destination. The Position IB operator must also take into account the flow plan established by flow control and current and forecast weather, required not only for flight plan preparation but also to perform the function related to providing in-flight advisories.

Position IIA processes and approves flight plans. He also makes provision for and monitors the progress of special and ancillary services offerred by the air traffic management system. He receives inputs and makes outputs that involve "airspace rules" -- structure, usage, areas of restriction, and so on. Position IIA deals also with current traffic, firm airspace reservations, the flow plan as created and updated by the flow control position, and with the weather.

Accepted flight plans, the "contract" between system and user, are fed to operators and machines at Position III, the flight surveillance and control position. The human operator at Position III deals, in his role as manager, with the overall traffic management plan as originally created by flight planning and flow control and as modulated or revised by changing demand, changing intentions, and exigencies. Position III works with the current traffic situation and with the present and near-term future situation both in en route jurisdictions and at terminal facilities. Position III deals also with exceptional events: unforeseen effects of weather (e.g., icing or turbulence), unexpected deviations from flight plan, runway reversals, and emergencies.

Something of the complexity that surrounds the management of air traffic can be seen in this simplified characterization of the system man-machine interface. Even at the recommended automation level, which implies extensive performance of routine tasks by machines, the human operator must manipulate information items and control entries in some fourteen distinguishable categories relating to the system, its users, and the environment. In theory, the combined capabilities of the system resource teams made up of machines and human operators suffice to deal with the anticipated demand. But it seems clear that, in practice, reaching the level of automation required to achieve the recommended task allocations to man and machine will be necessary, but not sufficient, to meeting the desired goals of system performance. It will be required not only that the basic apportionment of tasks to human operators and machines is an appropriate one, but also that the combined power of men and machines is not constrained or vitiated by the effects of conditions at the man-machine interface. Some of the factors affecting the character of the man-machine interface are discussed below.

In this study, the resource unit in an advanced air traffic management system was defined to consist of a human operator, an automated processor, and an input-output device. Up to this point, the discussion has been focused on the input-output device. The number and nature of the generic displays and controls that are the functional implication of system automation have been identified. It would be remiss, however, not to include some perspective on the results. This is best accomplished by pointing out some of the factors that must be considered by the system designer in arriving at a physical specification of display-control devices and subsystems for AATMS. Each of these factors has, it should be noted, implications for and repercussions on the man-machine interface at every level of detail in the design process.

Foremost among these design considerations is the effect of actual physical automation capabilities, as they will be in the 1990 era. A fairly detailed discussion of this factor is given in the chapter on implementation strategy (Chapter 6, Volume I), and the topic is further addressed in the RDT&E plan included in Chapter 8 of Volume IV. In the end, the tasks actually allocated to machines will reflect the extent to which machines can actually perform them. That will be the fundamental determinant of the nature of the relationship between man and machine, hence also of the input-output requirements at the man-machine interface. Deciding that a machine can "actually perform" a task should be taken to mean that the machine can be built, that its cost will not be prohibitive, and that when operated and maintained in field conditions by field personnel its reliability will be such that failures are neither a real nor a perceived-as-real problem.

In that connection, the value of this project is that a method has been derived for defining and updating the basic control/display requirement attendant to a given level of system automation. Studies and comparisons can be made as required when suggestions and proposals for system configurations and equipment designs are put forward, so that the basic effects of a particular approach on man-machine interactions can be addressed.

A second major factor that will affect the man-machine interface in the advanced air traffic management system also has to do with machines. It encompases, however, not only the machines required for internal system processes but also the machines used for communications, surveillance, and navigation. It also embraces the airspace structure, the system procedures, and the system concept actually pertaining at the time of AATMS implementation. The factor is termed "homogeneity". The extent to which the system is actually homogeneous is its make-up will greatly influence how much it can be centralized and how uniform its rules and procedures are. For example, consider the problems inherent in human performance in a non-homogeneous system. The air traffic controller of today must learn a very large number of "ground rules" (perhaps "air rules" would be a better term) to qualify for unassisted responsibility in a given sector. These rules relate to the influence of airspace structure, surveillance/navigation/communication anomalies, and local procedural arrangements on acceptable control strategies, tactics, and individual decisions. One reason for centralizing the human operators in the AATMS system concept was to be able to make relatively large shifts of resources in response to changing patterns of demand. However, this can only be accomplished to the extent that human intervention to solve some problem in one jurisdiction can be made in the same way as human intervention in another. In other words, a homogeneous system is one in which the system resources are disentangled from local "ground rules" that require special performance from jurisdiction to jurisdiction.

The third major factor affecting the man-machine interface relates mainly to functional management and human resource development. In maintaining an appropriate number of qualified human operators, it will be necessary to carry out training activities. If some training is to be done on the job, it may be necessary to design special display modes. Such modes would be required, for instance, in order to simulate operational activity or in order to allow a trainee to step through some problem-solving process that is ordinarily carried out in a continuous fashion. Similarly, it will almost certainly be necessary to create special display modes (and perhaps even special displays and operator positions) to exercise functional management and resource control, i.e., to assess the quality of performance of a given system resource unit and to shift resources to meet varying patterns of capacity and demand. Since these system management activities lie outside the inventory of generic <u>operational</u> tasks derived in this study, specific controls and displays for such purposes are not delineated here, but the need for them can be clearly foreseen.

Several recommendations for research and development in the area of system management and resource control are provided in the discussion of implementation strategy and in the RDT&E plan. However, for the convenience of the reader, two examples will be given here to save cross-referral.

Consider that, in a "management by exception" system, many of the exceptional conditions and situations that may develop are probabilistic in nature. For instance, the incidence of unplanned deviations from original flight intentions and the incidence of missed approaches could both be expressed as probabilities, the value of the probability being greatly influenced by factors like weather. Whenever either or both of these situations arises, i.e., whenever a pilot deviates from his flight plan or misses an approach, a certain quantity of machine and human resources is required to deal with the circumstances.

Suppose that the probability of these exceptions can be predicted -- that enough data about major interactive factors like weather have been collected to be able to predict with some certainty that in a given system jurisdiction when the weather becomes inclement, the expectation is that some knowable number of deviations and missed approaches will occur. Given a display of the forecast weather and some set of controls for marshalling resources, a system resource manager could use such a predictive paradigm to assign additional machines and operators to the jurisdiction in question.

Consider as a second example the same situation, where weather conditions increase the number of exceptional operator interventions due to flight plan deviations or missed approaches. The resource manager might also operate on a real-time basis. The number of control actions an operator makes per unit time is a measure of how busy he and his machine "partner" are. Displaying this measure in a dynamic form would give a resource manager the means to diagnose overloads and provide relief.

5.0 IMPLICATIONS FOR AN ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

In this chapter, the results enumerated in Chapter 4 are discussed in relation to current concepts of air traffic management. The discussion provides an overview of the implications of the study. Such a perspective will be useful in reading the chapter on implementation that completes this volume of the study report.

The main outcomes of the study can be said to be (1) the development of the generic products in the early study phases and (2) the derivation of the recommended automation level in the final study phase. For convenience in considering the implications of the study, the discussion which follows is divided into two separate sections, called "generic study products" and "generic automation level".

Each section begins with an outline of the limitations of the study and continues with a discussion of the benefits of the products. While the generic study products and generic automation level can have practical value in the realization of system resource requirement goals and the creation of system specifications, it is important to understand that there are many factors attendant to applying automation in air traffic management which, for several reasons, were not addressed in this study. Because one or more of these unexplored areas may ultimately have a material effect on the way in which the study tools may be employed in any future effort, it is best to discuss these limitations briefly before proceeding to a recitation of the utility of the study products.

5.1 GENERIC STUDY PRODUCTS

Two study products which can be reused in subsequent efforts are the system functional analysis and the DELTA model. The limitations and utility of these products are discussed below.

5.1.1 Limitations of the Generic Study Products

A principal limitation of the study is that equipment considerations were avoided. This approach kept the function and task analysis relatively concept-free as regards hardware so as to promote the utility of the general system functional description and the DELTA model in evaluating alternative proposals and plans for physical means. Generic models, however, cannot take into account the effects of choosing actual physical means to carry out functions and tasks. Therefore, the basic human and machine requirement specified in the generic system description will have to be refined and modified as necessary to reflect the effects of physical choices as they are made.

The following examples should help to illustrate the point.

1. The system manpower requirements were derived by multiplying frequency of task performance by task duration to obtain total performance time required for each task. Either the frequency or duration of tasks, or both, can be influenced by the choice of physical means. For instance, suppose that the navigation system adopted permits aircraft to follow planned paths with greater precision than at present. This, in turn, would tend to reduce the ground system interventions required to help aircraft maintain conformance with their flight plans, thus affecting the frequency of performance of certain system tasks. The total resource requirement would, therefore, be altered. A few of the equipment choices that might trigger this chain of effects include the adoption of some new navigation method which has a smaller inherent error, the development of some new cockpit navigation display, or the use of station-keeping equipment by groups of aircraft flying through system airspace.

2. The way in which information is entered, processed, and displayed within the system will have a significant effect, particularly in the "induced task" area. The functional analysis accounts for generic, not specific, induced tasks. An example would be the display of aircraft position to a human operator. While provision is made for such display in the system functional description (that is, machine resources are provided to generate the display and operator time is provided to read it), no specific tasks like "adjust display magnification" or "switch display mode" are included.

3. The two examples just presented illustrate ways in which the generic system model is directly affected by the choice of physical means. There are also indirect effects. For instance, advances in airframe performance characteristics or in weather forecasting techniques might change the frequency or the time required for system responses in weather avoidance vectors, missed approaches due to weather, and similar system tasks.

A second area in which the study scope was restricted is that it dealt primarily with first-order issues. For example:

1. While a rigorous scheme was used to identify and describe all generic tasks inherent in the management of air traffic, the scope of the work did not include any extended study of either administrative activities or internal system management functions. An "overhead" factor was applied in the staffing calculations to account for these requirements. However, study is required of the circumstances surrounding the performance of given functional resources composed of man-machine combinations such as those specified in the reccommended system configuration, so that the nature of and the means for process quality assurance and system resource control can be explored.

2. A second example of the concentration of work on first-order issues falls in the general area of human factors. The system configuration generated in this study provides for allocation of all system functions to operator positions. The position types appear to satisfy all requirements for system operation, i.e., all necessary tasks are accounted for. But extended attention to second-order human issues like intrinsic job satisfaction or career progression was not a part of the study. It is felt that such work would be premature; the answers to first-order questions like man-machine task allocations and productivity had to be obtained first.

The final limitation of the study that affects the generic study products relates to the system concept. Two aspects of the system concept which may change as the concept is further defined are the operational logic of the system and the configuration of facilities. Changes in the logic of the system concept will affect the ways in which system functions relate to system services and in which the system functions are internally related. This will cause changes in task inter-relationships and, ultimately, in resource requirements. Changes in the facilities configuration will affect system manning, i.e., the number and nature of the ground locations where system operators are deployed has an effect on the number of operators required to staff shifts.

It should be pointed out that while the nature of the limitations described above proscribes viewing the generic study products as a direct model of any specific <u>solution</u> to automation in air traffic control systems, the principal utility of these products is that they serve as a way to describe and derive requirements. In other words, the generic study products provide system specification guidelines rather than the specification themselves. Accepting that level of generality in the derivation of the products inevitably implied limitations; but it avoided the undesirable posture of commitment to specific physical means which, in light of the long-range nature of the study, would have injected the destructive factor of technical obsolescence. The practical value, then, of the generic study products is that they provide a theoretical prescription for use in developing physical designs. The process for their use is described in the paragraphs that follow.

5.1.2 Utility of the Generic Study Products

Within the limitations given above, the generic study products developed as tools for deriving the automation applications in this project can, it is believed, be re-used as aids to subsequent AATMS design and development. In brief, the function and task descriptions and the Automation Index provide a frame of reference for specifying the requirements for physical "packaging" and for assessing the qualitative effects of such hardware choices on system performance and system resource requirements. Basic quantitative effects can be derived through use of the DELTA model, which allows resource requirement trade-offs to be made.

Consider, for example, the situation in which alternative physical means are proposed to accomplish a given group of ATC tasks. Each of the alternative "packaging" concepts can be mapped into the system functional description. Checks can then be made to see that all generic tasks in the subset in question are accounted for and that allocation to either man or machine is appropriate for the required concept or system. Next, checks can be made of the way in which induced tasks are accounted for in each proposed physical configuration. Thirdly, since task interactions are defined explicitly according to the overall system logic, all points of interface with the rest of the system in the proposed physical configuration can easily be isolated for studies of interactive effects. Thus, the designer can perform a detailed examination of the functional consequences stemming from the adoption of one or other proposal for physical means, and thereby compare otherwise differing solutions.

Just as it is possible to compare differing proposals intended for adoption in the same time frame, so also can operational evolution be studied by comparing current with proposed future configurations. Again, the process involves mapping both into the overall system functional specifications, this time in order to isolate the changes for further study. Table 5.1-1, given at the end of this section, shows by example how a portion of NAS Stage A can be mapped into AATMS. Future versions of the air traffic system (e.g., the Upgraded Third Generation System) could be mapped in a similar way. This would allow the changes from version to version to be studied both in isolation and in relation to the system as a whole.

TABLE 5.1-1 AATMS/NAS STAGE "A" TASK CORRELATION

NAS STAGE A SUBFUNCTION & TASK[2] / AATMS TASK[1]	4.1.1 DETERMINE POINTS FOR WHICH ETOV'S ARE TO BE COMPUTED	4.1.2 COMPUTE ETOV'S/ETA	4.3.1 DETERMINE CHANGES REQUIRED TO MAKE FLIGHT PLAN ACCEPTABLE	4.4.2 CANCEL FLIGHT PLAN	5.1.1 DETERMINE IF IDENTIFICATION CODE ASSIGNMENT IS REQUIRED	5.1.2 COMPARE FLIGHT PROGRESS WITH CLEARANCE LIMIT AND EFC TIME	5.2.1 ASSIGN IDENTIFICATION CODE	6.1.1 RECEIVE/ENTER CORRELATED POSITION AND IDENTIFICATION	6.1.2 RECEIVE/ENTER POSITION	6.1.3 CORRELATE POSITION AND IDENTIFICATION	6.3.2 COMPUTE SHORT-RANGE EXTRAPOLATIONS	6.3.3 COMPUTE LONG-RANGE EXTRAPOLATIONS	6.4.2 DETECT AIRCRAFT EMERGENCIES	7.3.1 DETERMINE AIRCRAFT'S INTENDED FUTURE POSITIONS	8.1.2 PREDICT AIRCRAFT PATHS	9.1.1 DETERMINE IDENTITY AND ETA OF ARRIVING AIRCRAFT	9.1.2 DETERMINE IDENTITY AND ETD OF DEPARTING AIRCRAFT	9.1.3 LIST ARRIVING AND DEPARTING AIRCRAFT AND ETA/ETD	11.2.3 COMPUTE GROUND SPEED	11.2.4 COMPUTE ALTITUDE DIFFERENCE	11.3.1 COMPUTE AIRSPEED	13.1.1 CORRELATE AIRCRAFT POSITION WITH JURISDICTIONAL BOUNDARIES	13.3.1 TRANSFER RESPONSIBILITY FOR CONTROL	17.10.1 MAINTAIN TALLIES OF ACTIVE FLIGHT PLANS	17.10.3 STORE TRAFFIC DATA					
2.1.1.1 Flight Plan Data Inputs																														
2.1.1.1.1 Flight Plan Data					●																									
2.1.1.1.2 Amendment Data			●																											
2.1.1.1.3 Departure Data			●																											
2.1.1.1.4 Progress Report Data			●																											
2.1.1.1.5 Hold Data			●																											
2.1.1.1.6 Cancellation Data			●																											
2.1.1.1.7 Stereo Flight Plan Data			●																											
2.1.1.1.8 Mission Flight Plan Data			●																											
2.1.1.1.9 Beacon Request Data					●																									
2.1.1.2 Information Requests																														
2.1.1.2.2 Flight Plan Readout Request	●	●																												
2.1.1.2.3 Strip Request	●	●																												

SOURCE: 1. TRW REPORT NO. 22265-W006-RU-00, "AUTOMATION APPLICATIONS IN AN ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM: FUNCTION ANALYSIS OF AIR TRAFFIC MANAGEMENT" VOLUME 11, DECEMBER 1973.

2. FAA CONFIGURATION MANAGEMENT DIRECTIVE SPO-MD-309, "ATC OPERATIONAL COMPUTER PROGRAM DESCRIPTION (MODEL 3)", 1 APRIL 1972.

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TABLE 5.1-1 AATMS/NAS STAGE "A" TASK CORRELATION

NAS STAGE A SUBFUNCTION & TASK / AATMS TASK	4.1.1 DETERMINE POINTS FOR WHICH ETOV'S ARE TO BE COMPUTED	4.1.2 COMPUTE ETOV'S/ETA	4.3.1 DETERMINE CHANGES REQUIRED TO MAKE FLIGHT PLAN ACCEPTABLE	4.4.2 CANCEL FLIGHT PLAN	5.1.1 DETERMINE IF IDENTIFICATION CODE ASSIGNMENT IS REQUIRED	5.1.2 COMPARE FLIGHT PROGRESS WITH CLEARANCE LIMIT AND EFC TIME	5.2.1 ASSIGN IDENTIFICATION CODE	6.1.1 RECEIVE/ENTER CORRELATED POSITION AND IDENTIFICATION	6.1.2 RECEIVE/ENTER POSITION	6.1.3 CORRELATE POSITION AND IDENTIFICATION	6.3.2 COMPUTE SHORT-RANGE EXTRAPOLATIONS	6.3.3 COMPUTE LONG-RANGE EXTRAPOLATIONS	6.4.2 DETECT AIRCRAFT EMERGENCIES	7.3.1 DETERMINE AIRCRAFT'S INTENDED FUTURE POSITIONS	8.1.2 PREDICT AIRCRAFT PATHS	9.1.1 DETERMINE IDENTITY AND ETA OF ARRIVING AIRCRAFT	9.1.2 DETERMINE IDENTITY AND ETD OF DEPARTING AIRCRAFT	9.1.3 LIST ARRIVING AND DEPARTING AIRCRAFT AND STATUS	11.2.3 COMPUTE GROUND SPEED	11.2.4 COMPUTE ALTITUDE DIFFERENCE	11.3.1 COMPUTE AIRSPEED	13.1.1 CORRELATE AIRCRAFT POSITION WITH JURISDICTIONAL BOUNDARIES	17.1.1 TRANSFER RESPONSIBILITY FOR CONTROL	17.10.1 MAINTAIN TALLIES OF ACTIVE FLIGHT PLANS	17.10.3 STORE TRAFFIC DATA
2.1.2.1 Flight Strip Printer Outputs																									
2.1.2.1.1 Enroute Strips	●	●																	●		●				
2.1.2.1.3 Flow Control Strips																●					●				
2.1.2.1.4 Mission Flight Plan Strips																					●				
2.1.2.1.5 Planned Shutdown Strips																	●								
2.1.2.2 CRD Outputs																									
2.1.2.2.2 Flight Cancellation/ Reroute														●											
2.1.2.2.10 Indefinite Hold Update							●																		
2.1.2.2.11 Beacon Code Update													●												
2.1.2.5 FDEP Outputs																									
2.1.2.5.1 Departure Strips	●	●															●								
2.1.2.5.3 Approach Control Arrival Strips																●									
2.1.2.6 NAS to Remote Teletypes																									
2.1.2.6.3 Error Message			●																						

TABLE 5.1-1 AATMS/NAS STAGE "A" TASK CORRELATION

NAS STAGE A SUBFUNCTION & TASK / AATMS TASK	4.1.1 Determine points for which ETA's are to be computed	4.1.2 Compute ETA's/ETA	4.3.1 Determine changes required to make flight plan acceptable	4.4.2 Cancel flight plan	5.1.1 Determine if identification code assignment is required	5.1.2 Compare flight progress with clearance limit and EFC time	5.2.1 Assign identification code	6.1.1 Receive/enter correlated position and identification	6.1.2 Receive/enter position	6.1.3 Correlate position and identification	6.3.2 Compute short-range extrapolations	6.3.3 Compute long-range extrapolations	6.4.2 Detect aircraft emergencies	7.1.1 Determine aircraft positions	8.1.2 Predict aircraft paths	9.1.1 Determine identity and ETA of arriving aircraft	9.1.2 Determine identity and ETD of departing aircraft	9.1.3 List arriving and departing aircraft and ETA/ETD	11.2.3 Compute ground speed	11.2.4 Compute altitude difference	11.1.1 Compute airspeed	11.1.1 Correlate aircraft position with jurisdictional boundaries	11.1.1 Transfer responsibility for control	17.10.1 Maintain tallies of active flight plans	17.10.1 Store traffic data					
2.1.3.2 Fix Time Calculation																														
2.1.3.2.1 Automatic Updating														●	●															
2.1.3.3 Flight Plan Position Extrapolation																														
2.1.3.3.2 Extrapolation Status											●	●		●	●															
2.1.3.3.3 Flight Plan Position Fix Determination						●								●	●															
2.1.3.3.4 Flight Plan Position Determination						●								●	●															
2.1.3.4 Beacon Code Allocation																														
2.1.3.4.1 Automatic Assignment of Codes							●																							
2.1.3.4.2 Monitoring of Assigned Codes							●																							
2.1.3.8 Boundary Sensing																														
2.1.3.8.1 Center Boundary Crossing Fix Determination																						●								
2.1.3.8.2 Center Boundary Crossing Time																						●								
2.1.3.8.3 Distance to/from Sector Boundary																						●								

TABLE 5.1-1 AATMS/NAS STAGE "A" TASK CORRELATION

NAS STAGE A SUBFUNCTION & TASK / AATMS TASK	4.1.1 DETERMINE POINTS FOR WHICH ETOV'S ARE TO BE COMPUTED	4.1.2 COMPUTE ETOV'S/ETA	4.3.1 DETERMINE CHANGES REQUIRED TO MAKE FLIGHT PLAN ACCEPTABLE	4.4.2 CANCEL FLIGHT PLAN	5.1.1 DETERMINE IF IDENTIFICATION CODE ASSIGNMENT IS REQUIRED	5.1.2 COMPARE FLIGHT PROGRESS WITH CLEARANCE LIMIT AND CFC TIME	5.2.1 ASSIGN IDENTIFICATION CODE	6.1.1 RECEIVE/ENTER CORRELATED POSITION AND IDENTIFICATION	6.1.2 RECEIVE/ENTER POSITION	6.1.3 CORRELATE POSITION AND IDENTIFICATION	6.3.2 COMPUTE SHORT-RANGE EXTRAPOLATIONS	6.3.3 COMPUTE LONG-RANGE EXTRAPOLATIONS	6.4.2 DETECT AIRCRAFT EMERGENCIES	7.3.1 DETERMINE AIRCRAFT'S INTENDED FUTURE POSITIONS	8.1.2 PREDICT AIRCRAFT PATHS	9.1.1 DETERMINE IDENTITY AND ETA OF ARRIVING AIRCRAFT	9.1.2 DETERMINE IDENTITY AND ETD OF DEPARTING AIRCRAFT	9.1.3 LIST ARRIVING AND DEPARTING AIRCRAFT AND ETA/ETD	11.2.3 COMPUTE GROUND SPEED	11.2.4 COMPUTE ALTITUDE DIFFERENCE	11.3.1 COMPUTE AIRSPEED	13.1.1 CORRELATE AIRCRAFT POSITION WITH JURISDICTIONAL BOUNDARIES	13.3.1 TRANSFER RESPONSIBILITY FOR CONTROL	17.10.1 MAINTAIN TALLIES OF ACTIVE FLIGHT PLANS	17.10.3 STORE TRAFFIC DATA					
2.2.1.7 Correlation																														
2.2.1.7.0 Correlation										●																				
2.2.2.8 CROSSTELL																														
2.2.2.8.0 CROSSTELL								●	●																					
2.2.2.11 Matching																														
2.2.2.11.0 Matching										●																				
2.2.2.12 Track Next Fix																														
2.2.2.12.0 Track Next Fix						●																								
2.2.3.2 R Position Inputs																														
2.2.3.2.5 Drop Track and Flight Plan				●																										
2.2.3.2.6 Hold						●																								
2.2.3.2.7 Initiate Handoff																							●							
2.2.3.2.8 Accept Handoff								●															●							
2.2.3.2.9 Modify Assigned Altitude																				●										

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TABLE 5.1-1 AATMS/NAS STAGE "A" TASK CORRELATION

NAS STAGE A SUBFUNCTION & TASK / AATMS TASK	4.1.1 DETERMINE POINTS FOR WHICH ETOV'S ARE TO BE COMPUTED	4.1.2 COMPUTE ETOV'S/ETA	4.3.1 DETERMINE CHANGES REQUIRED TO MAKE FLIGHT PLAN ACCEPTABLE	4.4.2 CANCEL FLIGHT PLAN	5.1.1 DETERMINE IF IDENTIFICATION CODE ASSIGNMENT IS REQUIRED	5.1.2 COMPARE FLIGHT PROGRESS WITH CLEARANCE LIMIT AND EFC TIME	5.2.1 ASSIGN IDENTIFICATION CODE	6.1.1 RECEIVE/ENTER CORRELATED POSITION AND IDENTIFICATION	6.1.2 RECEIVE/ENTER POSITION	6.1.3 CORRELATE POSITION AND IDENTIFICATION	6.3.2 COMPUTE SHORT-RANGE EXTRAPOLATIONS	6.3.3 COMPUTE LONG-RANGE EXTRAPOLATIONS	6.4.2 DETECT AIRCRAFT EMERGENCIES	7.3.1 DETERMINE AIRCRAFT'S INTENDED FUTURE POSITIONS	8.1.2 PREDICT AIRCRAFT PATHS	9.1.1 DETERMINE IDENTITY AND ETA OF ARRIVING AIRCRAFT	9.1.2 DETERMINE IDENTITY AND ETD OF DEPARTING AIRCRAFT	9.1.3 LIST ARRIVING AND DEPARTING AIRCRAFT AND ETA/ETD	11.2.3 COMPUTE GROUND SPEED	11.2.4 COMPUTE ALTITUDE DIFFERENCE	11.3.1 COMPUTE AIRSPEED	13.1.1 CORRELATE AIRCRAFT POSITION WITH JURISDICTIONAL BOUNDARIES	13.3.1 TRANSFER RESPONSIBILITY FOR CONTROL	17.10.1 MAINTAIN TALLIES OF ACTIVE FLIGHT PLANS	17.10.3 STORE TRAFFIC DATA					
2.2.3.2.11 Modify Beacon Code							●																							
2.2.3.2.12 Modify Airspeed																			●											
2.2.3.2.13 Code Request							●																							
2.2.3.2.19 Beacon Code Readout													●																	
2.2.4.1 R Position PVD																														
2.2.4.1.1 Full Data Blocks								●											●	●										
2.2.4.1.2 Limited Data Blocks									●											●										
2.2.4.1.3 List Displays																														
2.2.4.1.3.1 Departure List																		●												
2.2.4.1.3.2 Inbound List																		●												
2.2.4.1.3.3 Hold List																		●												
2.2.4.1.3.4 Updating of List Displays																		●												
2.2.4.2 R Position CRD																														
2.2.4.2.5 Beacon Code Assignment							●																							

TABLE 5.1-1 AATMS/NAS STAGE "A" TASK CORRELATION

NAS STAGE A SUBFUNCTION & TASK \ AATMS TASK	4.1.1 DETERMINE POINTS FOR WHICH ETOV'S ARE TO BE COMPUTED	4.1.2 COMPUTE ETOV'S/ETA	4.3.1 DETERMINE CHANGES REQUIRED TO MAKE FLIGHT PLAN ACCEPTABLE	4.4.2 CANCEL FLIGHT PLAN	5.1.1 DETERMINE IF IDENTIFICATION CODE ASSIGNMENT IS REQUIRED	5.1.2 COMPARE FLIGHT PROGRESS WITH CLEARANCE LIMIT AND EFC TIME	5.2.1 ASSIGN IDENTIFICATION CODE	6.1.1 RECEIVE/ENTER CORRELATED POSITION AND IDENTIFICATION	6.1.2 RECEIVE/ENTER POSITION	6.1.3 CORRELATE POSITION AND IDENTIFICATION	6.3.2 COMPUTE SHORT-RANGE EXTRAPOLATIONS	6.3.3 COMPUTE LONG-RANGE EXTRAPOLATIONS	6.4.2 DETECT AIRCRAFT EMERGENCIES	7.3.1 DETERMINE AIRCRAFT'S INTENDED FUTURE POSITIONS	8.1.2 PREDICT AIRCRAFT PATHS	9.1.1 DETERMINE IDENTITY AND ETA OF ARRIVING AIRCRAFT	9.1.2 DETERMINE IDENTITY AND ETD OF DEPARTING AIRCRAFT	9.1.3 LIST ARRIVING AND DEPARTING AIRCRAFT AND ETA/ETD	11.2.3 COMPUTE GROUND SPEED	11.2.4 COMPUTE ALTITUDE DIFFERENCE	11.3.1 COMPUTE AIRSPEED	13.1.1 CORRELATE AIRCRAFT POSITION WITH JURISDICTIONAL BOUNDARIES	13.3.1 TRANSFER RESPONSIBILITY FOR CONTROL	17.10.1 MAINTAIN TALLIES OF ACTIVE FLIGHT PLANS	17.10.3 STORE TRAFFIC DATA					
2.8.3.1 Data Reduction and Analysis System																														
2.8.3.1.3 Operational Input/Output Summary																								●						
2.8.3.1.6 Flight Plan Data Base Analysis																									●					
2.8.3.1.7 Sector and Fix Load Summary																									●					
2.8.3.1.8 Discrete Beacon Code Analysis																									●					
2.8.3.1.9 Correlated/Decorrelated Data Analysis																									●					

5.2 GENERIC AUTOMATION LEVEL

The generic automation level derived in this study can be viewed as a goal statement. The computation of man and machine resource requirements was predicated on a given system concept and a specified demand for system services. At the recommended automation level, the manpower and machines requirement estimates so derived resulted in a system that was near minimum in terms of total system resource requirements. Thus, the automation level forms a guideline for task allocation to human operators and machines in developing system specifications in the same manner as the function analysis does. The limitations and benefits of the generic automation level are presented below.

5.2.1 Limitations of the Generic Automation Level

The limitations inherent in the generic approach that apply to the system functional analysis also apply to the generic automation level. One additional limitation is peculiar to the automation level itself. It stems from the way in which system tasks were arranged in relation to each other in order to establish the man-machine allocation. This array of tasks on an index of amenability to automation represents only one criterion for automation. The criterion, it is believed, is a useful one. It can be reasonably expected that the tasks recommended for allocation to machines are ones that require "machine-like" performance capabilities, and similarly that those tasks allocated to human operators are suited for "man-like" performance capabilities. The methodology for developing an index of tasks according to this criterion adds a new and systematic way to make engineering judgments about automation in complex systems, but this approach should be considered to be an addition to, rather than a substitute for, other necessary studies. Further examination of the automation level according to other parameters, e.g., cost trades, feasibility, and the like, is still required. These analyses are considered in some detail later, in Chapter 6 of this volume.

A second limitation of the study is that nearly all the effort in establishing an automation level was directed to the basic question of whether the task should be manual or automated. Thus, little time could be devoted to examinations of the degree or level of machine aiding for tasks allocated to manual performance means. Again, identification of this area as a topic for research has been made; it will be discussed later.

5.2.2 Utility of the Generic Automation Level

It was stated earlier that the generic automation level can be viewed as a target or goal for applying automation in air traffic management. There are several implications to such a view, relating both to defining the goal and to its ultimate achievement.

Definition of the automation goal can be done by examination of the system automation level with respect to safety, effectiveness, and cost. These factors, it will be recalled, are the principal metrics or standards of system performance presented at the beginning of this report.

In terms of safety, the automation level is one at which all tasks attendant not only to aircraft separation, but also to routine control of aircraft converging into terminal areas, aircraft whose paths converge in transit, and aircraft approaching each other on opposing courses are automated. Thus, providing data systems can be developed to do the job, the human operator will not be burdened with routine performance of safety-critical tasks; and full advantage can be taken of machine speed, accuracy, and reliability. A corollary benefit is that the human operator, because he handles only the unusual situation, does not have to be concerned with attending to routine while simultaneously dealing with exceptional conditions. The generic automation level reflects, with respect to safety, an overall design intent to maintain or improve the safety of system users as compared to today's system.

In terms of effectiveness, the generic automation level implies a system where mechanization is concentrated in functions relating to strategic and tactical control, i.e., in traffic planning and regulation and in determining system capability and status. Again, advantage can be taken of the speed and accuracy of machines in dealing with complex problems associated with flight planning, clearance generation and modification, and similar activities. For example, a measure of system effectiveness is the way in which the system acts to minimize delays. The system concept, i.e., the logic of a ground-based, strategic/tactical system for the management of air traffic was, it will be recalled, a "given". Within this overall concept, the automation level allows the full use of the power of machines in making plans and adjusting them as circumstances change. Thus, in the case where external factors such as weather force a reformulation of the air traffic management plan, the complex tasks of rerouting, speed adjustments, recomputation of ETOV/ETA, runway rescheduling, and so on are done by machines rather than by men.

The third aspect of goal definition is <u>cost</u>. The generic automation level describes a balance of human and machine participation such that, when resource requirements are computed at the anticipated demand level for the given system concept, both the operating manpower and data processing requirement estimates will result in near optimum total system resource requirements. It must be noted that, insofar as manpower is concerned, the result is only partly attributable to the automation level itself because of the effects produced by centralizing en route activities in two facilities, by manning requirements for terminals, and by specifying certain secondary terminals to be unmanned. It should also be noted that while satisfactory staffing and data processing requirements may be taken to imply satisfactory operating and maintenance costs at the recommended automation level, the question of research, development, testing and evaluation costs required to achieve the automation level was not addressed.

However, the study products do provide the means for carrying out such costing studies, because they can be used to assess present status, make comparisons with future needs, and so provide a detailed enumeration of RDT&E activities.

In general, the steps involved in using the generic products for research planning are these:

1. Update and modify the system functional description as required, to reflect changes in the system concept as they occur, choices of physical means, and so on.

2. Update and modify the automation level as required, to take research results into account and keep the man-machine allocation requirement statements current.

3. Map the existing or proposed system or subsystem into the generic system description, as illustrated in the preceding section.

4. Compare task allocations (projected for the system) to the generic allocations.

5. Express differences as R&D items. Set priorities by functional criticality, current policies, funding levels, and other applicable factors.

6. Carry out R&D. Feed results into steps 1 and 2 above to continue the cycle.

Thus, the generic automation level, together with the system functional description, can serve both as definitions of system requirements and as guidelines for system development. It should be kept in mind that while such planning techniques are probably necessary in an endeavor as large and complex as developing an air traffic management system, they are certainly not sufficient. Automation is only one in a network of interacting factors surrounding the system, its users, and the environment in which they operate. Fulfilling the promise of automation will require solving a very large number of specific problems associated with these factors.

Some examples have already been given, in the discussion about choices of specific surveillance, navigation, or communications devices, in the references to physical design of displays and controls at the man-machine interface, and in the description of the effects that will be produced by innovations in aircraft design and performance. There are many others, including for instance, airspace structure, procedural approaches to traffic regulation, actual and perceived definition of the human operator's responsibility if control is to be done by machines. Finally, there are national goals and priorities to be considered, with the inevitable and frequently overriding effect of outlook and availability of funds.

The task of moving from definition of functional requirements to physical reality is fraught with difficulty and complexity. Further discussion and examples of the issues to be addressed is given in the next chapter of this volume, whose subject is a recommended strategy for system development and deployment.

6.0 IMPLEMENTATION STRATEGY

This chapter provides a recommended strategy for implementation of automation in an advanced air traffic management system. In addition to description of the basic approach, it includes a series of illustrative examples. This implementation strategy is intended to complement the RDT&E plan presented in Volume IV of this report. The strategy addresses functional issues and logical priorities; the RDT&E plan describes programs, projects and schedules. The strategy can thus be considered to drive RDT&E and to provide an approach to relating research, development, demonstration, and deployment of AATMS automation.

The discussion begins with an outline of the general characteristics of the recommended implementation strategy. Next, the overall scenario and a scheme of logical priorities* for research and development are given. The application of the strategy to the phases of system development is illustrated by example. The chapter concludes with a discussion of system deployment and some recommendations for evaluating the effects of automation as system development and deployment proceed.

6.1 IMPLEMENTATION STRATEGY CHARACTERISTICS

The body of research literature on the air traffic control system is extensive. The history of the system as reflected in this documentation yields an image of dynamic evolution and change. Even as the system operates to meet the day-to-day requirements for service, new devices and procedures are being introduced. At times in the history of the system, the rate of change has been materially affected in both the positive and negative senses by such factors as technical progress and budgetary constraints. Yet, all in all, the system of the 1970's is not only larger but also different in many ways from the system of the 1950's. Examination of the preliminary fourth generation system design concepts described in recent studies (Boeing, 1973; Autonetics, 1973; DOT/TSC, 1973) suggests that even more dramatic and fundamental changes are in the making. In at least one

*It should be noted that research/development priorities are not necessarily deployment priorities.

aspect, this view is reinforced by the present study of automation applications. It appears that in the coming decades, as AATMS is implemented, there is a prospect for change in the role of man from "controller" to "system operator and manager."

Certainly, it is true that other aspects of the system will also change greatly. For example, the primary surveillance method will shift from radar to discrete address beacon; and the airspace structure and mode of navigation will be transformed from point-to-point air routes to area navigation. But these changes are perhaps not so revolutionary as they may seem when set against past events like the adoption of radar in surveillance and the replacement of ground marking by VOR. However, in the history of the air traffic system there is nothing comparable to the notion that routine decision making and control will be assumed by machines.

While the history of change in air traffic control can be characterized as dynamic, it cannot be said to have been headlong. The requirement to implement new features without disturbing ongoing operations is a firmly held constraint. Of equal importance is that new devices and concepts be thoroughly proven and tested in a rigorous and orderly way before adoption. Current FAA program planning, for example, provides for this development cycle:

- analysis and design
- prototype specification preparation
- prototype acquisition
- validation testing
- production specifications
- continuity in transition

(FAA, 1972)

In light of the scope of the changes to come, and especially considering the fundamental nature of the proposed shift in the role of human resources, there can be no relaxation of these requirements for care and orderliness. If anything, emphasis on R&D and R&D planning needs to be increased. For example, Holland and Garceau (1971) in an excellent genealogy of automation in the terminal environment posed some eleven examples of the questions that must be answered, among them:

- How can the capacity and safety of the transition, approach, local, and departure control areas be increased by the addition of one or more of the following?

  a. Area navigation

  b. Automatic voice

  c. Automatic up and down data link

  d. Improved data acquisition (accuracy, rate, blip-scan, heading)

  e. Airborne computers

  f. Cockpit situation displays.

- To what extent can the controller and pilot be taken out of the control loop and serve in a monitoring role? Also how many aircraft can a controller monitor?

Holland and Garceau emphasized that their questions were only <u>some</u> of those needing answers. In the same vein, counterpart questions can be formulated for the en route and flight service portions of the system. A further list of questions can also be made in regard to future concepts of system management.

It seems clear, then, that a strategy or method of approach is required for implementation of automation in AATMS. It is also clear that the strategy must isolate system automation as the principal target and yet at the same time allow for the inevitable interactive effects with other areas of system development.

These ends can best be achieved if the implementation strategy for AATMS automation follows these precepts:

1. <u>Maximize flexibility</u>

   a. Provide for cyclic and episodic re-evaluation of the automation concept and reformulate as required.

2. Incorporate and adopt ongoing R&D

   a. Avoid duplication of effort

   b. Relate AATMS automation to nearer-term future systems, i.e., the Upgraded Third Generation ATC system.

3. Preserve the concept of operational evolution

   a. Carry out development, demonstration, and pre-prototype test off-line

   b. Observe major development phases

   c. Deploy by increments.

4. Maintain the generic functional referent

   a. Assure functional integrity, thereby providing a basis for explicit comparison of differing approaches

   b. Separate automation from other aspects of the system, e.g., hardware, geography

   c. Discriminate between generic and induced tasks.

5. Achieve a system-level demonstration capability quickly

   a. Pinpoint system problems early

   b. Provide a basis for gaining acceptance by demonstrations involving controllers, users, and the public.

6.2 DEVELOPMENT SCENARIO AND FUNCTIONAL PRIORITIES

It has been pointed out that the priorities for research and development in AATMS automation are not necessarily the same as those for system deployment. In the same way, the priorities for research and development given below imply a logical rather than chronological order. For example, the scenario envisions early demonstrations of AATMS automation in active control and later more extended demonstrations of the AATMS "man-as-manager" concept. It might well turn out that the time required to perform the underlying research necessary to conduct "man-as-manager" demonstrations in a system context is not longer, but shorter than the time required to do the corresponding work in the functional areas of "active control."

The scheme of logical priorities, then, imposes no constraint on research chronology. It does, however, imply a specific approach and order to providing the system concept, viz. given the anticipated demand, first demonstrate that the system automation level satisfies all safety-related requirements, then demonstrate that the system automation level satisfies all requirements related to efficiency and capacity.

Thus, recalling that the purposes for developing a demonstration capability as quickly as possible are to pinpoint system problems early and to gain early opportunity for exposure of the system concepts to controllers, users, and the public, the general scenario for the demonstration of system automation is:*

1. Develop a basic demonstration capability
   a. A demand picture at appropriate levels and mixes
   b. Active control metafunction at the recommended automation level.
2. Develop and demonstrate the strategic nature of AATMS
   a. Automate the traffic planning and regulation metafunction to the recommended level
   b. Automate the "data base" portion of the housekeeping metafunction to the recommended level.

*The reader may wish to refer to Figure 6.2-1 as an aid in examing the scenario.

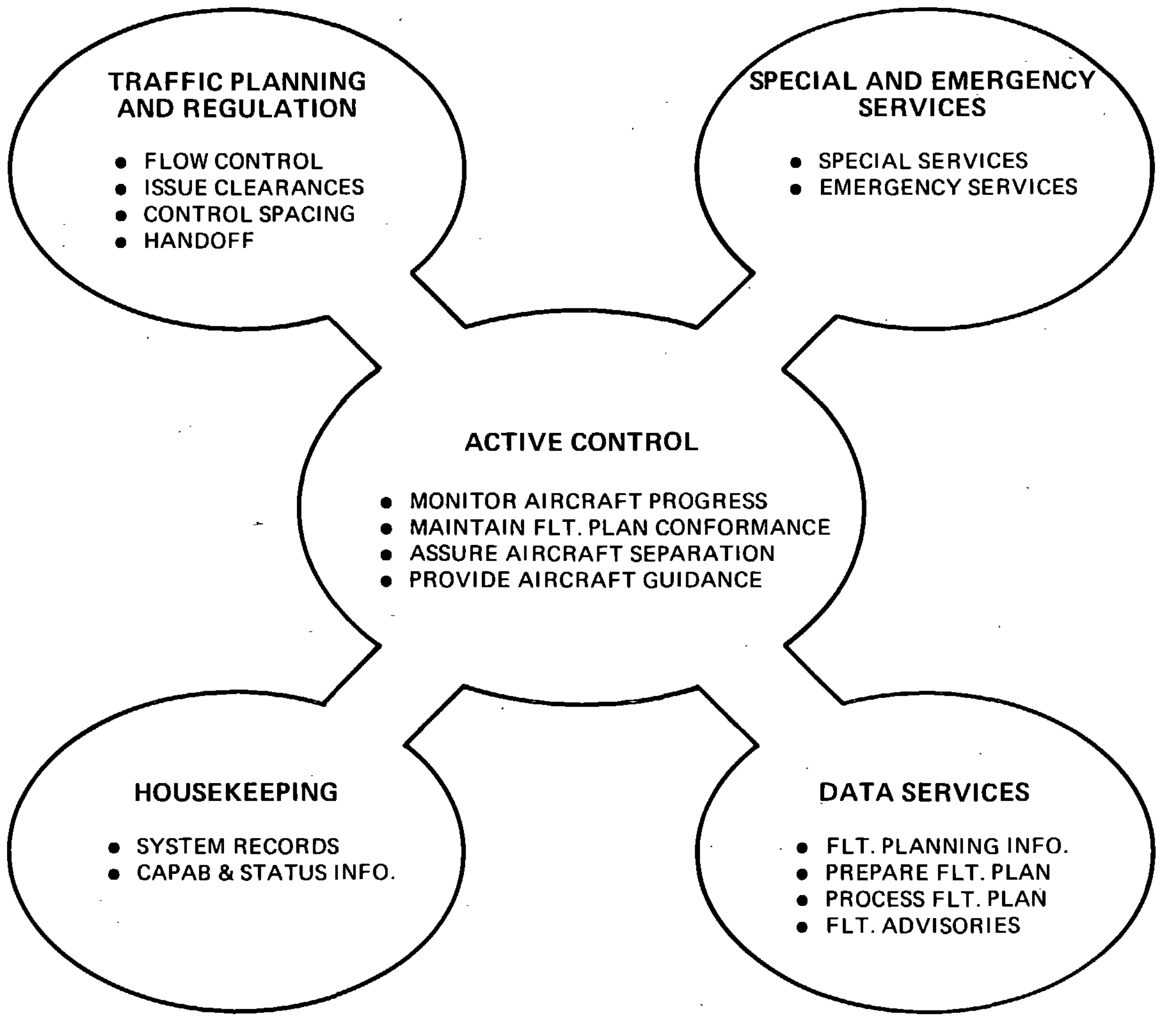

FIGURE 6.2-1 METAFUNCTIONS OF AN ADVANCED AIR TRAFFIC MANAGEMENT SYSTEM

3. Develop and demonstrate the AATMS management concepts

   a. Automate the remainder of housekeeping and the required portions of data services to the recommended level

   b. Develop and demonstrate dynamic resource control

   c. Develop and demonstrate the "man-as-manager" concept (non-pictorial process displays, job design and career progression, etc.)

   d. Develop the system deployment plan.

The brief discussion below is an explication of each of the three steps in the scenario.

Step 1

Early implementation activities will be characterized by exploration, development, and demonstration of AATMS baseline operations in the active control functions. It is in this area, and in certain portions of the traffic planning and regulation area, that AATMS compares very closely with the automation characteristics presently envisioned for the Upgraded Third Generation System. Prompt advantage can thus be taken of third generation system work in establishing the specifications for the AATMS prototype environment.

Step 2

Once an appropriate baseline of safety, capacity, and operator productivity is established, the steps required to develop and demonstrate the strategic nature of AATMS can be carried out. Again, advantage can be taken of matching third generation concepts in the areas of automated flow control, clearance delivery, and spacing/sequencing. At the same time, automation beyond that of the third generation system will also be implemented, especially in the "data base" (system capabilities and status) area. If the theoretical predictions are borne out, this will be the point at which large gains in productivity can be demonstrated, while maintaining or improving the existing levels of safety and capacity.

Step 3

The final steps in development and demonstration of AATMS are completion of the automation configuration (mostly involving automating the "data services" metafunction to the appropriate level) and development of the new relationship of man to the system environment at the final automation level. Final configurations of any new kinds of status and process displays will be developed. Preparation and validation of necessary training materials will be completed, as will other personnel subsystem activities like job design and career progression ladders. Thus, the scenario ends in that phase of implementation where final operational testing and deployment take place.

The nominal functional priorities supporting the scenario are:

Step 1 - Develop a basic capability, including:

- Monitor Aircraft Progress
- Flight Plan Conformance
- Separation Assurance
- Provide Aircraft Guidance

also part of:

- Clearances
- Spacing Control
- Handoff

Step 2 - Provide for strategic traffic management demonstrations, including the remainder of:

- Clearances
- Spacing Control
- Handoff

and adding:

- Flow Control

and part of:

- System Status and Capabilities

Step 3 - Final development, including the remainder of:

- System Status and Capabilities

and adding, to the appropriate automation level:

- Flight Advisories
- Flight Planning
- Flight Plan Processing
- System Records Keeping

Since special and emergency services functions are manual, they are not included in the priorities listing. Table 6.7-1 at the end of this chapter contains a more detailed listing of development priorities at the sub-function level.

It will be observed that the scheme of priorities set out above supports the concept of evolution by using the Upgraded Third Generation ATC System as the point of departure. In the area of active control, this will allow early demonstration that safety of operation can be maintained at the required level of capacity. It also permits prompt development of an AATMS demonstration facility through incorporation or adaptation of existing compatible third generation system hardware and software modules. Another feature of this scheme of functional priorities is that it allows baseline values of safety, capacity, efficiency, and productivity to be clearly established, thus isolating the effect on resource requirements of certain "high leverage" AATMS automation features. Finally, it should be noted that the sequence of implementation and deployment of functional components reflects the order of their criticality to overall system operation, providing for demonstration of normal and failure mode capabilities of the most critical functions first.

6.3 IMPLEMENTATION STRATEGY AND AATMS DEVELOPMENT

The implementation of automation in AATMS is conceived, for purposes of this discussion, to consist of six major phases. To the extent that feedback occurs, these phases overlap and interact. The six phases are:

1. Concept Formulation - Concept definition, examination of alternatives, study of automation as a concept independent of alternatives, functional description of the system, and determination of a theoretical automation level.

2. Prototype Design and Specification - Translation of the functional-theoretical description to physical specifications.

3. Prototype Demonstrations - Demonstration of automation concepts in an expanding functional context, at both the subsystem and system levels.

4. Prototype Test - Formal evaluation of prototype configuration.

5. Operations Test - Assumption of operations, formal evaluation under operational conditions.

6. Deployment - Transition to full operational use of the advanced system.

The first phase, concept formulation, has been carried out and documented in this and other AATMS reports. Of the remaining phases, the second (prototype specification) is likely to have the greatest impact on system characteristics, in that it may lead to re-evaluation of the concept of system automation at the most fundamental level.

The central problem in prototype design specification is to translate the theoretical automation level of choice into practical physical specifications. Figure 6.3-1 is a schematic representation of this phase. Examples of the parameters used to derive Configuration A, the generic theoretical automation level of choice, are given at the left in the figure. They include, for instance, the system concept (with its safety and capacity goals) supplied to the study team, the generic tasks and their logical interrelationships, and the functional failure analysis that was carried out in this study. Deriving a prototype specification for use in procuring equipment, building displays, and training personnel will require application of other parameters, e.g., software feasibility, operational evolution,

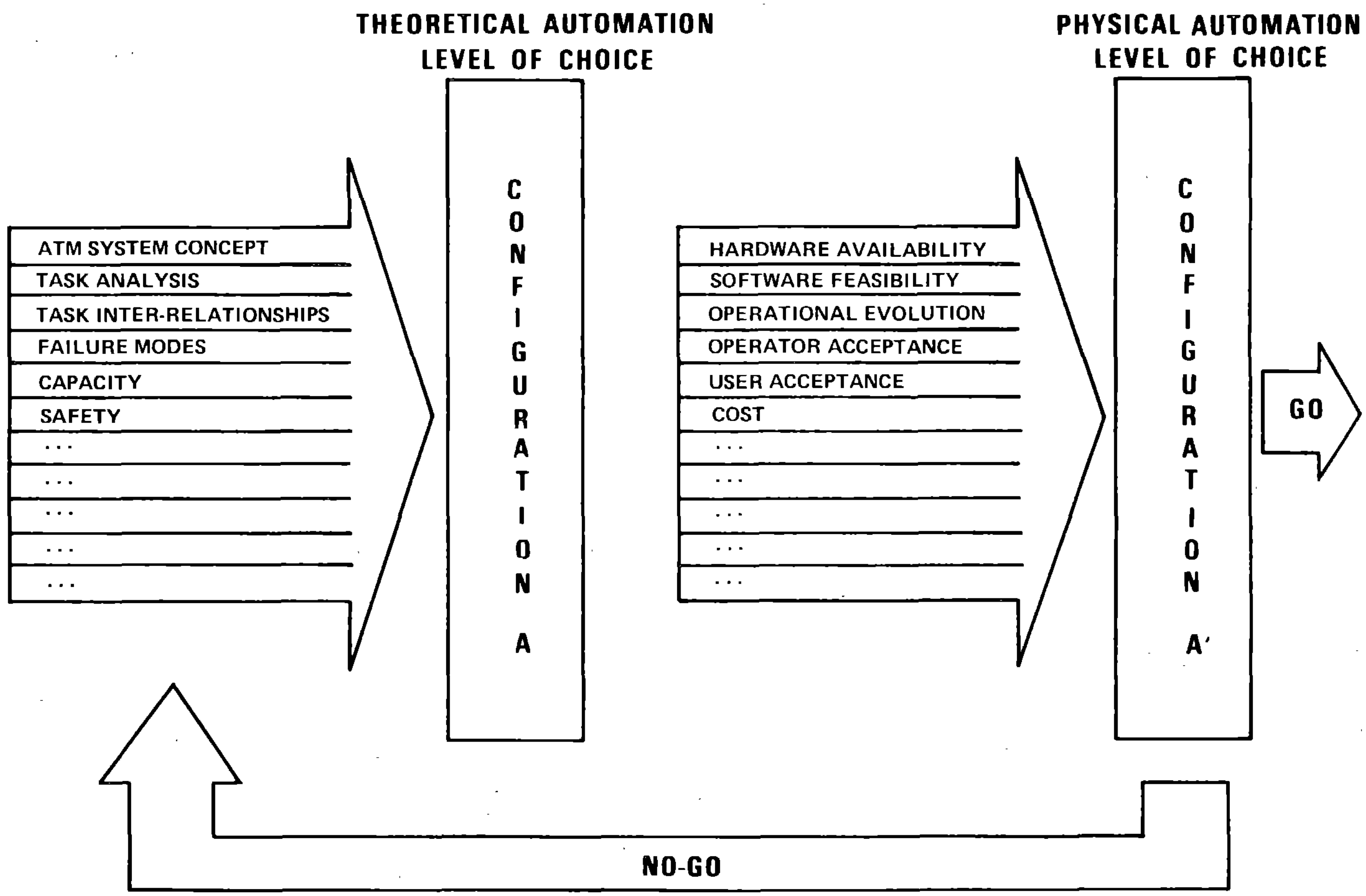

FIGURE 6.3-1 - AATMS PROTOTYPE SPECIFICATION DEVELOPMENT

cost trades, and the like. In cases where no available alternative meets the theoretical configuration, reformation of the configuration will be required. The end result of this interactive process will be the prototype specification, shown in Figure 6.3-1 as Configuration A'.

In the AATMS prototype specification, research and development will be the key means for achieving the necessary translation from functional-theoretical to physical-practical. Since the implementation strategy is postulated to be the executive source for R&D operations inputs, it is convenient to separate the two for illustration. Figure 6.3-2 shows such a relationship. Implementation activities are depicted in the upper part of the figure, separated from the supporting R&D by the horizontal dashed line. Implementation and R&D are ordered by time from left to right in the figure, and illustrated according to the major phases discussed earlier.

Each vertically oriented box in the figure represents an implementation milestone. Beginning at the left is the functional theoretical automation configuration, in which the automation level of choice is specified. After the prototype exploration, design, development, and demonstration phases are complete, the physical prototype configuration will be derived. Further testing (and any further demonstration that might be necessary) will lead to the operations test configuration. After completion of operations testing and the incorporation of any necessary modifications, the deployment configuration will be derived.

R&D, synchronized with the milestones of system implementation, is shown along the bottom of the figure. Each R&D activity receives inputs from implementation, and returns products and outputs to implementation, as shown by the vertical arrows. It will be recalled that the strategy must be sufficiently flexible to allow for reassessment of the automation concept as required (for example, if particular task allocations are not feasible for reasons of cost or technical difficulty). The vertical feedback arrow from R&D to each milestone configuration symbolizes that aspect of the strategy.

The small horizontal boxes in the upper part of Figure 6.3-2 symbolize particular processes or areas of activity within the overall implementation scheme. For example, testing and modification are shown to take place in

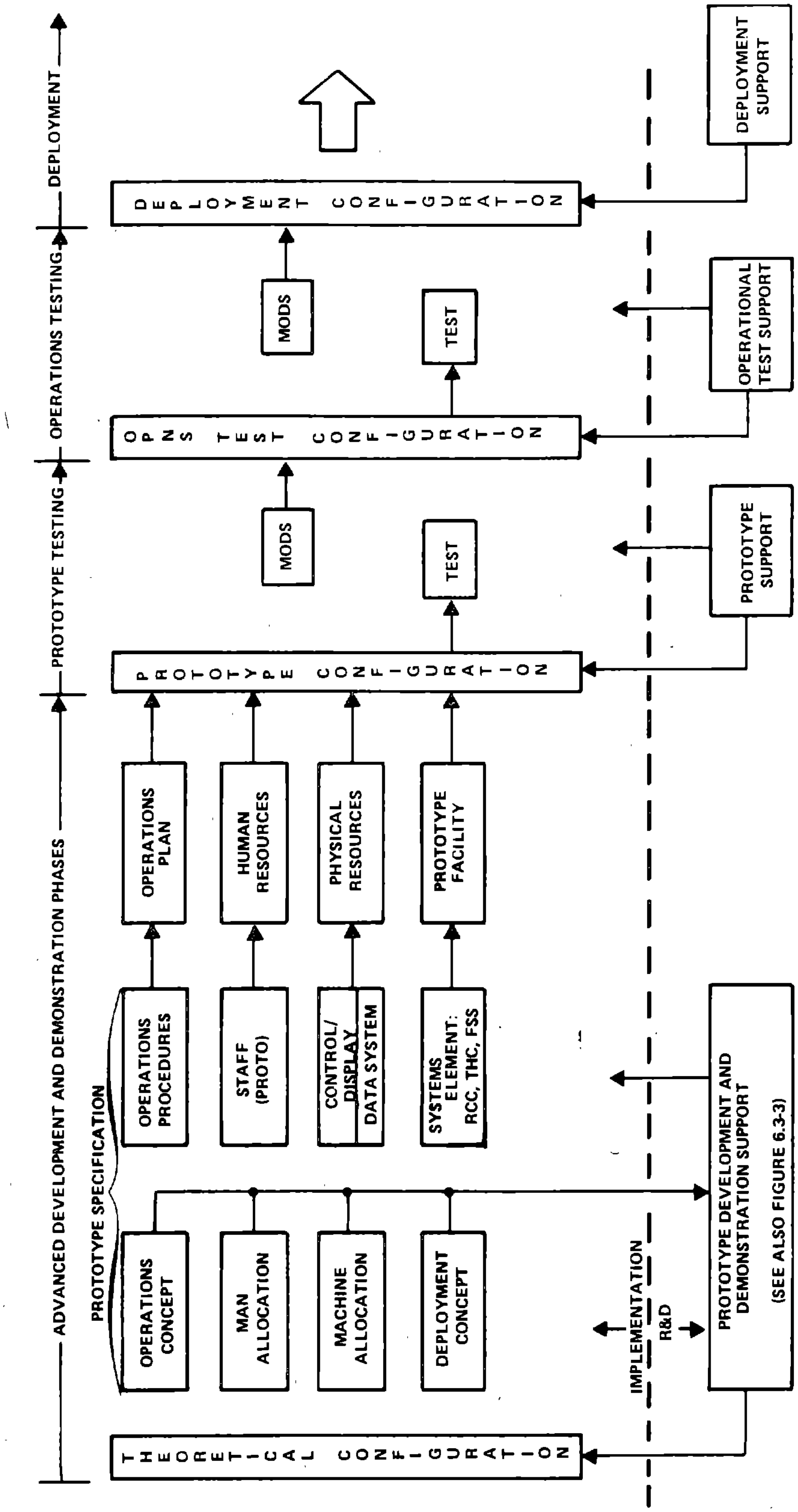

FIGURE 6.3-2 RELATIONSHIP OF AATMS IMPLEMENTATION TO R&D

the prototype and operational test phases of implementation. The critical phases of prototype specification, development, and demonstration have been represented in more detail than later phases in the figure to help illustrate the discussion that follows.

The total system configuration derived in this automation study can be considered to consist of the four major elements shown in Figure 6.3-2: an operations concept (including, for example, position descriptions and position functional allocations in normal and failure modes of operation), a basic allocation of tasks to human resources, a similar allocation to machine resources, and a deployment facilities concept. These elements are congruent with major areas of investigation for the prototype design specification phase. They provide inputs to prototype R&D, as shown by the vertical arrow in the figure. (Prototype R&D itself is discussed in more detail later.)

These inputs have implications both within their particular area and for system implementation as a whole. For example, it was pointed out earlier that the priorities given to prototype demonstration activities are based on function logic. They are ordered to provide first for early demonstration of the core of system services most directly related to safety in both normal and degraded modes of operation, and then to provide for expansion of the scope of the demonstration to include those aspects of AATMS automation that are related to efficiency and capacity. R&D planning must address itself to deriving a chronology that will permit the underlying research to be completed on a timetable that will fit the logical ordering.

According to that timetable, the R&D activity will produce:

- Refined operating procedures, reflecting the physical means selected for performance of each functional task and also reflecting any modifications or alterations to the man-machine, position, and management aspects of the system;

- System staffing requirements, also reflecting the physical means and matching the prototype task allocations to man (permitting derivation of the prototype staffing plan);

- Control-display and data system (hardware and software) specifications matching task allocations to machines;
- Facility specifications for the prototype.

Figure 6.3-2 illustrates that the next step will be to implement each plan to yield its particular outcome: an operations schedule, selection and training of human resources to man the prototype, and physical resources suitably housed in an AATMS prototype facility. (Some examples of the activities to be carried out in prototype development will be presented shortly). The figure then shows how the first phases are related to subsequent prototype testing, operational testing, and system development. While the figure was drawn to illustrate the implementation cycle at the system level, it can also be interpreted to represent the desired relationship of activities for specification, development, test, and deployment of particular subsystems.

Research and development to support the prototype phase is shown in more detail in Figure 6.3-3. At the top of the figure are the inputs from implementation and return outputs to implementation, shown by arrows. A horizontal dashed line symbolizes the division of R&D activities into two parts: those directed at early incorporation and adaptation of present efforts, shown above the line, and those in which additional required work is performed, shown below the line.

A key aspect of the implementation strategy is to take maximum possible advantage of present and near-term future research activities in the development of an AATMS prototype. This feature is in consonance with the concept of evolutionary system development and avoids duplication of efforts. Some examples of accepting and adapting ongoing or near-term future R&D may help illustrate the intent of this strategy. First, software algorithms currently under development for conflict prediction, metering, and spacing may well be appropriate for AATMS, even if languages and data systems capabilities change by the time of system deployment, since the problems are basically constant. Second, there may be a replacement of NAS/ARTS computers as a part of upgraded third generation system deployment. If the specifications for the new machines were to include provision for early parts of AATMS (such as interface capabilities, data rate compatibility, core sizing, etc.),

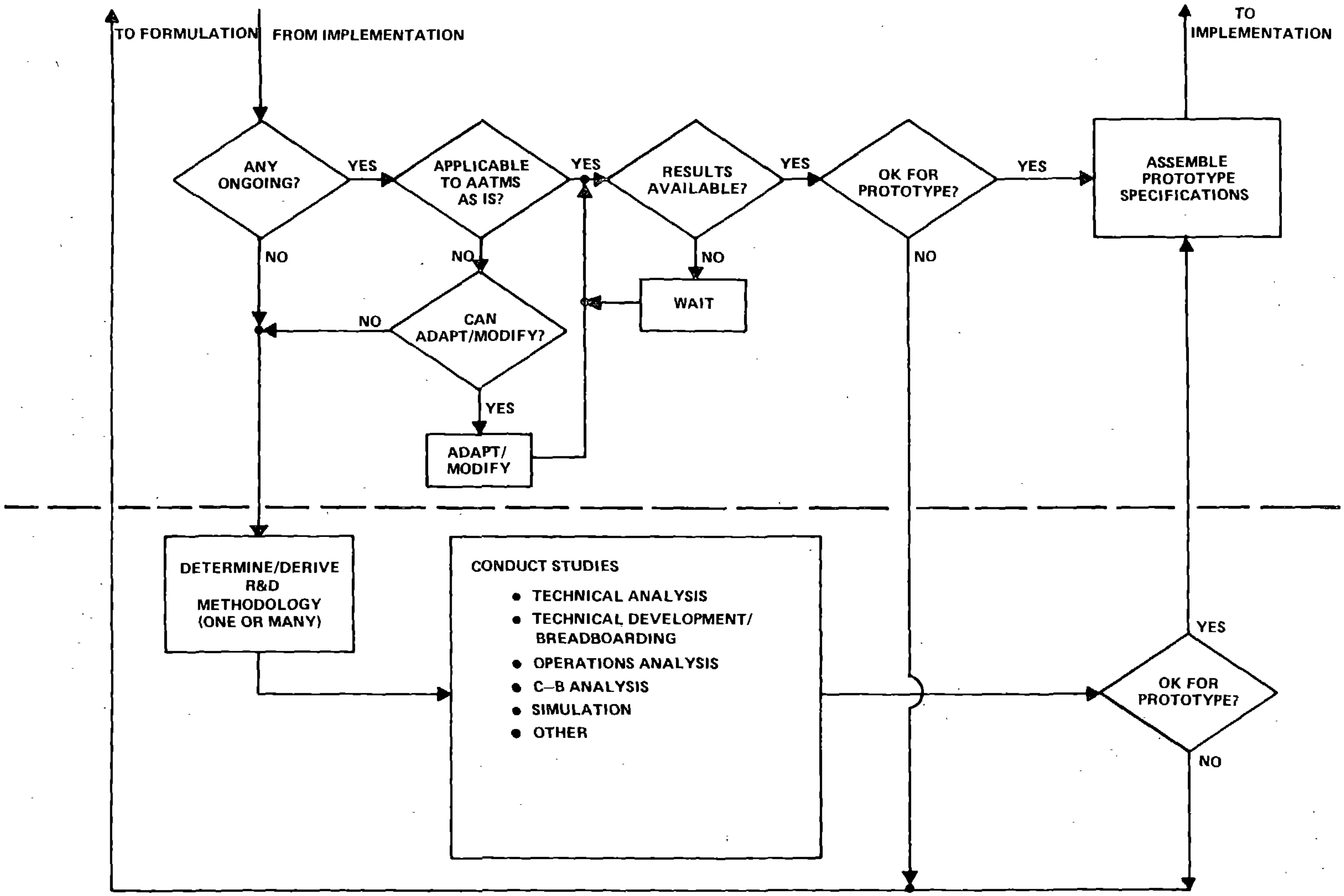

FIGURE 6.3-3 R&D SUPPORT OF PROTOTYPE IMPLEMENTATION

then initial AATMS deployment would be facilitated. Finally, if simulations are to be conducted in the upgraded third generation program to investigate man-machine relationships in the "active control" functions, they could perhaps include at no great additional cost provision for testing the effect of automating the additional functions planned for AATMS in the "system capability and status" area.

As Figure 6.3-3 shows, all elements of the AATMS functional automation configuration will be input to a single sorting function. The purpose of this step is to determine whether any part of the aviation community is performing, or plans to perform, research in related areas. If so, the next question asked is whether the work is applicable to AATMS as it stands or is planned. The affirmative case for succeeding questions proceeds to the right in the figure, with applicable results being incorporated in the prototype specifications.

In cases where work cannot be taken as it stands, it may still be possible to adapt or modify the effort to make it appropriate without conducting new work. The figure shows a provision for such an approach; only cases where no applicable research/development effort exists or where existing work cannot be satisfactorily adapted to AATMS needs will be tagged for independent R&D effort.

The portion of Figure 6.3-3 below the dashed line is a schematic illustration of the kinds of development work done to support the AATMS prototype. System issues not relatable to ongoing R&D are fed to a central function, where the next steps (e.g., type and timing of studies, breadboarding efforts, and the like) are decided upon. Any or all of the study types illustrated in the figure might be used, serially or singly, in carrying out the necessary translation from theoretical description to physical specification in prototype exploration, development, and demonstration. Some examples follow.

> In the man-machine interface area, several important questions must be addressed. System displays in the en route environment will likely involve much larger airspace volumes than those of today; displays providing means for easy assimilation of the traffic situation will be required. (One approach might be to suppress everything but essential symbology on all aircraft except those about to receive vectors, or those within a certain distance of sector

boundaries, etc. In a similar vein, "forced" displays of particular situations might be presented on a display area reserved for the purpose.) While terminal area sectors may not be much larger in volume than today, the same kind of questions about display data may apply. Individual controllers are envisioned to be attending to a different spectrum of interface actions than they do today, e.g., inputting changes in system capability and status data, such as runway reversals, acceptance rates, etc.

The man-machine interface will also be affected by the way in which the key questions about the man-as-manager aspect of the advanced system are resolved. For instance, it may well be much more productive for man to monitor machine processes rather than to examine directly machine solutions. That is, the controller would check the regularity of the solution process for deriving a vector instead of independently solving the vector problem. If this notion is proven out by research, then new kinds of displays, probably non-situational in nature, will be required.

Non-pictorial displays will almost certainly be required for non-product oriented assessments of machine operations, like input/output and core usage (current and predicted), maintenance status, and so on. These displays will be especially important in the business of resource control (shifting machine capability to match loads) and failure mode operations.

In the man-machine allocation area, at a more fundamental level than displays and controls, verification of the hypothesized apportionment of tasks to man and machines is necessary. The apportionment of tasks on the basis of performance capabilities was, it is felt, an appropriate one. The data on task times and resource requirements appear to confirm the choice of automation level. But all this work is theoretical, and therefore does not constitute proof that the expected operator productivity can in fact be achieved. It should be treated instead as a starting point for investigations.

The examples given so far typify the kinds of technical investigations involved in AATMS prototype exploration, design, and development. Other kinds of study are also required. For instance, just as analysis of benefits and costs will be useful in choosing among surveillance system, communications, and navigation aid alternatives, so will it be necessary to study alternative means to achieve system automation. It is assumed that such work will be reviewed and repeated as new approaches become feasible and as technology advances.

As Figure 6.3-3 shows, the intent of prototype phase R&D is to supplement ongoing work with independent R&D, only insofar as necessary to obtain complete translation from AATMS functional descriptions to AATMS prototype physical specifications. Further discussion of the kinds of work required and the priorities involved is given in the next section.

6.4 APPLYING THE STRATEGY

The implementation strategy given in this section and the RDT&E plan included in Volume IV of this report are intended to provide an approach to implementing AATMS automation. The paragraphs below suggest, through examples, the way in which the approach would be applied. To facilitate cross-reference to the RDT&E plan, the appropriate program/project identifier is given for the examples.

6.4.1 Implementation Planning

A first order of business will be to derive a plan and timetable for AATMS implementation. The plan, insofar as it affects automation, will be administered through the AATMS automation program element (RDT&E element 222). The research priorities and chronology necessary to meet the overall prototype acquisition timetable will be given, through the program element office, to each affected subprogram element (-100 human factors, -200 operational software, -300 operational hardware, and -400 systems engineering and integration). This will be done by forming the teams required from the four subprogram elements to carry out specific projects.

The implementation plan will be the specific basis for organizing activities that can be characterized in general as: pre-prototype activity, prototype activity, subsystem or special aspect scope, system scope. To derive a comprehensive, integrated prototype specification will require considerable pre-prototype work, much of it at the subsystem or special aspect level. Acquisition of the prototype will permit the scope of investigation to be expanded to include all appropriate system level demonstrations and investigations.

The examples that follow are selected from both pre-prototype and prototype activity areas and range in scope from single aspects to the system level.

6.4.2 Establishing Actual Automation Limits (RDT&E Project 222-101, Man-Machine Interfaces)

The general automation level of choice reflects a particular assignment of AATMS generic tasks to human or machine resources. The translation from a functional-theoretical description to physical-practical specification that is the principal first phase implementation activity will require verification - and, almost certainly - modification of the theoretical assignment. For instance, there are three aspects that, singly or together, may affect the system automation level. Further study of the tasks for which no clear automation ranking was achieved when the automation index data were analyzed is one aspect. Cost is another. Controller/user acceptance is a third. During the development of the basic prototype capability, and on some more or less continuous basis thereafter as higher levels of system automation are explored, examinations of the effects of those parameters will be necessary.

One example of that kind of study is the allocation of tasks in Function 6, Monitor Aircraft Progress. Position III operators in en route centers and at terminals have the responsibility for flight surveillance and control; Function 6 is a part of flight surveillance. At the recommended automation level, Function 6 is nearly completely automated. Two tasks, "request aircraft identity" and "assign arbitrary aircraft identification" are, on the basis of the automation index, reserved for manual performance.*

One question that must be addressed is whether the machine apportionment is practical in the light of cost. For instance, a task titled "receive and enter reports of aircraft capability changes" is envisioned to be automated. If the reports come from aircraft themselves, then either the cost of the ground receipt/entry components or the cost of the sending components on the aircraft may prove prohibitive, at least to some airspace users. If there is no prospect of finding cheaper automated means, then the task may have to be re-allocated to manual performance.

However, while assignment to man or machine is basically a dichotomy, allocation to the human operator should not be taken to mean excluding the machine altogether. Machine aiding might prove an adequate solution to the cost problem of total automation, while preserving most of the inherent design productivity. Accordingly, "receipt and entry of reports of aircraft capability changes" might be done manually but with some level of machine aiding.**

*It should be noted that these task capabilities are included so that the manual situation of partial beacon transponder failure can be coped with.

**The degree of machine aiding might be characterized in the same manner as the automation levels themselves, viz. computational aids, decision aids, etc.

The same strategy may well apply even where the basic allocation to men or machines of a given task or tasks is not at issue. The tasks of requesting aircraft identity and assigning arbitrary aircraft identification that remain allocated to manual means in Function 6 (Monitor Aircraft Progress) should still, in all likelihood, be carried out with some form of machine aid -- for instance, a forced display of any aircraft not identifiable -- by its beacon response to alert the controller. Another possible solution might be machine computation of arbitrary identification symbols or numbers, with assignment perhaps done by pointing out the aircraft with a stylus.

These studies of the automation level and its limits will be a major activity area in prototype exploration and design since they will produce the necessary refinement of the general automation level on a task-by-task basis. The goal will be to achieve a practical combination of means of performance that does not unduly affect functional integrity or inherent productivity.

6.4.3 Baseline AATMS Automation in Normal and Back-Up Modes (RDT&E Project 222-103, Human Engineering)

It will be recalled that one reason for establishing the functional priorities and increments discussed earlier was to preserve the relationship between function and service in terms of criticality. (See the failure modes analysis, Volume IV, Chapter 5.) This will support early studies of operations in both normal and back-up modes, so that "worst case" requirements of the man-machine interface can be derived.

An appropriate example of this case is Function 11, Provide Aircraft Guidance. At the recommended automation level, the entire function is automated (with, it is assumed, guidance commands and vectors being transmitted by data link). Two questions about the man-machine interface that must be answered are:

1. What are the operator's display needs in normal operation?

2. Do these needs change in failure modes?

In normal operation, the information displayed to the human operator will depend greatly on the degree to which he is given responsibility to monitor and intervene. Suppose, for instance, that vector displays in the normal mode of operation are only presented to the operator when the aircraft in question is given a conflict avoidance vector or when a routine vector is not responded to. If, additionally, the first ground-air communications backup on the groundside is computer-generated voice on UHF, then once UHF contact is established with any aircraft whose link fails, the operator may well find the normal display situation satsifactory.

That would not apply in the case where failure forces a return to manual voice communications. In that situation, the operator must be presented with a display of every vector to the aircraft, so that he can read it over the radio. (Note that link failure is considered here, but not internal failure of the vector computation subfunctions. The backup strategies for these involve alternate machine resources rather than reversion to manual means.)

Finally, the operator may need to select or sample vectors being generated even when the ground system has not failed, either for monitoring the function on some sampling basis or for providing some special service -- for example, helping an aircraft verify that its link is functioning properly.

All these considerations, it can be seen, will have implications for the nature, capabilities, modes, and normal/non-normal information content of the displays and controls at the man-machine interface. In turn, this will have an impact on AATMS baseline capability requirements, operations, and productivity. The implementation strategy allows for first priority to be given to solving the most critical problems with respect to safety and capacity.

6.4.4 AATMS Automation and Functional Management (RDT&E Project 222-102, Personnel Subsystems)

It has been pointed out that a critical distinction between man's role in past generations of air traffic systems and his role in AATMS is that in AATMS man is expected to function more as manager than as participant. Yet, even at the extended level of system automation envisioned in AATMS, man must still participate directly in system processes. At the theoretical automation level of chioce, many generic tasks remain allocated to manual means. This set of activities, as refined and modified according to the results of the research and development exemplified in this section, will define the "participation" portion of the totality of man's role in AATMS. Similar definition of the "management" portion must also be derived.

It should be pointed out that the term "management" is used here not in the administrative or supervisory sense but in the functional sense. Functional management includes, for example, assessments of the "goodness" of system processes and outcomes and actions taken to match system resources to system loads. "Managing", therefore, can be viewed as a form of induced task in AATMS.

The concept is illustrated schematically in Figure 6.4-1. The box contains generic tasks, some allocated to automated resources (A) and some to humans (H). Functional Management is represented by the circle segment (MGT).

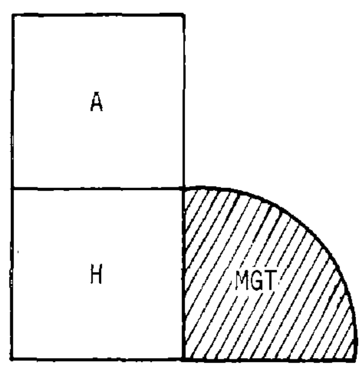

FIGURE 6.4-1 AATMS FUNCTIONAL MANAGEMENT

There are, of course, many ways to approach functional management. Figure 6.4-2 shows two approaches -- centralized and decentralized.

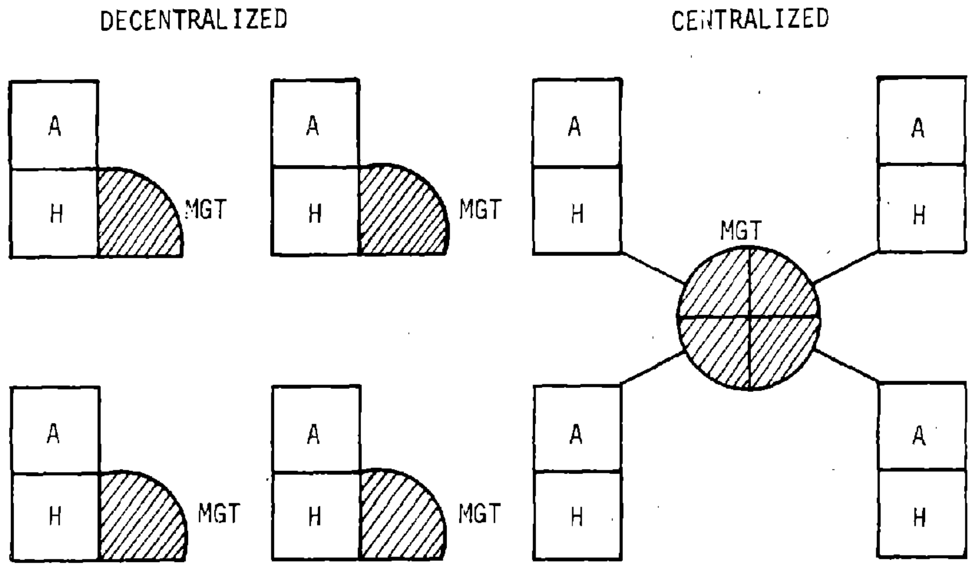

FIGURE 6.4-2 CENTRALIZED AND DECENTRALIZED AATMS FUNCTIONAL MANAGEMENT

The design of the AATMS automation prototype, and ultimately the deployment configuration, will be impacted by the results of investigation and development of the systems functional management concepts in ways likely to be as fundamental as those devolving from the studies of generic participation itself. It is recommended that investigations in this area begin at the earliest stages of pre-prototype study.

6.4.5 The AATMS Prototype

The investigations just described are examples of the kind of work that will be needed to arrive at a complete set of specifications for the AATMS automation prototype. After completion of the prototype facility, this work will continue in the more applied setting of the prototype facility. Other kinds of studies will be carried out as well. To facilitate such research, the prototype facility should have certain characteristics. They are:

1. Convertible to Operational Use - After development and demonstration activities are completed, it may be economical to use the facility in the operational system.

2. Incorporation of Essential System Elements - The prototype should be configured to include operator positions in all three options, for both terminal and en route airspace, so that all system functions can be exercised.

3. Flexible Data Acceptance - The prototype should be as flexible as possible both with respect to external or "air picture" data acceptance and to internal data exchange. Much early demonstration and development work will be done using a simulated "air picture," but later in the cycle it will probably be desirable to be able to input "live" data. With respect to internal data operations, the prototype should be structured to allow for incremental progression of automation. In data interchanges, for example, data sources should be represented by other means so that data rate compatibility can be achieved. This should help in demonstrations of baseline safety, capacity, and productivity and also help avoid the impression that some interim configuration increases operator workload.

4. Flexible Internal Configuration - Assuming that the theoretical position-task allocations made in this study will be verified and refined by trading off tasks according to some experimental concept, it will be desirable to configure the prototype so as to allow for such study. For example, the effects of reassigning Function 13, Handoff, from one position III console to another in two-man sector configurations, might be studied in normal and failure modes of operation.

5. Flexible Console Design - The changed relationship of man to the system in the automated environment is expected to be the stimulus for at least two kinds of development:

   a. "Man as participant" studies of workspace layout and control/display configuration for those system tasks allocated to manual performance;

   b. "Man as manager" studies of new kinds of process/product displays, some probably non-pictorial in nature, that will allow operations monitoring, resource control, and failure modes detection and backup.

For these reasons, prototype operator consoles should permit the widest possible latitude in manipulating man-machine interface variables.

6. Special Monitoring/Recording Capabilities - Since the prototype facility will be the setting for numerous basic development and demonstration activities, the specification should include provision for any required instrumentation, beyond normal system records-keeping needs, that will be used for data recording and analysis of processes and results.

6.4.6 AATMS Automation Studies in the Prototype Facility (RDT&E Project 222-102, Personnel Subsystems)

Once the scope of automation within the prototype facility reaches the levels which allow demonstration of the strategic nature of the system, studies directed toward these ends can be conducted. For example, the notion of resource control (shifting man and machine resources to meet load variations, similar to today's sector staffing shifts) can be explored.

As presently conceived, en route activities are to be carried out in two Regional Control Centers (RCC). The theoretical system description generated in this project yielded a staffing estimate of 200 operators on watch per RCC shift. For study purposes, each RCC was construed to be composed of 10 subdivisions. Each subdivision requires 17 operators and three supernumeraries if one-man en route sectors are used. Alternatively, the RCC might consist of 10 two-man sectors in each of its 10 subdivisions.

Starting in early prototype development and continuing through later stages of implementation, the questions of sectorization, sector manning, and resource control must be studied for their effect on the operational concept. Present en route sector activity includes a large amount of planning and coordination as well as active control. This pattern is expected to change dramatically as strategic and tactical planning and active control become automated. In turn, this may permit an operating concept emphasizing one-man sectors under normal conditions, with two-man staffing during heavy loads. Since the en route activities are centralized, the resource pools are relatively large if subdivisions are ignored, viz:

17 operators and 3 supernumeraries per subdivision, or
170 operators and 30 supernumeraries per RCC.

Depending then on how it is decided to achieve flexibility, large shifts of resources to meet varying patterns of demand are a possible aspect of the AATMS operating concept.

The examples given above are, perhaps, sufficient to illustrate the nature and pattern of activities implied by the AATMS implementation strategy. Emphasis has been given to the prototype design and development phase, since it is the nearest in time and has the most potent impact on the system. Activities in the succeeding stages of prototype testing, operational testing, and operational transition are also a part of the implementation strategy. While not described in detail here, they are covered in the RDT&E plan presented in Volume IV, Appendix B.

6.5 AATMS DEPLOYMENT AND SYSTEM AUTOMATION

At the beginning of this discussion of AATMS implementation strategy, it was pointed out that the priorities for R&D are not necessarily the priorities for system deployment. The principal objective of R&D in the pre-prototype and prototype stages is to satisfy the requirement for demonstrating the safety and efficiency of the AATMS automation concept in the anticipated system operating environment. As these proofs are generated in prototype and operational testing, the activities attendant to system deployment -- transition to the final AATMS automation level and configuration -- can begin. In contrast to R&D, deployment priorities for AATMS can be considered to be driven by factors associated with ease of transition rather than operational criticality. In other words, the basic safety and efficiency of the automation configuration will have been established; deploying in increments that facilitate a smooth, economical transition to AATMS is the object in deployment planning.

With regard to deployment, then, the logical ordering of system activities into priorities for planning and transition is seen differently than it is for development. For purposes of this discussion, deployment is construed to be the transition from pre-AATMS to AATMS automation levels and configuration, in terms of assumption of functional responsibility. The general scenario is that transition will be accomplished in two steps: first, a period of shared operation, in which certain functions are performed through AATMS and others through the predecessor system; then a period of transition, in which AATMS gradually assumes all system functions.

It should be noted that the concept of assuming functional responsibilities should have only very limited physical implications. It is to be hoped (and if implementation strategy is assiduously applied, it may even be expected) that the degree of physical dislocation and duality will reflect only:

1. The extent of difference in the physical "packaging" or embodiment of functional requirements between AATMS and its predecessor.

2. The extent to which the present centralized AATMS concept is reflected in the final configuration.

Within that context, the strategy as it applies to deployment should allow two goals to be met:

1. The physical "packaging" of system functions should allow the total system to be installed according to an orderly deployment scheme. If, for example, AATMS is to begin operation by performing functions associated with flight planning and flight preparation, the physical design of the system should permit such an operating mode (both normal and degraded).

2. To preserve and enhance operator and user acceptance, interim system operating procedures associated with interim configurations should not impose extraordinary burdens on either ground operators or aircrew.

While the point with respect to hardware is straightforward, the point bearing on acceptance may require illustration. Older and Cameron (1972) surveyed controllers' impressions of the effect on workload produced by implementation of NAS Stage A and ARTS III. The results are reproduced in Figure 6.5-1. It must be pointed out that the systems in question, NAS Stage A and ARTS III, did not necessarily have the specific design goal of reducing controller workload. Nevertheless, the controller's subjective feelings about an anticipated change can be seen to be negative*. Care must be taken in AATMS implementation to prevent or dispel, to the extent possible, such reactions because they may have lasting effect on system acceptance.

A scheme of functional priorities for deployment has been developed as a part of this study. It is included as Table 6.7-2 at the end of this chapter. The tabulation can be seen to reflect the following order for assumption of functional responsibilities by AATMS.

1. Deploy a basic capability - Functions 1, 17, 14 (Flight Planning, Data Base, Records)

2. Begin providing data services to users - Function 12 (Flight Advisories)

3. Commence strategic system operation - Function 2 (Flow Control)

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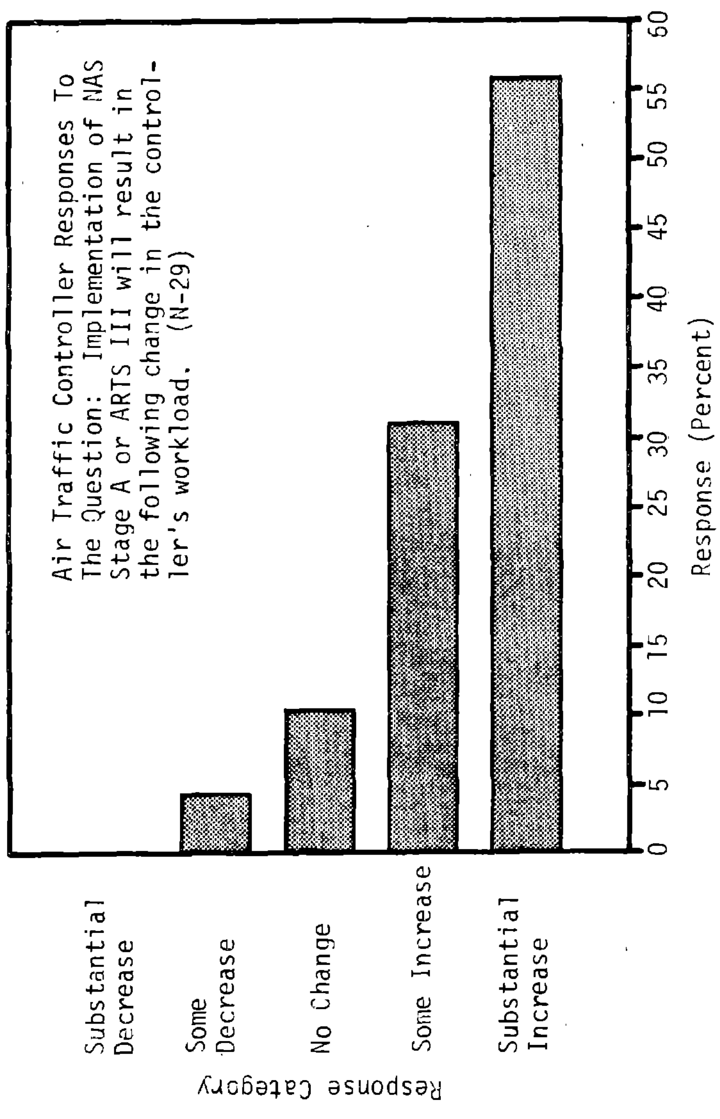
* Anecdotal information indicates that controller attitudes have become more positive in the time since this survey was taken.



(After Older & Cameron, 1972)

FIGURE 6.5-1 EFFECT OF AUTOMATION ON CONTROLLER WORKLOAD

4. Commence traffic planning and regulation (tactical) - Functions 5, 6, 7, 9 (Clearances, Progress Monitoring, Flight Plan Conformance, Spacing/Sequencing)

5. Commence operations in active control - Functions 8, 11, 13 (Separation Assurance, Guidance, Handoff)

(NOTE: Emergency Services and Special Services, Functions 16 and 15, are included in the tabulation but not listed above since they are reserved for performance by human operators)

This priority scheme for deployment is intended to serve in the same way as that given for RDT&E, i.e., as a first offering to be refined in the light of subsequent events. As the order is refined and modified, the results can be checked against the deployment strategy hardware and acceptance criteria given earlier to update the system automation deployment plan.

6.6 SOME APPROACHES TO EVALUATING AATMS AUTOMATION

Throughout the implementation of automation in AATMS, provision should be made for re-evaluation of the automation level and system configuration to allow for unforeseen technical development and to allow for differing outcomes in pre-prototype R&D and later configuration testing. The paragraphs below complete the discussion of an implementation strategy with a description of some recommended approaches for such re-evaluation.

There are many possible conditions that might stimulate a re-evaluation of the automation level. In general, these circumstances fall into either of two categories: research/development or testing/evaluation. For example, it might be brought out during R&D that the allocation of certain tasks to automated resources is not technically feasible or, though feasible, too costly. In testing and evaluation, it might be found that a certain allocation of tasks does not yield the expected results in terms of capacity, safety, or efficiency. Given either of these circumstances, there are four possible courses of action which, singly or in combination, might be taken in an attempt to find remedial action. They are outlined in the subsections below.

6.6.1 Further Study of Procedures

The phrase "automating the manual system" is a commonplace, at least in the oral history of automated information processing. When the application of automation in a particular information processing system does not produce the anticipated results, especially in terms of human productivity, systems analysts tend to look closely at the nature and relationships of the procedures and processing algorithms that underlie the automated system to see whether energy is being dissipated in performing steps or processes that were appropriate in the manual setting but unnecessary in an automated environment.

At a system level, the most likely source of such anomalies lies in a faulty definition of the role of man in the air traffic management process. Biermann (1969) addressed this possibility, stating in part:

> "The lack of strong support for development efforts leading to early removal of the controller from active control decision-making in routine operations is likely to perpetuate ATC's present constraint on air traffic growth far longer than necessary."

The discussion and examples of RDT&E activities given earlier contained the recommendation that early attention be given to this area so that work already underway (for example, Ratner et al., 1972) can be refined and extended and so that any necessary further proofs of the basic feasibility of removing the controller from the routine decision/communications loop can be obtained. The recommended automation level and man-machine configuration for AATMS derived in this study rest, in part, on the assumption that it is in fact possible to remove man from many decision-making and communication processes.

Another way in which the definition of man's role may be faulty is through errors of omission in the definition of system tasks. An example of this was given in a study of controller productivity by Rucker et al. (1971). In a discussion of the effects of automating and centralizing certain functions of flight data processing in NAS Stage A, it was pointed out:

> "It is interesting to note that while the FLIDAP functions are almost fully automated, the number of controllers involved actually increased. The "A" positions can be thought of as decentralized FLIDAP positions for handling the residual manual functions left after the automation of FLIDAP:
>
> 1. Flight strip handling at the sector prior to display at the "D" position.
> 2. Question of unacceptable flight plans not corrected by the source.
> 3. On-the-job training at the sector for controller-trainees."

Because increased controller productivity was not an explicit design goal in NAS Stage A, this observation should not be read as a criticism of the NAS system. However, in the case of AATMS, it is expressly desired that operator productivity be increased. If automation in one system function or task has a negative net effect on productivity in others, then the cause may lie either in an error of including unnecessary "holdover" tasks from the manual era or in an error in the basic AATMS configuration itself. Re-evaluation of the automation configuration should not exclude either possibility.

6.6.2 Raising the Automation Level

The level of automation derived in this study was recommended because it resulted in a more efficient balance of human and machine resource requirements. If the theoretical expectations in terms or productivity are not met when the theoretical configuration is translated into a physical configuration, and if other possible remedial approaches do not apply, then one way to approach the problem would be to automate more tasks. Careful attention should first be given to verifying the tentative conclusion reached in this study that the additional machine requirements would not be too high in relation to manpower savings.

6.6.3 Further Centralization

One reason for the relatively high operator productivity figures obtained in the en route portion of the system is that work is centralized. Very efficient disposition of human operators is thus possible. While centralization in the en route portion has had a highly favorable effect on productivity, this benefit does not extend to the terminal portion of the system. This stems primarily from the requirement to maintain a minimum staffing of two men at secondary airports, regardless of demand. If productivity at manned secondary terminals is deemed to be lower than desired, one solution would be to increase the number of unmanned secondary terminals beyond the 227 specified in the present configuration, thus centralizing low volume operations in transition hub centers and attaining a more favorable ratio of operators to aircraft.

6.6.4 Re-Allocation of Ground/Air Functional Responsibilities

The allocation of responsibilities between the ground portion of system and the user aircraft postulated in this study reflects the position that the system user (particularly the general aviation user) should have only a minimum burden of requirements placed on him to be entitled to cooperative use of controlled airspace. In other words, it was felt that many general aviation users could not afford more than a minimum of onboard equipment. If a way around the cost problem can be found, then productivity might well be enhanced by relieving the ground system of certain tasks and re-allocating responsibility to the aircraft. For example, Connelly (1972) studied (by simulation) the effects of providing aircrews with an Airborne Traffic Situation Display (ATSD). Among his findings were:

> "Approaches in which an ATSD was available to the pilot required 67% fewer controller-initiated communications than conventional radar vectored approaches. Channel occupancy time was reduced by 66% and spacing errors at the outer marker were reduced by 70%. The greater communications efficiency with the ATSD is due to the elimination of heading and speed commands intrinsic in radar vectoring, and to the elimination of traffic advisories."

Connelly's simulation-based investigation produced other findings favorable to further exploration of the ATSD concept. Again, the cost factor would be of critical importance in further study of the ATSD; but it must be noted that, in a sense, cost burdens not borne by users must be borne by the ground-based system. Also, gaining user acceptance for automatic data link may involve providing some form of information display to replace the present aircrew practice of "listening to the party line" to gain information on the present and anticipated behavior of other aircraft in their vicinity.

Any or all of the approaches described herein, and others as appropriate, may be employed in the course of regular or episodic re-examinations of the AATMS automation level and man-machine configuration. The general intent should be to keep the strategy as flexible and adaptive to change as possible in order to maximize the ultimate system cost-benefit.

6.7 LOGICAL DEVELOPMENT AND DEPLOYMENT PRIORITIES

6.7.1 Subfunction Tabulations (Development)

Table 6.7-1, beginning on the next page, lists system activities for each major development step. The list, given at the subfunction level, reflects the order of system criticality for each activity. That is the recommended logical order for system automation research and development.

6.7.2 Subfunction Tabulations (Deployment)

Table 6.7-2, beginning on page 6.7-5, lists system activities for each major deployment step. The tabulations reflect an order of assumption of system responsibilities which reserves critical functions to late stages of deployment.

TABLE 6.7-1 DEVELOPMENT PRIORITIES

STEP 1, BASIC CAPABILITY

SUBFUNCTION NUMBER	TITLE
	(Subfunctions below are complete functions needed in Step 1)
6.1	Determine Present Position
6.2	Compile Aircraft Time-Position Profile
6.3	Predict Future Positions/ETA's of the Aircraft
6.4	Determine Aircraft Capability and Status
7.1	Detect Long-Term Conflict Among Flight Plans
7.2	Determine Current Deviations from Flight Plan
7.3	Predict Deviations from Flight Plan
7.4	Determine Appropriate Resolution of Deviations
8.1	Predict Conflicts
8.2	Resolve Conflicts
11.1	Initiate/Terminate Guidance
11.2	Compute Vector Requirements
11.3	Compute Air Vector
11.4	Compute Guidance Commands
11.5	Compile and Transmit Guidance Instructions
	(Subfunctions below are partial functions needed in Step 1)
5.3	Compile and Issue Clearance
9.5	Initiate Implementation of Sequence/Schedule
13.3	Effect Transfer of Responsibility

TABLE 6.7-1 DEVELOPMENT PRIORITIES (Cont'd)

STEP 2, STRATEGIC TRAFFIC MANAGEMENT

SUBFUNCTION NUMBER	TITLE
	(Subfunctions below are complete functions needed at Step 2)
2.1	Determine System Capacity
2.2	Determine System Demand
2.3	Determine and Resolve Capacity Overload Situations
	(Subfunctions below are partial functions needed at Step 2)
5.1	Check Clearance Status
5.2	Determine Clearance to be Issued
9.1	Maintain Predicted Arrival/Departure Schedule for Each Airport
9.2	Determine Requirement for Spacing Control
9.3	Establish Runway Configuration Schedule
9.4	Determine Most Efficient Arrival and Departure Sequence/ Schedule for Runway
13.1	Determine Handoff Responsibility Requirements
13.2	Determine Communication Channel Assignment
17.1	Determine Current and Forecast Weather
17.2	Update Rules and Procedures Information
17.6	Update Hazards to Flight Information
17.7	Determine Capability and Status of COMM-NAV System
17.8	Determine Capability and Status of Ground Facilities
17.9	Maintain User Class Information

TABLE 6.7-1 DEVELOPMENT PRIORITIES (Cont'd)

STEP 3, FINAL DEVELOPMENT

SUBFUNCTION NUMBER	TITLE
	(Subfunctions listed below are remaining subfunctions that are fully or partially automated. Wholly manual subfunctions in special and emergency services are not listed.)
1.1	Receive Requests for Flight Planning Information
1.2	Select Information to Service the Request
4.1	Develop Intended Time-Position Profile
4.2	Review Flight Plan
4.3	Propose Modified Flight Plan
4.4	Determine Responsibility for Control and Communication
12.1	Service Request for Information
12.2	Issue Flight Service Advisories and Instructions
12.3	Notify Pilot of Imminent Encounter with Hazardous Weather Phenomenon
14.1	Prepare Operational Reports
14.2	Compile and Store System Records
14.3	Prepare and Maintain Statistical and Special Reports
17.3	Update Airspace Structure and Jurisdictional Boundary Information
17.4	Update Route Information
17.5	Update Airspace Restriction Information
17.10	Compile Traffic Summaries
17.11	Prepare Preformatted Data Modules

TABLE 6.7-2 DEPLOYMENT PRIORITIES

STEP 1, DEPLOY A BASIC CAPABILITY

SUBFUNCTION NUMBER	TITLE
1.1	Receive Requests for Flight Planning Information
1.2	Select Information to Service the Request
1.3	Format and Display the Requested Information
17.1	Determine Current and Forecast Weather
17.2	Update Rules and Procedures Information
17.3	Update Airspace Structure and Jurisdictional Boundary Information
17.4	Update Route Information
17.5	Update Airspace Restriction Information
17.6	Update Hazards to Flight Information
17.7	Determine Capability and Status of COMM-NAV System
17.8	Determine Capability and Status of Ground Facilities
17.9	Maintain User Class Information
17.10	Compile Traffic Summaries
17.11	Prepare Preformatted Data Modules
14.1	Prepare Operational Reports
14.2	Compile and Store System Records
14.3	Prepare and Maintain Statistical and Special Reports

TABLE 6.7-2 DEPLOYMENT PRIORITIES (Cont'd)

STEP 2, COMMENCE PROVIDING DATA SERVICES TO USERS

SUBFUNCTION NUMBER	TITLE
12.1	Service Request for Information
12.2	Issue Flight Service Advisories and Instructions
12.3	Notify Pilot of Imminent Encounter with Hazardous Weather Phenomenon

STEP 3, COMMENCE STRATEGIC SYSTEM OPERATION

SUBFUNCTION NUMBER	TITLE
2.1	Determine System Capacity
2.2	Determine System Demand
2.3	Determine and Resolve Capacity Overload Situations

TABLE 6.7-2 DEPLOYMENT PRIORITIES (Cont'd)

STEP 4, COMMENCE TRAFFIC PLANNING & REGULATION

SUBFUNCTION NUMBER	TITLE
4.1	Develop Intended Time-Position Profile
4.2	Review Flight Plan
4.3	Propose Modified Flight Plan
4.4	Determine Responsibility for Control and Communication
5.1	Check Clearance Status
5.2	Determine Clearance to be Issued
5.3	Compile and Issue Clearance
6.1	Determine Present Position
6.2	Compile Aircraft Time-Position Profile
6.3	Predict Future Positions/ETA's of the Aircraft
6.4	Determine Aircraft Capability and Status
7.1	Detect Long-Term Conflicts Among Flight Plans
7.2	Determine Current Deviations from Flight Plans
7.3	Predict Deviations from Flight Plan
7.4	Determine Appropriate Resolution of Deviations

TABLE 6.7-2 DEPLOYMENT PRIORITIES (Cont'd)

STEP 5, ASSUME OPERATIONS IN ACTIVE CONTROL

SUBFUNCTION NUMBER	TITLE
8.1	Predict Conflicts
8.2	Resolve Conflicts
9.1	Maintain Predicted Arrival/Departure Schedule for Each Airport
9.2	Determine Requirement for Spacing Control
9.3	Establish Runway Configuration Schedule
9.4	Determine Most Efficient Arrival and Departure Sequence/ Schedule for Runway
9.5	Initiate Implementation of Sequence/Schedule
11.1	Initiate/Terminate Guidance
11.2	Compute Vector Requirements
11.3	Compute Air Vector
11.4	Compute Guidance Commands
11.5	Compile and Transmit Guidance Instructions
13.1	Determine Handoff Responsibility Requirements
13.2	Determine Communication Channel Assignment
13.3	Effect Transfer of Responsibility

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