AD-A125 358 SOCIOECONOMIC IMPACT ASSESSMENT COMMUNICATIONS INDUSTRY PHASE IV IMPACT A..(U) ACUMENICS RESEARCH AND TECHNOLOGY INC BETHESDA MD 21 FEB 81 FAA-APO-81-11 1/3

UNCLASSIFIED DOT-FA78WAI-932 F/G 17/2.1 NL

AD A125358

Technical Report Documentation Page

Final Report

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[illegible] to labor saving. The extent to which future technology is [illegible] to be labor saving will be a function of the capital investment level, the efficiency of that capital and the future scenario in which the capital will function.

The present volume of the report is comprised of thirteen sections including the introduction. The general structure of the volume is to start with the notion of technology and the [illegible] for [illegible] effects (II). The functions of [illegible] technology are then defined (III). A [illegible] summary of [illegible] and foreseeable effects of planned [illegible] (IV). Section V introduces the general [illegible] to estimate agency effects. The conceptual intro- [illegible] is followed by a brief discussion of production functions (VI). The [illegible] is followed by a description of the [illegible] used in the analysis (VII). Part VIII identifies the [illegible] and the specific effects to be estimated. Section IX [illegible] the agency capital requirement for each [illegible] through the year [illegible]. Sections X to XII present the [illegible] of [illegible] for various scenario combinations. Section XIII [illegible] the [illegible] for each scenario.

II. NATURE OF TECHNOLOGY

The purpose of this section is to provide a basis for the classification of generic impacts. The creation of impact classification allows one to examine the nature of impacts and determine the generic effects of impact. The use of such classification schemes does not imply that one paradigm obtains for all technology. Rather, a classification scheme allows one to distinguish among types of effects so that *a priori* decisions about the focus of this study can be applied with some degree of efficiency.

A technology can be defined as that knowledge or set of physical objects that allow a "want" of man to be attained. As such, the technology and the use thereof are an attempt by mankind to overcome inherent physical or intellectual limitations. The adoption of technology occurs if man perceives that some function can best be performed using a human surrogate. The use of technology alters the way in which a function has been performed previously. The non-human performance of function requires that a technology operate. The act of operation requires the consumption of resources and generation of by-products. The impacts of technology, therefore, derive from function and operation.

The effects of function refer to the purpose of technology in its societal context; such effects represent or are indicative of the consequences of a class of technologies fulfilling the same or similar societal objectives. The effects of operation refer to the consequences of a technology's "being". As such, the effects of operation are independent of social purpose. For example, man has expressed a want for centrally generated electrical power. The function can be performed using a number of available technologies coal-fired power plants, hydroelectric power plants, oil-fired power plants and nuclear power plants. The effects of the function are to provide an intermediate good that satisfies needs and wants.

The magnitude of such functional effects vary with the specific technology. However, the effects of operation are dependent upon the specific technology not the function performed. As such, each technology will have different impacts on natural resource requirements. In addition, each technology will yield different actual or potential by products, e.g., the potential destructive force of nuclear vs. coal-fired power plants.

Operational effects do not influence the nature of functional effects. Rather, the act of operation influences the magnitude of functional effects. That is, the operation of a technology may alter the magnitude of process variables, where process variables are defined as those parameters common to a class of technologies performing the same or similar societal functions. For example, process variables in communication include: time required to traverse the channel, quantity of information carried and operating costs. The magnitude of each of these variables will vary with the "being," and the function, of a specific technology.

The function and operational aspects of technology are displayed in schematic form in Figure 1. The demand for technology originates as a derived demand. The underlying need for technology results due to demand for some other form of goods and services. For example, the demand for aircraft technology is generated by the existence of those customers desiring some form of [illegible] transport services.

In the act of operation, the technology has various effects due to the function. For example, television has various effects due to its function as a channel of communication. These effects include a lessening of newspaper readership, movie going, radio listening, etc. The technology also has various effects which emanate from the being. Television, for example, may emit radiation, uses electricity, has deleterious effects on vision, etc. The function of television can be performed by other technologies including radio, newspapers, books, movies, magazines, etc. The effects of the communication function will be the same in kind, but not magnitude, for each of the respective technologies. The effects of operation for each technology, however, will be different. In addition, the magnitude of the process variables for this communications class of technology will vary. The process variables with respect to communication technology

ACUMENICS

FUNCTION AND OPERATIONAL ASPECTS OF TECHNOLOGY

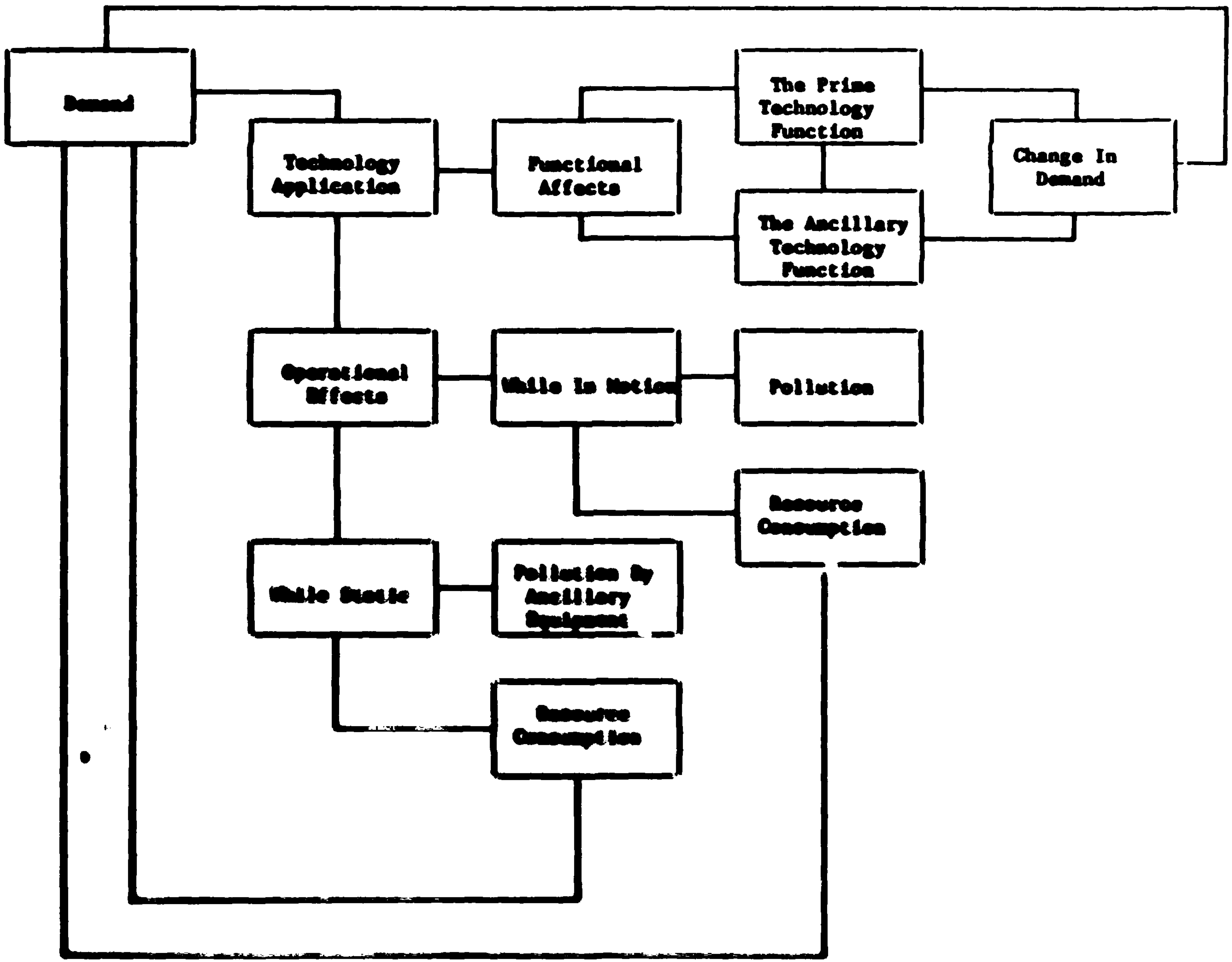

Figure 1

might include: time, content, the nature of the transaction, ease of use, cost, etc. The relationship between various communication technologies and process variables is illustratively shown in Figure 2.

1) the application of technology occurs due to the derived demand for some other good or service,
2) the effects of technology derive from its function and being,
3) the effects of technologies having the same function are similar in kind but vary in degree,
4) the magnitude of effects due to function vary with the magnitude of sundry process variables,
5) the effects of operation are due to the physical attributes of the technology,
6) the effects of a technology due to operation are independent of function, and
7) the operation effects of technologies having similar physical attributes are alike in kind but vary in degree.

While the notion of technology is complex and the effects of "being" vary with specific technologies, some general propositions concerning machines can be stated. It should be noted that the statements derive from the use of the technology (i.e., turning on the switch) rather than from fulfilling a societal objective. In this respect then, technology in use has the following results

COMMUNICATION TECHNOLOGIES AND PROCESS VARIABLES

Technology	Cost of Infrastructure to User	Cost of Use	Ease of Use	Distance	Time	Content	Nature of Transaction	Mode
Television	H	L	E	C	L	V	1	P
Radio	M	L	E	C	L	V	1	S
Newspaper	L	M	M	C	M	V	1	W
Book	L	H	D	F	H	X	1	W
Telephone	M	M	E	C	L	X	2	S
C.B.	H	L	E	C	L	X	2	S

H = High
L = Low
E = Easy
M = Medium
D = Difficult
C = Close
F = Far
V = Varied
X = Limited
1 = One Way
2 = Two Way
W = Written
P = Pictoral
AP = Animated Pictoral
S = Spoken

Figure 2

attributable to operation:

1) it serves and specifies social or economic functions,

2) it yields a product or service,

3) it is self-consuming,

4) it consumes energy,

5) it consumes resources necessary for the production of a good or provision of a service,

6) it emits excess energy

7) it causes noise,

8) it may cause air pollution,

9) it may influence the ecology,

10) it employs/displaces labor,

11) it substitutes for another technology,

12) there is a risk associated with operation--
i.e., non-operation, structural failure,
injury to labor.

Each of these "results" can be treated as variables and, to some extent, be measured. The specific variables associated with each result include:

Result	Variable
It serves a specific social or economic function.	Define function.
It yields a product or service.	Identify product or services.

ACUMENICS

[illegible]

III. FUNCTIONS OF COMMUNICATIONS TECHNOLOGY IN AN AVIATION SETTING

As noted in the preceding section man uses technology to satisfy wants. In doing so, technology substitutes for actions that man will, is able, or attempts to perform. The initial effect of technology is to diminish man's role in the performance of specific functions. As such the division of labor between man and machine may remain constant or shift with the introduction of new technology. The extent of the change in the division of labor depends upon the current functions of man and machine, as well as changes in the level or nature of the functions performed. Therefore, it is necessary to identify and examine the functions of import to this effort.

Functions of Communications Technology

The purpose of the study is to identify and examine the likely effects on users of future aviation communications technology. In general, two groups will be impacted by the adoption of new technology. First, users of the airspace system will be impacted. Such users include the various genre of pilots and aircraft owners including general aviation, trunk and local service carriers, commuter airlines, air taxi services, etc. The managers of the airspace system will be the second group to accrue impacts due to the adoption of technology. The airspace managers include various FAA operations and management personnel from ATC, AFS and FSS.

The effects of new technology will derive from the functions performed and/or needed by airspace users and managers. The magnitude of effects will depend upon the extent which new technology usurps existing or creates new functions. Therefore, to examine those effects one must identify functions requiring or compatable with the new technology. This section of the report will identify the airspace manager or user functions attendant to the National Aviation System.

Air Traffic Management

A 1974 study by TRW[1] prepared under the auspices of the Transportation System Center identified ten categories of air traffic management services. The ten categories include:

A. Airport/Airspace Use Planning - this service refers to the provision of strategic services for the establishment and/or modification of plans for airport and airspace use. The planning effort is designed to enhance user safety as well as improve the operating efficiency. The components of the service include flight planning process and development, national and local air traffic flow control, air

[1] Automation Applications In An Advanced Air Traffic Management System, Volume IIA, Functional Analysis of Air Traffic Management. Prepared for Transportation Systems Center by TRW Systems Group (August 1974).

traffic conflict prevention, efficient allocation of airspace through planning, and the flight clearance process.

B. Flight Plan Conformance - the purpose of flight plan conformance includes the tactical effort required to implement the airport/airspace use plan. This includes direct discourse between airspace users and managers. The components of flight plan conformance include; monitoring of air traffic activity to determine deviations from the extant plan, definition of actions necessary and implementation of corrections to the plan, modifications of the plan, monitoring air traffic to identify conflicts in the airport/ airspace use plan, identification of and implementation of actions to ameliorate conflicts.

C. Separation Assurance - separation assurance is a tactical service designed to improve the level of user safety in airspace. The service includes conflict and collision prevention. Tactical conflict prevention includes the following components; monitoring and predicting violations of specific airspace. Tactical collision prevention includes; monitoring to determine actual violations of airspace and resolution of airspace violations.

D. Space Control - space control includes tactical services designed to increase the efficient use of available airspace. The components of spacing control include: runway configurations scheduling and allocation of runway "slots" for takeoffs and landings; the determination of the appropriate sequence of aircraft for landings, takeoffs and en route movement; and identification and adjustment of separation distance among aircraft.

E. Airborne, Landing and Ground Navigation - this service identifies and defines the location of aircraft at a discrete point in time.

F. Flight Advisory Service - this service provides information to the pilot during all phases of flight. The information provided includes data concerning weather, air traffic, facilities, routes, obstructions and procedures and regulations.

G. Information Services - information services provide pilots with a variety of data during pre-flight planning. Pilots may obtain information about weather, air traffic, facilities, routes, obstruction, and regulations and procedures.

H. Record Services - record services include the actions, events, and documentation necessary to permit operations records.

i. __Ancillary Services__ : This service includes the provision of special services requested by the air traffic control. Such special services include communication of weather observations, military flight testing, experimental flight testing, and search and rescue coordination.

j. __Emergency Services__ : Emergency services include the provision of information and of guidance information due to critical conditions.

A subsidiary review of the ten service categories and their components resulted in the identification of nineteen generic air traffic management functions. The nineteen air traffic management functions are as follows:

a. __Function 1__ - Provision of Flight Planning Information - The provision of pilot requested information of use in pre-flight planning.

b. __Function 2__ - Control Traffic Flow - Control traffic flow is a series of actions and events that balance system demand and capacity. In addition, the control traffic flow function includes the identification and resolution of excess demand conditions.

[illegible] Subtask [illegible] - [illegible] Flight Plan - During this func- [illegible]

[illegible] Subtask [illegible] [illegible] Flight Plan : The purpose of [illegible]

[illegible] Subtask [illegible] - [illegible]

[illegible] Subtask [illegible] - [illegible]

[illegible]

G. <u>Function 7</u> - Maintain Conformance to Flight Plan - The purpose of this function is to monitor whether or not an aircraft is being flown in conformance with the flight plan. Actual and predicted deviations from the flight plan are evaluated. Actions are implemented to correct dangerous situations caused by flight plan deviations.

H. <u>Function 8</u> - Assure Separation of Aircraft - The purpose of this function is to predict and ameliorate (actual) conflicts between aircraft.

I. <u>Function 9</u> - Control Spacing of Aircraft - The purpose of this function is to sequence and schedule aircraft to allow optimal use of airspace and facilities.

J. <u>Function 10</u> - Provide Airborne, Landing, and Ground Navigation Capability - The purpose of this function is to provide signals that can be utilized by the pilot to determine aircraft position.

K. <u>Function 11</u> - Provide Aircraft Guidance - The purpose of this function is to route the aircraft to a distant airport using specified vectors.

L. <u>Function 12</u> - Provide Flight Advisories and Instructions - The purpose of this function is to provide information to the pilot before and during planning.

M. <u>Function 13</u> - Handoff - The purpose of this function is to transfer the responsibility for management of aircraft from one Air Traffic Management (ATM) jurisdiction to another.

N. <u>Function 14</u> - Maintain System Records - The purpose of this function is to compile and store documentation necessary to record the history of airspace operations statistical and special reports.

O. <u>Function 15</u> - Provide Ancillary and Special Services - The purpose of this function is to provide to system users special service delineated in the controller's manuals.

P. <u>Function 16</u> - Provide Emergency Services - The purpose of this function is to provide secondary special services in the event of an accident or failure.

Q. <u>Function 17</u> - Maintain System Capability and Status Information - The purpose of this function is to maintain a current database describing the status and capability of airspace.

The seventeen functions delineated above are generic activities. That is, one or more of the functions may support a specific service category. The relationship between the seventeen generic functions and the ten service categories is shown in Table 1. The relationship among generic functions and service categories is designated by one or more of the following:

- I = this function provides necessary information to support a service,
- D = this function generates a decision in the provision of services, and,
- A = this function generates an action that is used to implement a service.

It should be noted that 112 relationships are identified. Information transfer accounts for 67% of the relationships, decisions 15%, and actions 18%. Further, neither decisions nor actions occur without information transfer. Thus, the provision of ATC service is information dependent.

It should be noted that seventeen generic functions do not exist in an isolated environment. That is, the performance of a specific function is dependent upon information obtained from other functions. In addition, the performance of a function often requires information transfer to or from a pilot, the aircraft, and other exogenous factors. The information transfer between functions and external sources is shown on Table 2.

Table 1

RELATIONSHIP AMONG GENERIC FUNCTIONS AND SERVICE CATEGORIES

SERVICES / FUNCTIONS	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	[illegible]		I		I		
17. Maintain system capability & status information	I	I	I	I	I	I	I	I	I	I

I = Information
D = Decision
A = Action

Source: Automatic Application in an Advanced Air Traffic Management System. Vol. IIA. Functional Analysis of Air Traffic Management. Prepared for Transportation System Center, DOT by TRW Systems Group, 1974. (Contract No. DOT-TSC-512-2a)

Table 2

INFORMATION FLOW AMONG FUNCTIONS

FROM	TO 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Pilot	Acft	Exog	End
1																		✓			
2				✓	✓				✓			✓	✓					✓			✓
3				✓																	✓
4			✓		✓	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓			✓
5			✓				✓	✓	✓		✓			✓		✓		✓			
6				✓	✓		✓	✓	✓		✓	✓	✓	✓		✓	✓		✓		
7				✓	✓									✓		✓	✓		✓		✓
8														✓					✓		✓
9				✓	✓																✓
10																			✓		
11														✓		✓			✓		✓
12											✓			✓		✓			✓		✓
13					✓									✓							✓
14																				✓	✓
15				✓				✓			✓	✓					✓		✓		✓
16					✓		✓				✓	✓							✓	✓	✓
17	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓
Pilot	✓	✓	✓																		
Acft					✓	✓	✓	✓			✓	✓			✓	✓	✓				
Exog	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				

Source: Automatic Application in an Advanced Air Traffic Management System. Vol. IIA. Functional Analysis of Air Traffic Management. Prepared for Transportation System Center, DOT by TRW Systems Group, 1974. (Contract No. DOT-TSC-512-2a)

Tables 1 and 2 identify the services and functions among which information is transferred for ATM. If communication is defined as movement of information from one location to another, the information in Tables 1 and 2 represents communication channels. As such, future communication technology could be adopted and/or could effect the relationships indicated in Tables 1 and 2. Further, examination of the relationship between functions and information flow requires a detailed description of the causal relationships between functions. Such relationships are portrayed in Figure 3. The detail provided in this diagram allows the potential uses of future communication technology to be identified. As such, the diagram will serve as a basis for identifying discrete tasks and functions that might be influenced by the adoption of new communication technology. The products and independent variables for each function are delineated in the following section.

Detailed Outline of Function of Communications Technology

The following section expands on the functions of communications technology shown in Table 1. A detailed outline of these functions is given to show whether the communication required is external to the system (E) or internal to the system (I).

INFORMATION FLOW

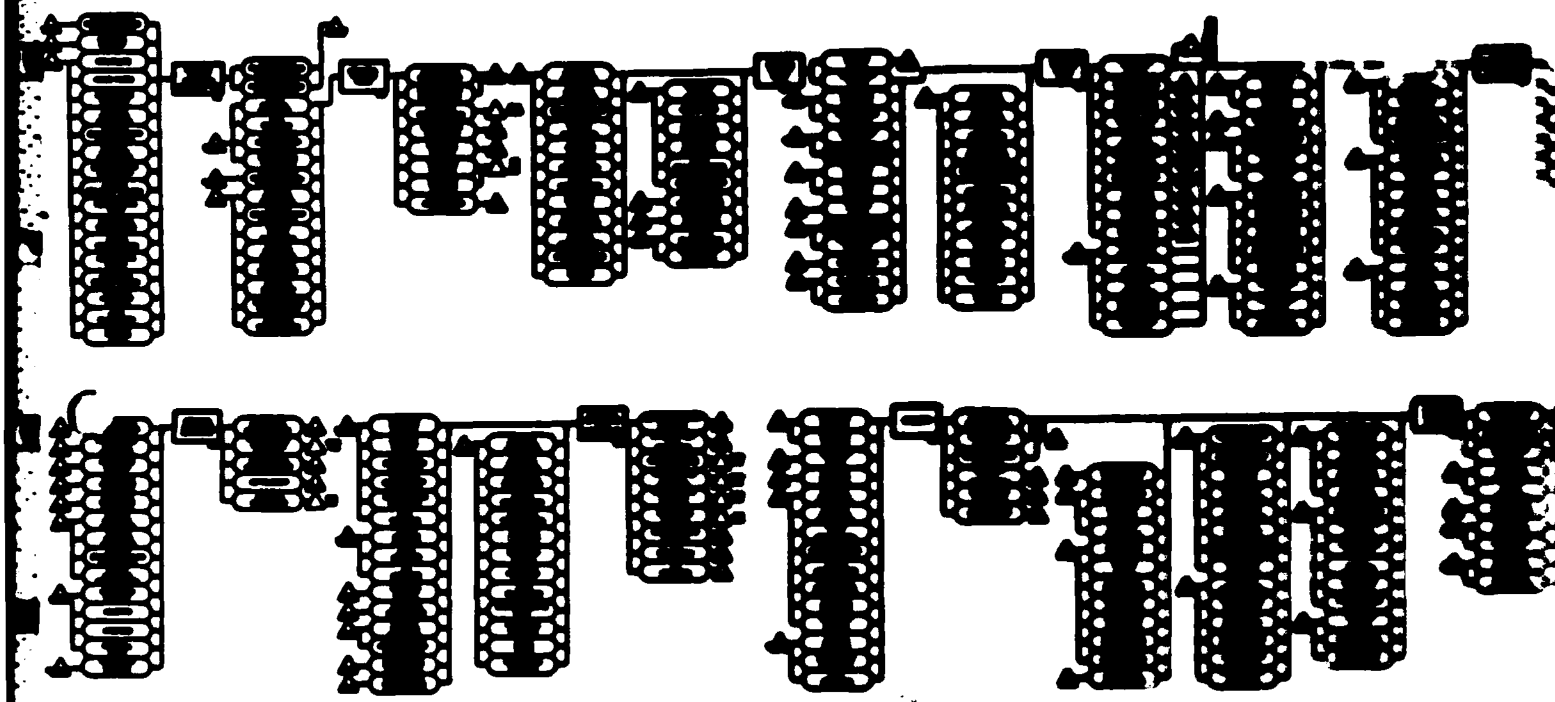

FIGURE 3

(Page 1 of 2)

Source: Automatic Applications in an Advanced Air Traffic Management System. Vol. II A. Functional Analysis of Air Traffic Management. Prepared for Transportation System Center, DOT by TRW Systems Group, 1974. (Contract No. DOT-TSC-512-2a)

INFORMATION PLAN

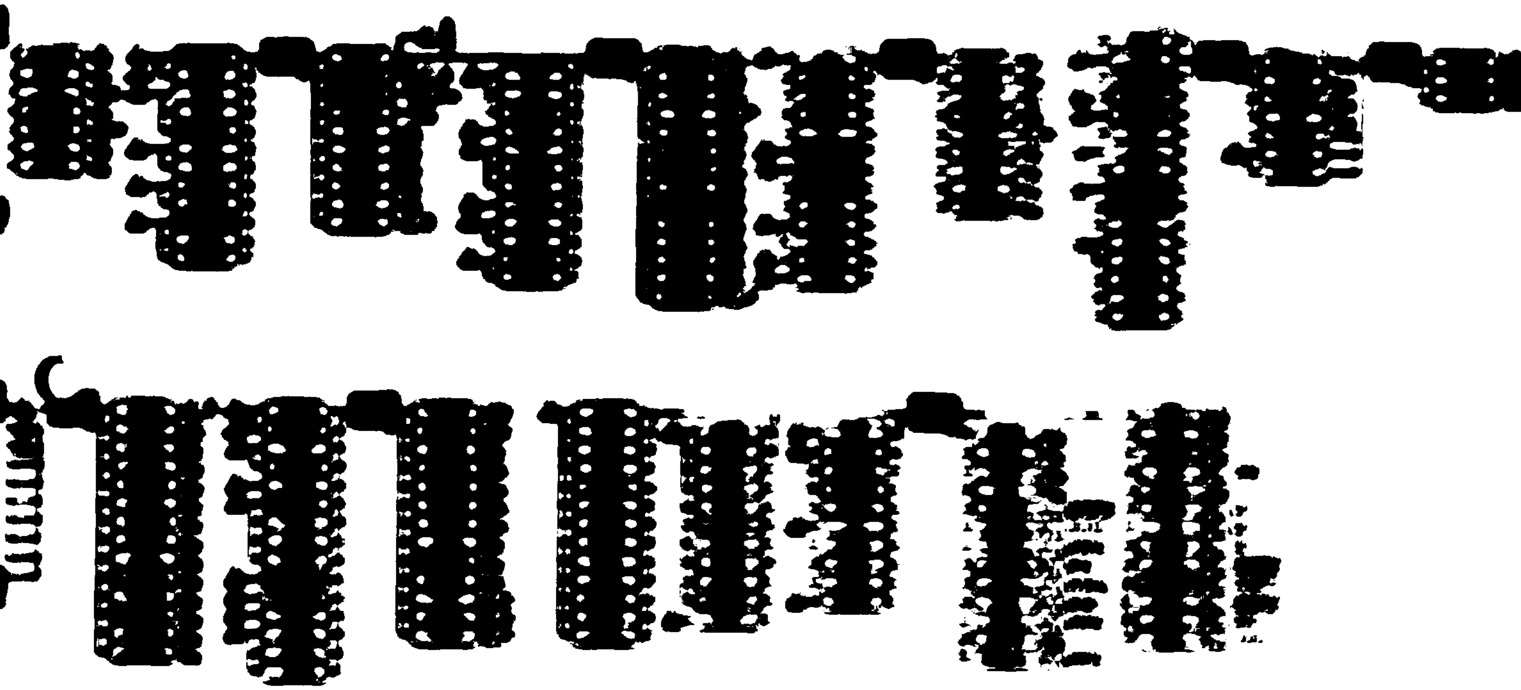

FIGURE 3
(Page 2 of 2)

Source: *Automation Applications in an Advanced Air Traffic Management System*. Vol. II A. Functional Analysis of Air Traffic Management. Prepared for Transportation System Center, DOT by TRW Systems Group, 1974. (Contract No. DOT-TSC-512-2a)

A. <u>Provide Flight Information Planning</u>

Communication Required

1. Products

   a. Displayed Flight Planning Information

   b. Transmitted Flight Planning Information — E

2. Independent Variables

   a. Request for Flight Planning Information by Pilot.

   b. Maintain System Capability (Function 17) — I

B. <u>Control Traffic Flow</u>

1. Products — E

   a. Deleted Reservation

   b. Reservation Disapproval with Alternate Available Times — E E

   c. Confirmed Reservations

   d. Terminal Jurisdiction Total Demand as a Function of Time — I

   e. Terminal Delays — I

   f. Terminal Release Quotas — I

   g. En route Jurisdiction Release Quotas

   h. No Capacity Overload

	Communication Required
2. Independent Variables:	
a. Exogenous Sources	
Flow control paradigm	
Time Stimulus	E
List of Terminal Jurisdictions in ATM System	I
Commercial Schedules	E
b. Pilot Request to Establish or Cancel Reservation	E
c. Maintain System Capability (Function 17)	I

C. <u>Prepare Flight Plan</u>

	Communication Required
1. Products:	E
a. Cancel Flight Plan	E
b. Submitted Flight Plan	
2. Independent Variables:	
a. Pilot	
Decision to use airspace intentions	E
Aircraft capability and status	
Status of Onboard Equipment	
Pilot Qualifications	
Aircraft Identification and Type	
b. Issue Clearance and Clearance Changes (Function 5)	E
c. Process Flight Plan (Function 4)	E
d. Maintain System Capability (Function 17)	I
e. Exogenous Sources	
Flight Plan Format	E
Consistency Checking Paradigm	E

	Communication Required
D. Process Flight Plan	
1. Products:	
a. Intended Time position Profile	I
b. Priority of Proposed Flight Plan	I
c. Inform Pilot of Flight Plan Approval	E
d. Inform Pilot that Flight Plan must be Changed	E
e. Accepted Flight Plan	E
f. Cancellation of Flight Plan	E
g. Define Communication Channels Between Aircraft and ATM System	E
h. Special Services Required	E
2. Independent Variables:	
a. Maintain System Capability (Function 17)	I
b. Control Traffic Flow (Function 2)	I
1. Terminal release quotas	
2. En route jurisdiction release quotas	
c. Submitted Flight Plan (Function 3)	E
d. Monitor Aircraft Progress (Function 6)	I
1. Correlated position and identification	
2. Predicted long range time-position profile	
e. Maintain Conformance with Flight Plan (Function 7) - Proposed Flight Plan Revision	E
f. Control Spacing of Aircraft	I
1. Proposed revised flight plan	
g. Provide Ancillary and Special Services	E
h. Exogenous	
1. Approval criteria	
2. Priority criteria	

	Communication Required
i. Pilot	
1. Acceptance of Flight Plan	E
2. Request for Flight Plan cancellation	I

E. <u>Issuance and Changes in Clearance</u>

	Communication Required
1. Products:	
a. Proceed to Alternate	E
b. Request Approach	E
c. Flight Plan Tolerances	E
d. Vectoring Requirements	E
e. Transmit Clearance	E
f. Unable to Issue Clearance	E
g. Issued Clearance	E
2. Independent Variables:	
a. Exogenous Sources	
1. Identification code usage procedures	I
2. Time stimulus	
3. Identify Code Paradigm	I
4. Terminated Code Assignment	I
5. Clearance Format	I
b. Control Traffic Flow (Function 2)	
1. Terminal Release Quotas	I
2. En route Jurisdiction Release	I
c. Process Flight Plan (Function 4)	
1. Accepted Flight Plan	I
d. Monitor Aircraft Progress (Function 6)	
1. Long range predicted time-position profile	I
2. Correlated position and identification	I
3. Readiness of aircraft	E

Communication Required

e. Maintain Conformance/Flight Plan (Function 7)

1. Present out-of-tolerance deviations — E
2. Pilot preference return to Flight Plan — E
3. Pilot preference for a Revised Flight Plan — E
4. Conflicts Identified — I,E

f. Handoff (Function 13)

1. Handoff Not Acceptable — I
2. Responsible Facility — I
3. Functions Transferred — I
4. Communication Channels — E

g. Provide Emergency Services (Function 16) — I,E

h. Maintain System Capability (Function 17) — I

i. Control Spacing of Aircraft (Function 9) — E,I

j. Aircraft and Pilot — E

F. <u>Monitor Aircraft Progress</u>

1. Products:

a. Identify Request — I
b. Correlated Position and Identification — I,E
c. Updated Actual Time-Position Profile — I
d. Predicted Time-Position Profile — I
e. Readiness of Aircraft — E
f. Emergency Ended — E
g. Current Aircraft Status — I
h. Current Aircraft Capability — I

ACUMENICS

Communication Required

[illegible]

ACUMENICS

Communication Required

3. Long-term predicted time-position profile — I

4. Correlated position and identification — I

d. Provide Emergency Services (Function 16):

1. Emergency flight plan — E
2. Revised emergency flight plan — E
3. Emergency ended — E

e. From exogenous source:

1. Time stimulus
2. System capacity to perform Function 7 — I

f. From aircraft:

1. Statement of preference for correction back to flight plan — E
2. Statement of preference for revision of flight plan — E

g. Maintain System Capability and Status Information (Function 17): — I

1. Active flight plan count

H. Assure Separation of Aircraft

1. Products:

a. High imminence conflict pairs — I
b. No action required — I
c. Careful monitoring required — I
d. Performance correction required — I
e. Transmitted performance change message — E
f. Transmission required — E
g. Revision required (of performance message) — I
h. Revision not required — I
i. Action classification updated — I

	Communication Required
2. Independent Variables	
a. From exogenous source:	
1. Time stimulus	
2. Destination of airspace volumes for conflict detection	I
3. Destination of time intervals for conflict detection	I
4. Path probability paradigm	I
5. Update cycle time	
b. Monitor Aircraft Progress (Function 6):	
1. Predicted short-range time-position profile for the aircraft	I
2. Predicted long-range time-position profile for the aircraft	I
3. Current aircraft capability (includes performance capability and user class)	I
c. Provide Ancillary and Special Services (Function 15):	
1. Definition of special separation minima	I
2. Special service no longer required	I
d. From the Aircraft:	
1. Acknowledgement (of performance change message)	E
e. Maintain System Capability and Status Information (Function 17):	
1. Stored database item (rules and procedures-minimum separation standards)	I
f. Issue Clearance and Clearance Changes (Function 5)	
1. Clearance issued	E

	Communication Required
I. Control Spacing of Aircraft	
1. Products:	
a. Acceptable distribution (spacing not required)	I
b. No ETA/ETD changes required	
c. Performance necessary to implement sequence change	I
d. Revised flight plan	E
2. Independent Variables:	
a. Control Traffic Flow (Function 2):	
1. Terminal/jurisdiction total demand as a function of time	I
b. Process Flight Plan (Function 4):	
1. Priority of the proposed flight plan	I
2. Accepted flight plan	I
c. Issue Clearance and Clearance Changes (Function 5)	
1. Flight plan tolerances	I
2. Request approach	E
d. Monitor Aircraft Progress (Function 6)	
1. Predicted short-range time-position profile for the aircraft	I
2. Predicted long-range time-position profile for the aircraft	I
3. Current aircraft capability (includes performance capability and user class)	I

	Communication Required
e. Maintain System Capability and Status Information (Function 17):	
1. Stored weather sequences	I
2. Stored weather forecasts	I
3. Stored database items (rules and procedures - minimum allowable separation), (ground facilities status)	I
4. Stored user class database items	I
f. From exogenous source:	
1. Baseline capacity	I
2. Time stimulus	I
3. Criteria of excess demand and slack	I

J. <u>Provide Airborne, Landing and Ground Navigation Capability</u>

1. Products:

a. En route navigation signals	E
b. Landing navigation signals	E
c. Ground navigation signals	E

2. Independent Variables:

The specific inputs are a function of the implementation chosen for the navigation subsystem but consist of some form of the following from exogenous sources:

a. Geographic location of the nav aid
b. A time reference
c. The navigation system structure

Note: The airborne, landing and ground navigation service provides a position location capability which is available for use by the aircraft. It does not determine an aircraft's position, merely provides signals which may be used onboard the aircraft to make that determination. These signals are produced and transmitted by the equipment. Their production places no demands on the "controllers." This results in the "function" which produces that service being considerably different from the other ATM functions.

This function does not utilize inputs produced by the other functions, nor produce outputs used by them. It does not require a series of man-machine interactions to produce the service provided.

There are, of course, monitoring, calibration, and maintenance tasks which must be performed. However, monitoring to determine if the function equipment is operating properly has been included with similar tasks in Function 17, Maintenance System Capability and Status Information. The nature of calibration and maintenance activities are a function of system implementation. They are not generic air traffic management activities. Therefore, the analysis of Function J has not been extended to the subfunction level.

	Communication Required
K. Provide Aircraft Guidance	
1. Products:	
a. Vectoring not required	I
b. Transmitted vectoring message	E
c. Responding as commanded	E
d. Not responding as commanded, retransmit	E
e. Not responding as commanded, declare emergency	E
2. Independent Variables:	
a. Monitor Aircraft Progress (Function 6):	
1. Correlated position and identification	I

Communication Required

b. Maintain System Capability and Status Information (Function 17)

1. Stored weather sequences — I
2. Stored weather forecasts — I
3. Stored severe weather phenomena data — I
4. Stored database items (flight hazard information) — I

c. Provide Emergency Services (Function 16)

1. Description of guidance assistance required — E

d. Provide Ancillary and Special Services (Function 15):

1. Description of guidance assistance required — E

e. Issue Clearance and Clearance Changes (Function 5): — E

1. Vectoring requirement

f. Provide Flight Advisories and Instruction:

1. Vectoring desired — E

g. From Aircraft:

1. Vectoring request — E
2. Heading — E
3. Airspeed — E
4. Vertical speed — E

h. From exogenous source:

1. Vectoring message format — E

Communication Required

L. **Provide Flight Advisories and Instruction**

1. Products:

   a. Acknowledgement of pilot request (for information) — E
   b. Information requested not available — E
   c. Transmitted preformatted advisory message — E
   d. Transmitted special response — E
   e. Transmitted message to pilot — E
   f. Vectoring desired — E
   g. No vectoring desired — E
   h. No applicable aircraft (i.e., no aircraft need the information) — E
   i. No response — E

2. Independent Variables

   a. Maintain System Capability and Status Information (Function 17)

      1. Stored weather sequences — I
      2. Stored weather forecasts — I
      3. Stored database items — I
         (rules and procedures)
         (route information)
         (airspace restrictions information)
         (hazards to flight information)
         (COMM-NAV system status)
         (ground facilities status)
      4. Stored user class database item — I
      5. Stored traffic data — I
      6. Printouts (NOTAMS) — I
      7. Voice tapes — I
      8. Electronic displays — I

   b. Process Flight Plan (Function 4):

      1. Accepted flight plan — I

	Communication Required
c. Monitor Aircraft Progress (Function 6)	
1. Correlated position and identification	I
2. Short-range predicted time-position profile for the aircraft	I
d. From Exogenous Source:	
1. Response message format	E
2. Acknowledgement message format	E
3. Flight advisory distribution paradigm	E
4. Advisory priority distribution paradigm	E
5. Alert message format	E
6. Time stimulus	E
e. From the aircraft:	
1. Pilot information request message	E
2. Pilot's response	E
3. No response	E
f. Control Traffic Flow (Function 2):	
1. Terminal delays	I
g. Provide Ancillary and Special Service (Function 15)	
1. Description of required advisories	E
h. Provide Emergency Service (Function 16)	
1. Description of required technical instructions	E

V. <u>Handoff</u>

1. Products:

a. Ground-to-ground handoff not required	I
b. No air-to-ground/ground-to-air handoff required	I

	Communication Required
c. Handoff not acceptable	I
d. Functions transferred	I
e. Responsible facility	I
f. Communication channel	I
2. Independent Variables:	
a. Process Flight Plan (Function 4):	
1. Accepted flight plan	I
b. Monitor Aircraft Progress (Function 6)	
1. Correlated position and identification	I
c. Maintain System Capability and Status Information (Function 17):	
1. Stored weather sequences	I
2. Stored weather forecasts	I
3. Stored database items (rules and procedures) (airspace structure and jurisdictional boundary information) (airspace restriction information) (hazards to flight information) (COMM-NAV system status)	I
4. From exogenous source:	
a. Pilot's request (for ground/air handoff)	E
b. Assignment paradigm	I
c. Time stimulus	
5. Control Traffic Flow (Function 2):	
a. Terminal release quotas	
b. En route jurisdiction release	I
quotas	I

N. <u>Maintain System Records</u>

1. Products:

a. Operational report not required	I
b. Completed statistical or special reports	I

ACUMENICS

	Communication Required
2. Independent Variables:	
a. Process Flight Plan (Function 4)	
1. Accepted flight plan	I
2. Cancellation of the flight plan	E
3. Communication links to be used between aircraft and ATM system	E
b. Issue Clearance and Clearance Changes (Function 5)	
1. Transmitted clearance	E
c. Monitor Aircraft Progress (Function 6):	
1. Actual time-position profile	I
2. Current aircraft status	I
3. Current aircraft capability	I
d. Maintain Conformance with Flight Plan (Function 7)	
1. Conflicts identified by location, time and aircraft involved	I
2. Closed flight plan	E
3. Present out-of-tolerance deviations from flight plan (x, y, h and t)	I
4. Short-range predicted out-of-tolerance deviations from flight plan (x, y, and h)	I
5. Long-range predicted out-of-tolerance deviations from flight plan (t)	I
6. Statement from pilot that he prefers correction of performance in order to return to existing flight plan	E
7. Statement from pilot that he prefers a revised flight plan	E

	Communication Required
e. Assure Separation of Aircraft (Function 8):	
1. High imminence conflict pairs	I
2. Performance correction required	I
3. Careful monitoring required	I
4. Transmitted performance change message	E
5. Transmission required	I
6. Performance change revision required	I
f. Provide Aircraft Guidance: (Function 11)	
1. Transmitted vectoring message	E
2. Responding as commanded	E
3. Not responding as commanded, retransmit	E
4. Not responding as commanded, declare emergency	E
g. Provide Flight Advisories and Instruction (Function 12):	
1. Transmitted preformatted message to pilot	E
2. Transmitted specially formatted message to pilot	E
3. Transmitted message (severe weather warning) to pilot	E
4. No response (to severe weather warning)	E
5. Vectoring desired	E
6. No vectoring desired	E
h. Handoff (Function 13)	
1. Responsible facility	I
2. Functions transferred	I
3. Communication channel	I
i. Maintain System Capability and Status Informaion (Function 17)	
1. Stored database items (rules and procedures)	I

Communication Required

j. From exogenous source:

1. Classification paradigm — I
2. Database form and format criteria — I
3. Database storage paradigm — I
4. Operational report information — I
5. Additional required information (not in database) — E
6. Request for special report — I
7. List of stored formats available — I
8. Recurring reports schedule — I

O. <u>Provide Ancillary and Special Services</u>

1. Products:

a. Special service no longer required — E
b. Cease action because of safety — E
c. New flight plan priority — E
d. Definition of area of restriction — I
e. Description of guidance required — E
f. Definition of special separation minima — E
g. Description of required advisories — E
h. Description of NOTAM requirement — E
i. No new flight plan priority required — E
j. No area of restiction required — E
k. No guidance required — E
l. Special separation minima not required — E
m. Advisories not required — E
n. NOTAM not required — E

2. Independent Variables:

a. Process Flight Plan (Function 4):

1. Special services required — E
2. Priority of the proposed flight plant — I

b. Maintain System Capability and Status (Function 17)

1. Stored database items (rules and procedures) — I

	Communication Required
c. From the aircraft	
1. Request for special service	T
2. Information regarding progress of service	T
d. From exogenous source	
1. Request for special service	T
2. Information regarding progress of service	T

P. Provide Emergency Services

1. Products

a. Information request (for additional information about the emergency)	T
b. Description of required technical instructions	T
c. Description of guidance assistance required	T
d. Assistance instructions (to assisting aircraft)	T
e. Emergency ended, assisting aircraft cease assistance	T
f. Instructions to provide ground support assistance	T
g. Instructions to cancel ground support assistance	T
h. None required (ground support assistance, assistance from other aircraft, technical instructions, guidance)	T
i. Emergency communications link not required	T
j. Instructions to change to emergency communications link	T
k. Emergency flight plan	T
l. Revised emergency flight plan	T
m. Emergency ended	T

ACUMENICS

	Communication Required
3. Independent Variables	
a. From the pilot or an exogenous source	
1. Additional required information	I
2. Information regarding the progress or status of the emergency	I
b. Monitor Aircraft Progress (Function 6)	
1. Description of emergency situation	I
2. Emergency ended	I
3. Current aircraft capabilities	I
4. Corrected position and identification	I
c. Issue Clearance and Clearance Changes (Function 5)	
1. Unable to issue clearance	I
d. Provide Flight Advisories and Instruction (Function 12)	
1. Information not available	I
e. Propose Flight Plan (Function 4)	
1. Accepted flight plan	I
2. Communication links to be used between aircraft and ATC system	I
f. Monitor Conformance with Flight Plan (Function 7)	
1. Proposed revision to emergency flight plan	I
g. Provide Aircraft Guidance (Function 11)	
1. Not responding as commanded, retransmit	I

	Communication Required
b. Maintain System Capability and Status Information (Function 17):	
1. Stored weather sequences	I
2. Stored weather forecasts	I
3. Ground facilities status database item	I

Q. <u>Maintain System Capability and Status Information</u>

1. Products:

	Communication Required
a. Weather observation report not required	I
b. Request for PIREP	I
c. Transmitted weather observation report	E
d. Purged data	I
e. Stored database items (rules and procedures) (airspace structure and jurisdictional boundary information) (route information) (airspace restriction information) (flight hazard information) (COMM-NAV system status) (ground facilities status)	I
f. No change in status	I
g. Stored user class database items	I
h. Active flight plan count	I
i. ETA's and ETD's by destination and origin	I
j. ETOV's by jurisdictional boundary	I
k. Stored traffic data	I
l. Preformatted data module not required	I
m. Printouts (NOTAMS)	I
n. Voice tapes	I
o. Electronic displays	I
p. Stored weather sequences	I

Communication
Required

2. Independent Variables:

a. From Exogenous Sources:

1. Time stimulus
2. Weather sensors data
3. Weather observation report schedule
4. Weather observation report criteria
5. Weather transmission schedule
6. Position and movement of severe weather phenomena
7. Weather sequences
8. Weather forecasts
9. Weather charts
10. Weather route summaries
11. Rules and procedures change information
12. Airspace structure and jurisdictional boundary change information
13. Route change information
14. Airspace restriction change information
15. Hazards to flight change information
16. NAV equipment status
17. COMM equipment status
18. Ground facilities status
19. Pilot qualification changes
20. Aircraft capability changes
21. Avionics changes
22. Event counting criteria
23. Preformatted data module criteria

b. From the aircraft:

1. PIREPS
2. NAV equipment status
3. COMM equipment status
4. Ground facilities status

c. Monitor Aircraft Progress (Function 6)

1. Correlated position and identification

d. Process Flight Plan (Function 4)

1. Accepted flight plan

e. Maintain Conformance with Flight Plan (Function 7)

   1. Closed flight plan

f. Provide Ancillary and Special Services (Function 15):

   1. Description of NOTAM requirements
   2. Definition of area of restriction
   3. Description of required advisories
   4. Special service no longer required

The preceding section delineated the components of each function. The critical factors or performance parameters for each function are shown in Figure 4. Any system construct should consider the variables identified in Figure 4.

PERFORMANCE PARAMETERS

Function	Description	Product	Accuracy	Capacity	Completeness	Flexibility	Validity	Availabilit	Utility	Timeliness	Speed	Renewal Rate
1.	Provide Flight Plan Information	IDA		X	X	X	X	X	X			
2.	Control Traffic Flow	IDA	X		X	X	X					
3.	Prepare Flight Plan	I	X		X	X	X			X		
4.	Process Flight Plan	IDA	X	X	X	X	X	X	X	X		
5.	Issue Clearance and clearance changes	IDA	X		X		X	X		X		
6.	Monitor Aircraft Progress	ID		X	X		X		X	X		
7.	Maintain Conformance with Flight Plan	IDA	X	X		X	X			X		
8.	Assures Separation of Aircraft	IDA	X	X	X		X		X		X	
9.	Control Spacing of Aircraft	IDA	X				X			X		
10.	Provide Airborne, Landing & Ground Navigation Cability	IDA	X							X		
11.	Provide Aircraft Guidance	IDA	X		X		X			X	X	
12.	Provide Flight Advisories and Instructions	IDA	X		X	X	X	X		X	X	
13.	Handoff	IDA	X	X		X	X	X	X	X		
14.	Maintain System Records	IDA	X	X	X		X		X			
15.	Provide Ancillary & Special Services	IDA				X						
16.	Provide Emergency Services	IDA				X				X		
17.	Maintain System Capability and Status Information	I	X	X	X	X	X	X	X	X	X	X

FIGURE 4

Pilot Functions

The attached Tables 3 through 8 examine the major functions performed by pilots. Related functions are grouped into six areas:

- Flight path control
- Collision avoidance
- Navigation
- Operation and monitoring of aircraft engines and systems
- Command decisions
- Flight documentation

It should be noted that in the above construct some functions occur in more than one area. Also, a function in one area may be contributory to a function in a different area. Basic pilot functions and other factors are using IFR air carrier operations as a paradigm. Other, less sophisticated types of aircraft operations may not require every pilot function listed or they may be performed in a different way.

In determining and evaluating the effects of future technology, the need for communications is derived from the need to perform the pilot functions that are delineated in the attached tables. Even though the literature describes communication as a separate functional area, it is not considered a basic pilot function in this report. Rather, communication is viewed as a necessary means to perform a basic function. This method permits one to analyze communications in the context of functions which must be performed in flying. In this way, one can identify which communication technology may be appropriate for performing the basic pilot functions more efficiently.

Communications functions, as currently performed, are identified for each pilot function. Functions contributing to basic pilot functions are also shown. These identify other elements which infringe upon the need for communications. Controlling elements associated with each function identify the methods for performing basic pilot functions. As such, controlling elements serve to define the structure of the current communications flow. New technology can alter the structure of communications flows. In fact, this must occur so that basic pilot functions can be performed more efficiently.

In the attached tables, communication functions are described as either internal or external. Internal communications (denoted by "I") are defined as those that occur within a particular system, i.e., an aircraft, an FSS, an enroute ATC Center, etc. Internal communications flows are described as either man-man, man-machine, or machine-machine. External communication functions (denoted by "E") are described as those which occur between systems, i.e., one aircraft to another aircraft, an aircraft to a radar scope, a pilot to a controller, etc. The same descriptions are used for external communication flows as are used for internal communication flows.

In assessing the potential of new technology to permit flight to be accomplished more efficiently, one must examine the communications requirements attendent to specific pilot functions. The use of new technology can alter the elements used in the current communications flow. For example, a man-machine flow may be converted to a machine-machine flow through automation.

The data in this section indicates that the airspace management and aircraft operation have significant communication components. In particular, airspace management is primarily a set of communication functions. As such, communication technology in the context of the assessment effort is the entire complex of agency capital. That is, functions previously performed using air to ground voice communications coupled with pilot and controller judgement, have been replaced by technology to some extent. The technology improves the accuracy of the information, changes the nature of the information transferred, alters the location of the information terminal, but does not change the need for information.

The new stock of communication technology will alter the efficiency of agency capital. As such, it may shift more communications functions from man to machine. However, such communications functions will remain.

TABLE 3

FLIGHT PATH CONTROL

FLIGHT PATH CONTROL	FUNCTIONS CONTRIBUTING	CONTROLLING ELEMENT	COMMUNICATIONS FUNCTONS
CONTROL OF ALTITUDE	ANGLE OF ATTACK POWER	AUTOPILOT AUTOTHROTTLE or PILOT	MACHINE-MACHINE (I) MACHINE-PILOT (I)
CONTROL OF ALTITUDE	PITCH BANK	GYROSCOPE INSTRUMENTS AUTOPILOT or PILOT	MACHINE-MACHINE (I) MACHINE-PILOT (I)
CONTROL OF SPEED	ANGLE of ATTACK POWER	AUTOPILOT AUTOTHROTTLE or PILOT	MACHINE-MACHINE (I) MACHINE-PILOT (I)
CONTROL OF DIRECTION	BANK NAVIGATION INSTRUMENTS	AUTOPILOT FLIGHT DIRECTOR or PILOT	MACHINE-MACHINE (I) MACHINE-PILOT (I)
AIRPORT ARRIVAL/DEPARTURE	RADAR STD. APPROACHES STD. APPROACHES	PILOT CONTROLLER PUBLISHED INFO.	PILOT-CONTROLLER (E) PILOT-CREW (I)
NOISE ABATEMENT	CONTROL OF ALTITUDE CONTROL OF SPEED CONTROL OF DIRECTION	PILOT AUTOPILOT AUTOTHROTTLE LOCAL REGULATIONS	 MACHINE-MACHINE (I) MACHINE-PILOT (I)

TABLE 4

COLLISION AVOIDANCE

COLLISION AVOIDANCE FUNCTION	FUNCTIONS CONTRIBUTING	CONTROLLING ELEMENT	COMMUNICATIONS FUNCTONS	
EXTERNAL SURVEILLANCE	RADAR	PILOT	PILOT-CONTROLLER	(E)
	BCAS EQUIP. IN OTHER AIRCRAFT	BCAS	MACHINE-PILOT	(I)
	LOCATION OF AIRCRAFT	CONTROLLER	MACHINE-CONTROLLER	(I)
COMMUNICATIONS SURVEILLANCE	RADIO RECEIVER	PILOT	PILOT-PILOT	(E)
VERTICAL SEPARATION	CONTROL OF ALTITUDE	PILOT	PILOT-CONTROLLER	(E)
	RADAR	CONTROLLER	MACHINE-MACHINE	(E)
	MODE C	AUTOPILOT	MACHINE-PILOT	(I)
			MACHINE-CONTROLLER	(I)
			PILOT-CONTROLLER	(E)
HORIZONTAL SEPARATION	CONTROL OF SPEED	PILOT	MACHINE-MACHINE	(E)
	CONTROL OF DIRECTON	AUTOTHROTTLE AUTOPILOT	MACHINE-PILOT	(I)
	RADAR	CONTROLLER	MACHINE-CONTROLLER	(I)
	TRANSPONDER		PILOT-CONTROLLER	(E)
TRACK SEPARATION	VERTICAL SEPARATION	CONTROLLER	PILOT-CONTROLLER	(E)
	HORIZONTAL SEPARATION		MACHINE-CONTROLLER	(I)
SEPARATION FROM ENVIRONMENTAL HAZARDS	CONTROL OF ALTITUDE	ALTIMETER	MACHINE-PILOT	(EI)
	CONTROL OF DIRECTION	RADAR		
		GROUND PROXIMITY WARNING SYSTEM		
		PILOT		
EVASIVE ACTION	CONTROL OF FLIGHT PATH	PILOT	PILOT-CONTROLLER	(E)
		CONTROLLER	PILOT-PILOT	(E)
GROUND HAZARD AVOIDANCE	CONTROL OF TAXI PATH	PILOT	PILOT-CONTROLLER	(E)
	CONTROL OF OTHER AIRCRAFT AND VEHICLES	GROUND CONTROLLER	PILOT-HANDLER	(E)
		GROUND HANDLERS		

TABLE 5

NAVIGATION

NAVIGATION FUNCTION	FUNCTIONS CONTRIBUTING	CONTROLLING ELEMENT	COMMUNICATIONS FUNCTONS
CONTROL OF COURSE	CONTROL OF BANK RADAR	PILOT NAVIGATION INSTRUMENTS FLIGHT DIRECTOR OMEGA/VLF	PILOT-CONTROLLER (E) MACHINE-PILOT (I) MACHINE-CONTROLLER (E) MACHINE-MACHINE (EI)
ALTIMETER SETTING	ATOMOSPHERE PRESSURE	PILOT TOWER/DEPARTURE CONTROL APPROACH CONTROL	PILOT-MACHINE (I) PILOT-CONTROLLER (I)
COMPUTATION OF NAVIGATION DATA	WEATHER DESTINATION FLIGHT PLANNING	PILOT FLIGHT DIRECTOR FSS	PILOT-CONTROLLER (I) PILOT-MACHINE (E)
OPERATION OF NAVIGATION EQUIPMENT	LOCATION	PILOT CONTROLLER	MACHINE-PILOT (EI)
FLIGHT PLANNING	LOCATION WEATHER	PILOT FSS	PILOT-CONTROLLER (E)

TABLE 6

OPERATION AND MONITORING OF AIRCRAFT ENGINES AND SYSTEMS

FUNCTION	FUNCTIONS CONTRIBUTING	CONTROLLING ELEMENT	COMMUNICATIONS FUNCTONS
PERFORM CHECKLIST	PHASE OF FLIGHT -START-UP -TAKE-OFF -LANDING	PILOT AIRCRAFT TYPE COMPANY PROCEDURES AIRCRAFT OPERATING MANUAL	PILOT-PILOT (I) MACHINE-PILOT (I)
MOTIVE POWER	MONITORING OF ENGINE INSTRUMENTS	PILOT	MACHINE-PILOT (I)
SYSTEM MONITORING		ANNUCIATOR FOR CONDITIONS	MACHINE-MACHINE (I)
PRESSURIZATION SYSTEM MONITORING/SETTING		PILOT INSTRUMENTS	MACHINE-PILOT MACHINE-MACHINE (I)
ELECTRICAL SYSTEM MONITORING		PILOT INSTRUMENTS	MACHINE-PILOT MACHINE-MACHINE (I)
FULL SYSTEM MONITORING		PILOT INSTRUMENTS	MACHINE-PILOT MACHINE-MACHINEf (I)
HYDRAULIC SYSTEM MONITORING		PILOT INSTRUMENTS	MACHINE-PILOT MACHINE-MACHINE (I)
PRE-FLIGHT AND IN-FLIGHT TEST AND FAULT DIAGNOSIS	MONITORING OF SYSTEMS	PILOT INSTRUMENTS	MACHINE-PILOT (I)
COMPUTATIONS AND INTERPRETATION OF INSTRUMENTS	COMPANY PROCEDURES AIRCRAFT FLIGHT MANUAL	PILOT FLIGHT MANAGEMENT SYSTEM	MACHINE-PILOT (I)

TABLE 7

COMMAND DECISIONS

COMMAND DECISIONS FUNCTION	FUNCTIONS CONTRIBUTING	CONTROLLING ELEMENT	COMMUNICATIONS FUNCTONS
FLIGHT PLANNING	ROUTE TIME	PILOT FSS	PILOT-CONTROLLER (E)
PERFORM EMERGENCY PROCEDURES	AIRCRAFT CONDITION WEATHER CONDITION AIRCRAFT POSITION	PILOT	PILOT-CREW (I)
CLEARANCE RECEIPT	TAKE-OFF DEPARTURE ENROUTE ARRIVAL LANDING	PILOT CONTROLLER	PILOT-CONTROLLER (E)
PRIORITY SETTING		CAPTAIN/PILOT	PILOT-CREW (I)
CONFLICT RESOLUTION		CAPTAIN/PILOT	PILOT-CREW (I)
CHECKLIST INTEGRITY	AIRCRAFT CONDITION	CAPTAIN/PILOT	PILOT-CREW (I)
MAINTAIN OPERATING PROCEDURE STANDARD	AIRCRAFT TYPE TYPE OF OPERATION CLEARANCES OBTAINED	CAPTAIN/PILOT	PILOT-CREW (I)
MONITOR WEATHER	WEATHER SERVICE WEATHER RADAR	PILOT	PILOT-CONTROLLER (E)
MONITOR CREW ROLES	REGIME OF FLIGHT	PILOT/CAPTAIN	PILOT-CREW (I)
BRIEF CREWS	CREW ROLES FLIGHT PLAN	PILOT/CAPTAIN	PILOT-CREW (I)

TABLE 8

FLIGHT DOCUMENTATION

FLIGHT DOCUMENTATION FUNCTION	FUNCTIONS CONTRIBUTING	CONTROLLING ELEMENT	COMMUNICATIONS FUNCTIONS
AIRCRAFT PERFORMANCE LOGS	INSTRUMENTS AIRCRAFT CONDITIONS COMMUNICATE MAINTENANCE FLIGHT ABNORMALITY REPORTS	COMPANY PROCEDURES PILOT FLIGHT MANUAL	PILOT-DISPATCHER (E) MAINTENANCE (E) PILOT
FLIGHT LOGS	AIRCRAFT HOURS AIRCRAFT CONDITIONS	COMPANY PROCEDURES PILOT FLIGHT MANUAL	PILOT-DISPATCHER (E) PILOT-MAINTENANCE (E)
POSITION REPORTS	LOCATION AND TIME	PILOT DISPATCHER	PILOT-DISPATCHER (E)

II. GENERIC AND ANTICIPATED EFFECTS

The evolution of new aviation communication technology will not alter the system functions that need to be performed. Rather, technology will change the way in which such functions are performed. As such, new technology is likely to change the man-machine division of labor as well as decrease the time attendant to each function. Generic effects of new technology on users can be placed in the following categories: system wide, agency staff, agency facilities.

The system-wide effects refer to major shifts that impact all parties. Such effects include but are not limited to:

- o change in the methods for conduct of flight,
- o change in the basis and method of navigation.

The shift in the basis and method of navigation will have significant effects on users. In particular, new technology will change navigation from a terrestrial to a space-based reference system. As such, the present type of segmented flight path will be eliminated. That is, flight paths dictated by the position of ground based reference points will no longer be necessary. Rather, standard flight paths will be determined by the needs of the users and the agency. Future flight paths may well be segmented, but such definition will be referenced to airborne rather than terrestrial reference points.

The shift in the basis for navigation will alter the method of flight. That is, a pilot will not necessarily fly the same route with new technology as with old. In addition, new technology will allow the pilot to be more self sufficient, since the aircraft in a technical sense will be a flying TRACON.

Agency staff and capital will change significantly due to new technology. Likely effects of new technology will include, but not be limited to:

- increased substitution of capital for labor;
- increased capacity in terminal and en route airspace; and
- impacts due to the operation of the technology.

Increased substitution of capital for labor will result in an increased objective role for technology. The division of labor between man and machine will result in a reduction of the personnel requirement for many functions. In addition to reducing the number of personnel required per unit of activity, more capital intensive technology will change the nature and extent of responsibility for ATC personnel.

Increased capability in the terminal and en route environment will result from the widespread use of faster and more efficient technology. New technologies will provide more precise position, speed and altitude information on a more frequent basis. The technology will objectively analyze such information and issue directions to aircraft in the system. Aircraft will respond more quickly owing to advances in automated control as well as the instantaneous availability of required information. As such, spacing minimums for en route and terminal airspace will be reduced. Further, better control will afford reduced spacing in approved patterns at airports. Diminished spacing will allow more aircraft to utilize runways per unit of time.

The operation of new technology will diminish the role of FSS personnel. Much of the information at present made available by FSS will be obtained by system users through automated communication. As such, the role of FSS personnel will be altered from information interpretation and provision to automated system management.

The availability of automated information conveyed by satellite or land lines will diminish the need for voice guard communication equipment. Communications among facilities with respect to traffic management will be between machines, not personnel.

Impacts in the user environment derive from the agency investment in capital. As such user impact will emanate from alternatives, in the method of navigation, and operations imposed by the agency adoption of new technology. New navigation techniques will require retraining of the extant cadre of pilots and different means of training for new pilots. In addition, increased agency dependence on automation will result in the demise of VFR flight, owing to the precision and order required by new technology.

Anticipated Effects

The purpose of this section is to summarize the expected gain in productivity of air traffic controllers as a result of at present planned ATC Automation, and to discuss the policy impacts of ATC Automation on job satisfaction.

The productivity gains are summarized for three discrete automation levels. The levels are consistent with the DOT/FAA plans for upgrading the Third generation ATC System discussed in Controller Productivity Study (FAA-EM-73-3), Section 1.2.

To quantify the effects of identified systematic changes to the automated system on controller staffing, the concept of "productivity gain" is used. In general, the productivity gain factor P, can be defined as the following ratio:

P = (Demand Serviced per Controller in an Improved System) divided by (Demand Serviced per Controller in the system before improvement).

The "P" values for each automation level are assumed to apply in these years:

Automation Level	Comparison Year
NAS Stage A Model 3d	1976
Upgraded 3rd, Phase I	1980
Upgraded 3rd, Phase II	1985

The above comparisons are picked on the assumptions that: 1) The designated system has been fully deployed and has been operational long enough to assume that users and operators of the system are well up on the learning curve, and 2) the productivity contributions of the succeeding system have not yet been realized in a significant way.

Slippage of the assured schedule does not change the "P" values, but does change the year in which they apply. The characterizations of the automation levels are shown in Table 9.

Productivity of En Route Controllers

The combined productivity impact of both pre- and data link eras is estimated to be 2.19 due to automation.

A. The contributors to en route ATC productivity are as follows:

1. 3rd generation (NAS Stage A)

   a. Automated Flight Data Processing/Forwarding

   b. Automated Tracking Displays with Alphanumerics

   c. Automatic and Manual Display Filtering

   d. Surveillance Data Mosaicking

   e. Simplified Clearance/Coordination Procedures

   f. Centralized Flow Control

TABLE 9

AUTOMATION LEVELS CHARACTERIZED

SYSTEM GENERATION	CHARACTERIZATION
3rd	- NAS Stage A En Route - ARTS III plus Enhancement
Upgraded 3rd, Phase I	- Software additions to 3rd generation - New controller work station design - RNAV Applications
Upgraded 3rd, Phase II	- Discrete Address Beacon System (DABS) - Extensive data link applications - Microwave Landing System (MLS) - Higher levels of automation for both ATC and FSS

Source: Controller Productivity Study (FAA-EM-73-3).

2. Upgraded 3rd, Phase I

   a. Flight Plan Error Correction by Source

   b. Automatic Clearance Coordination

   c. Conflict-Free Clearances, including 2D/3D RNAV

   d. Track Conflict Detection and Resolution Aids

   e. More Flexible Allocation of Local Control Capacity

   f. Man-Machine Interface Improvements (Device Software)

   g. Modifications to Three-Man Sector Design (to permit reduced manning under light loads)

3. Upgraded 3rd, Phase II

   a. Automatic Clearance/Command Generation by ARTCC Computer

   b. Automatic Clearance/Command Delivery via Data Link

   c. Automatic IPC Services to Assure VFR/IFR Separation/Segregation

   d. Terminal Area Metering Aids, including automatically scheduled clearances (2D or 3D)

   e. Man-Machine Interface Improvements (possibly new display systems)

   f. Two-Man Sector Design (operable by one man under light loads)

B. Average Number of Controllers Per Sector

One means to achieve en route ATC productivity gain is to reduce the average number of controllers per sector. This can be accomplished by:

1. Reducing support workload;

2. Revising control team organizations; and

3. Redesigning control positions.

C. Average Instantaneous Aircraft Count Per Sector

Another means to achieve en route ATC productivity gain is to increase the average Instantaneous Aircraft Count per sector. This can be accomplished by:

1. Increasing "radar" controller capacity; and

2. Increasing capacity utilization efficiency.

D. Trends in the En Route System

It is expected that in en route traffic will nearly double between 1982 and the end of the century. The controller staff required to operate this system would have to increase accordingly. The staffing requirements of the baseline system (without any automation) would grow from 16,000 in 1985 to 29,000 controllers by the year 2000. This represents a growth of about 80%. With the automation planned for the pre-data link era, the controller staff requirement would be reduced, but would still grow during the same period from 12,000 to 21,000 controllers or about 75%. Restricting the growth of the staffing requirements in the en route system is the objective of the advanced automation concepts for the en route system.

Increases in productivity between 1985 and 1990 would restrain the increase in staff in the en route systems by an estimated 92,000 man-years and result in a savings of 2.25 billion dollars.

Productivity in the Terminal Controllers

Controller productivity would increase as a result of implementing the Upgraded Third Generation Air Traffic Control Automation programs.

A summary of the combined productivity gains in terminal facilities is shown in Table 10.

A. The contributors to terminal ATC productivity are as follows:

1. 3rd Generation (ARTS IV, V)
   a. Automated Flight Data Processing/Forwarding (by NAS Stage A)
   b. Automated Tracking Displays with Alphanumerics
   c. Automatic and Manual Display Filtering
   d. Simplified Clearance/Coordination Procedures
   e. Arrival Metering and Spacing Automation

2. Upgraded 3rd, Phase I
   a. Improved Metering and Spacing Automation
   b. Automatic Clearance Coordination

c. Conflict-Free Clearances, including 2D/3D RNAV

d. Track Conflict Detection and Resolution Aids

e. More Flexible Allocation of Local Control Capacity

f. Man-Machine Interface Improvements (Device Software)

3. Upgraded 3rd, Phase II

a. Automatic Clearance/Command Generation by ARTCC Computer

b. Automatic Clearance/Command Delivery via Data Link

c. Automatic IPC Services to Assure VFR/IFR Separation/Segregation

d. Terminal Area Metering Aids, including automatically scheduled clearance (2D or 3D)

e. Automated Final Approach Monitoring on Close-Spaced Parallel Runways

f. Man-Machine Interface Improvements (possibly new display systems)

g. All-Weather Ground Guidance and Control

B. Average Control Capacity Per Team

One means to achieve terminal ATC productivity gain is to increase average control capacity per team.

1. Tower = ground controller and local controller.

2. TRACON = arrival, departure and area controllers.

C. Number of Support Positions Per Team

Another means to achieve terminal ATC productivity gain is to reduce the number of support positions per team.

a) Tower = Clearance delivery, flight data, coordinators.

b) TRACON = Radar assistants, flight data, coordinators.

D. Trends in the Terminal System

According to the latest FAA Forecasts, the traffic growth in the terminal system is expected to approximately double between 1985 and the year 2000. Accordingly, the staffing requirements would have to grow substantially in order to handle this traffic increase. Even when the productivity benefits from the implementation of the pre-data link improvements are realized, which would reduce the staffing requirements from those of the baseline system, the staffing of the ARTS-IV terminals is still expected to grow from approximately 5000 controllers to 9000 controllers. This represents a growth in the ARTS-III terminal staff of about 80%. Restricting this growth is the objective of advanced automation concepts for the terminal facilities in the data link era.

Increases in productivity between 1985 and 1990 would restrain the increase in staff in the terminal system by 22,00 man-years and result in a savings of .5 billion dollars.

Total (En Route and Terminal) O & M Cost

Growth in the baseline system means increasing the controller staff from 32,500 by 1985 to 55,000 by the year 2000. By then, the cost of ATC is about 1,350 million dollars per year in terms of 1975 dollars. If the productivity impact of the improvements planned for the pre-data link era are fully realized, the growth would decrease in absolute value but the rate of growth beyond 1985 is not significantly impacted. Thus, staffing in the improved system would grow from 25,000 by 1985 to 45,000 controllers by the year 2000. Even with pre-data link improvements, the annual dollar cost for operating the ATC system at the end of the century is about 1.1 billion dollars. This is about a 20% decrease from the cost of the baseline system.

Approaches That Can Be Taken to Achieve Productivity Gains in Flight Service Stations

It is estimated that productivity gains from flight plan filing and briefings automation can most readily be achieved if one or more of the following approaches are taken:

A. The pilot is encouraged to file his IFR or DVFR flight plan directly with the automated ATC system, thereby eliminating manual handling of individual flight plans by FSS specialists.

B. The pilot is encouraged to serve himself in obtaining pre-flight weather and system status briefings, rather than depending upon personalized service by the FSS specialist.

C. Where personal briefing services are offered, automated aids are provided to the FSS specialist which significantly reduce the workload associated with these services.

D. Search and rescue services are provided by a more cost-effective method than the failure of the pilot to cancel his activated VFR flight plan. The problem is the cost of manually handling millions of VFR flight plans yearly to provide this service to a few hundred overdue aircraft.

E. If VFR flight plans are needed, they are filed, activated, and cancelled directly by the pilot and/or the FSS specialist with an automated system. Entries would be automatically forwarded and booked at one or more centralized locations.

<u>Ways to Achieve FSS Productivity Gains</u>

Productivity in the delivery of flight services can be achieved in one or more of the following ways:

A. Automate the delivery of Flight Services
   1. Automation aids to FSS specialists
   2. Pilot self-service automation

B. Reduce number of Flight Service Stations required
   1. FAA's reconfiguration plan
   2. Centralization of service automation

Flight Service Trends

Of the many services extended by Flight Service Stations, three stand out as the major determinants of the staff required. In order of importance to workload, they are:

A. Flight plan handling (IFR, DVFR and VFR)

B. Pilot briefings (pre-flight and in-flight)

C. Air-ground communications (all contacts)

The total number of flight plans originated in FY 63 was 3.6 million, about evenly split between IFR and VFR. The current estimate for FY 72 is 6.5 million, with IFR-DVFR flight plans representing over half of the total. For the same period, briefings will have grown nearly 6 times from 2.4 million for FY 63 to 13.7 million in FY 72. Radio contacts will have increased from 7.4 million in FY 63 to 10.5 million in FY 72.

To provide all flight services the number of specialists employed at Flight Service Stations has remained relatively constant at around 4 thousand between FY 63 and FY 70. The present FAA plan calls for 4.6 thousand in FY 72. The increased volume of services delivered has been achieved to date through more efficient methods of operation and by cutting back other services.

Policy Impacts of ATC Automation: Human Factor Considerations

Implementation of new ATC systems will both require and induce changes in the processes by which the FAA functions. Operational impacts would be felt in such areas as:

A. Policy review

B. Program planning

C. Resource allocation

D. Management of ATC services and regulatory responsibilities. ATC automation will affect the following control processes:

   1. Sector traffic flow planning
   2. Aircraft flight path planning
   3. Separation assurance decision making
   4. Flight information decision making, and
   5. Control message transmission

As planning and tactical control become more automated, the controller's work stress and job satisfaction would be affected. Factors which describe pertinent performance capabilities of humans are:

A. Job satisfaction and motivation

   1. Achievement - work alignment
   2. Recognition
   3. Responsibility
   4. Control authority
   5. Utilization of perceived skills
   6. Challenge - discretionary flexibility
   7. Performance feedback
   8. Interest

B. Man-Machine Interface

1. Vigilance
2. Stress
3. Intricacy
4. Restrictiveness
5. Rigidity
6. Decision Making

C. Failure-Mode Operations

1. Failure recognition
2. Failure recovery
3. Failure operations

Factors and functions that will change and the reasons for those changes are shown in Table 11.

TABLE 11

FACTORS AND FUNCTIONS THAT WILL CHANGE

FACTORS THAT WILL CHANGE	HOW AND WHY
I. Productivity of enroute and terminal area air traffic controllers.	Controller productivity will increrse as a result of implementing the Upgraded Third Generation Air Traffic Control Automation programs. Terminal Facilities (1) Combined productivity gain impact of Advanced Automation on large terminal facilities (including both the IFR room and tower CAB) is shown in this report to be about 1.33. (2) The impact on medium ARTS-III facilities is shown to be about 1.25. (3) No impact on small facilities is expected. (4) Averaging the controller productivity gain over all ARTS-III facilities regardless of size results in a weighted average gain of 1.3. (5) Combining this with the average gain in ARTS-III facilities, regardless of size, results in a gain of 1.72. (6) Average productivity impact of non-ARTS-III facilities was evaluated to be 1.05 at the end of the pre-data link era. The following features of Advanced Automation are expected to have a significant impact on controller productivity in the terminal facilities: (1) Automatic Generation of Routine Control Messages (2) Automatic Delivery of Control Messages via Data Link (3) Advanced Metering and Spacing (Multiple Runway & Departure)

FACTORS THAT WILL CHANGE	HOW AND WHY
	<u>En route Facilities</u> (1) The potential impact of Advanced Automation is shown in this report to be a productivity gain of 1.62. (2) Combined productivity impact of both pre-data link and post data link eras is 2.19. (3) The productivity gain in the data link era due to improvements of that period increases linearly from unity to 1.62. The following features of Advanced Automation are expected to have a significant impact on controller productivity in the enroute facilities: (1) Flight Profile Generation (2) Sector Clearance Planning (3) Flight Progress Monitoring (4) Automatic Clearance Delivery
II. Staffing	Increase in productivity between 1985 & 1990 would <u>restrain the increases in staff</u> in both enroute and terminal systems. Substantial savings would result. Potential Savings (in Data Link Era): <u>Terminal</u> <u>Enroute</u> Staff 22,000 man years 92,000 man years $ .5 billion 2.25 billion

FACTORS THAT WILL CHANGE	HOW AND WHY
III. Workload	Workload would be reduced with the aid of automation which may result in a productivity gain.
IV. Average Number of Controllers per Sector	One means to achieve enroute ATC productivity gains is to reduce the average number of controllers per sector. This can be accomplished by: (1) reducing support workload; (2) revising control team organization; and (3) redesigning control positions
V. Average Instantaneous Aircraft Count per Sector	Another means to achieve enroute ATC productivity gains is to increase the average Instantaneous Aircraft Count per sector. This can be accomplished by: (1) increasing "radar" controller capacity; and (2) increasing capacity utilization efficiency Contributors to Enroute ATC Productivity A. 3rd Generation (NAS Stage A) (1) Automated Flight Data Processing/Forwarding (2) Automated Tracking Displays with Alphanumerics (3) Automatic & Manual Display Filtering (4) Surveillance Data Mosaicking (5) Simplified Clearance/Coordination Procedures (6) Centralized Flow Control B. Upgraded 3rd Phase I (1) Flight Plan Error Correction by Source (2) Automatic Clearance Coordination (3) Conflict-Free Clearances, including 2D/3D RNAV (4) Track Conflict Detection & Resolution Aids (5) More Flexible Allocation of Local Control Capacity (6) Man-Machine Interface Improvements (Device Software) (7) Modifications to Three-Man Sector Design (to permit reduced manning under light loads)

FACTORS THAT WILL CHANGE	HOW AND WHY
	C. Upgraded 3rd Phase II (1) Automatic Clearance/Command Generation by ARTCC Computer (2) Automatic Clearance/Command Delivery via Data Link (3) Automatic IPC Services to Assure VFR/IFR Separation/Segregation (4) Terminal Area Metering Aids, including automatically scheduled clearances (2D or 3D) (5) Man-Machine Interface Improvements (Possibly new display systems) (6) Two-Man Sector Design (operable by one man under light loads)
VI. Average Control Capacity per Team	One means to achieve terminal ATC productivity gains is to increase average control capacity per team. (a) Tower: Ground Controller & Local Controller (b) TRACON: Radar Assistants, Flight Data, Coordinators
VII. Number of Support Positions per Team	Another means to achieve terminal ATC productivity gains is to reduce the number of support positions per team. (a) Tower: Clearance Delivery, Flight Data, Coordination (b) TRACON: Radar Assistants, Flight Data, Coordinators

FACTORS THAT WILL CHANGE	HOW AND WHY
	Contributors to Terminal ATC Productivity A. 3rd Generation (ARTS III, II): (1) Automated Flight Data Processing/Forwarding (by NAS Stage A) (2) Automated Tracking Displays with Alphanumerics (3) Automatic & Manual Display Filtering (4) Simplified Clearance/Coordination Procedures (5) Arrival Metering & Spacing Automation B. Upgraded 3rd, Phase I: (1) Improved Metering & Spacing Automation (2) Automatic Clearance Coordination (3) Conflict-Free Clearances, including 2D/3D RNAV (4) Track Conflict Detection & Resolution Aids (5) Man-Machine Interface Improvements (Device Software) C. Upgraded 3rd, Phase II: (1) Automatic Clearance/Command Generation (2) Automatic Clearance/Command Delivery via Data Link (3) Automated IPC Services to Assure VRF/IFR Separation/Segregation (4) Terminal Area Metering Aids, including automatically scheduled (2D or 3D) (5) Automated Final Approach Monitoring on Close-Spaced Parallel Runways (6) All-weather Ground Guidance & Control

FACTORS THAT WILL CHANGE	HOW AND WHY
VIII. Delivery of Flight Services	One means to achieve productivity in the delivery of flight services is to <u>automate</u> the delivery of flight services. This can be accomplished by: (1) Automation aids to FSS specialists; and (2) Pilot self-service automation
IX. Number of Flight Service Stations	Another means to achieve productivity in the delivery of flight services is to <u>reduce</u> the number of Flight Service Stations required. This can be accomplished by: (1) FAA's reconfiguration plan; and (2) Centralization of services automation <u>Contributors to Flight Service Station Productivity</u> (1) The forecast number of flight plans to be handled; (2) The number of individual pilot briefings to be given. <u>Approaches to Achieve FSS Productivity Gains</u> (1) The pilot is encouraged to file his IFR or DVFR flight plan directly with the automated ATC system, thereby eliminating manual handling of individual flight plans by FSS specialists. (2) The pilot is encouraged to serve himself in obtaining pre-flight weather and system status briefings, rather than depending upon personalized service by the FSS specialist. (3) Where personal briefing services are offered, automated aids are provided to the FSS specialist which significantly reduce the workload associated with these services.

FACTORS THAT WILL CHANGE	HOW AND WHY
	(4) Search and rescue services are provided by a more cost-effective method than the failure of the pilot to cancel his activated VFR flight plan. (5) If VFR flight plans are needed, they can be filed activated, and cancelled directly by the pilot and/or the FSS specialist with an automated system. Entries would be automatically forwarded and booked at one or more centralized locations.
X. Policy Review; Program Planning; Resource Allocation; Management of ATC Services; and Regulatory Responsibilities	Implementation of new ATC systems will require and induce changes in the processes by which the FAA functions. Operational impacts would be felt in these areas.
XI. Communications; Surveillance Navigation Procedures; Separation Standards; Airspace Sectorization; Sector Control Equipment; Sector Manning Strategies; and Airspace Traffic Flow Regulations	Changes in these areas will be caused by technological developments.

FACTORS THAT WILL CHANGE	HOW AND WHY
XII. Human Factors A. Job Satisfaction & Motivation (1) Achievement - work alignment (2) Recognition (3) Responsibility (4) Control Authority (5) Utilization of perceived skills (6) Challenge - discretionary flexibility (7) Performance Feedback (8) Interest B. Man-Machine Interface (1) Vigilance (2) Stress (3) Intricacy (4) Restrictiveness (5) Rigidity (6) Decision/Making C. Failure-Made Operations (1) Failure Recognition (2) Failure Recovery (3) Failure Operations	These human factors decribe pertinent performance capabilities of humans.

V. THE CONCEPT OF PRODUCT IN THE AIRSPACE SYSTEM

The national airspace system can be viewed as a competitive market within which users buy goods from providers of service. The users of the system include air carriers, commuters, air taxis and general aviation. Service providers are the constituent elements of the federal aviation agency, air traffic control and flight standards.

The providers of service are producing allowed levels of activity either in terminal or enroute facilities. Measures of such activity include operations, aircraft handled, and aircraft contacted. The users of the system procure "allowed activity" to provide for "user produced activity." As such, the levels of activity provided by the FAA and consumed by the user are numerically congruent. Thus, for the purpose of this analysis, allowable and user produced operations are equivalent.

If one examines the FAA allowable operations, it is seen that given levels of capital and labor provide a specific range of operation. Capital in this instance includes the technology required to provide an *a priori* specified level of service. In particular, capital is the technology measured in money terms that allows the functions defined in the previous section to be performed with established proficiency. Labor refers to the number of people required to operate the technology to obtain specific levels of product.

Similar for the user side, a given number of aircraft combined with the set of pilots results in the performance of a certain level of operations. Labor for the user side is defined by the number and composition of pilots. User capital includes the number and composition of aircraft. Thus for both the system user and provider of service the relationship can be specified as

$$\text{Operations} = f(\text{LABOR, CAPITAL}).$$

The above specification is similar to that of an industrial production function in which,

$$Q = f(\text{LABOR, CAPITAL})$$

where Q is the product of the industry. The production function relates the level and composition of production factors to product or service. As such, the production function considers the state of technology, or the relative substitution of capital for labor or labor for capital. If the products of two industries are the same then the production functions of each can be compared for the same level of product. That is, if industry one has a production function $Q_1 = f(L_1,C_1)$, and industry two has a production function $Q_2 = g(L_2,C_2)$ and $Q_1 = Q_2$ then, $f(L_1,C_1) = g(L_2,C_2)$.

The preceeding formulation provides a basis to determine the effects of shifts in productivity factors in one industry on the quantity of labor or capital in the second industry.

In the context of the present study, shifts in the level or composition of capital and labor for users will require changes in the FAA capital and labor to provide the services, or vice versa. New technology will alter the man-machine relationship in the performance of functions. However, the change in functions will ultimately affect the levels of capital and labor necessary to provide a specified level of service. Thus, the production functio construct may be used to estimate the impact of technological change on systems users and the providers of service.

The industries of concern are not homogeneous. Rather both the agency and industry can be desegregated into smaller components. The agency can be considered to be composed of three industries that have distinct production functions:

1) terminal areas
2) en route centers, and
3) flight service stations.

Each of the above industry segments has distinct measures of produc Terminal area product is measured in terms of annual aircraft operations. Aircraft handled is the measure of en route center product. Flight service station activity is measured as contacts.

If the notion of product is an acceptable hypothesis for the airspace constraint, then the effects of new technology can be measured using the production function construct. The construct allows one to estimate the relationships among industry product and the factors of production. Estimates of the present production function coefficients can be obtained from existing agency data. The production function coefficients can be modified based on the estimated change in the efficiency of the technology. The new technology production function coefficient can then be employed to estimate the shifts in labor or capital attendant to the new technology.

VI. PRODUCTION FUNCTIONS

The previous section discussed the notion of product and the factors of production in the airspace system. The production function construct is used in succeeding sections to estimate the change in agency labor owing to new technology. This section of the text will discuss the major production functions. The application of production functions will be described in the next section.

Since the Cobb-Douglas production function has proved so useful to the analysis employed in this study, this section provides a non-technical discussion of some of the important concepts relating to production functions, especially in regard to the measurement of technological change. Many of these concepts can quickly involve complicated mathematical expressions that, in a technical treatise, would require strict mathematical definition, derivation and proof. However, this is not a technical economics paper and in the discussion below the derivations, proofs, and even some of the more cumbersome formulas themselves will not be fully developed.[2] Instead, the general notion of the production

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[2] For further information, the reader is referred to the following texts, particularly the first two, Brown, Murray, On the Theory and Measurement of Technological Change. Massachusetts: The University Press, 1968; Chiang, Alpha C., Fundamental Methods of Mathematical Economics (2nd ed.). New York: McGraw Hill, 1974. (Especially pages 186-7 and 404-422).; Lave, Lester B., Technological Change: Its Conception and Measurement. New Jersey: Prentice-Hall, Inc., 1966, Mansfield, Edwin, The Economics of Technological Change. New York: W. W. Norton Company, Inc., 1968: Samuelson, Paul A., Economics, (9th ed.) New York: McGraw-Hill Book Company, 1973; and Shepard, Ronald W., Theory of Cost and Production Functions. New Jersey: Princeton University Press, 1970.

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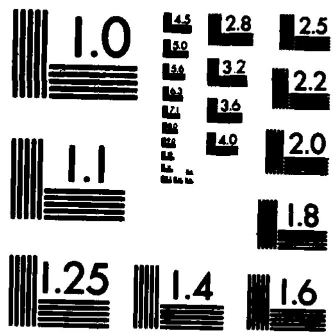

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function and how it relates to technological change will be discussed first. Next, the Cobb-Douglas production function will be explained in as non-technical a manner as possible, and its choice for this study explained. Because the Cobb-Douglas formulation is a special case of the constant elasticity of substitution (CES) production function, that function will then be briefly defined and discussed. A brief summary will conclude this section.

General Notion of the Production Function

The production function concept was developed to deal with the relationship between inputs and outputs, specifically, the maximum output possible for the various possible inputs to a production process, given the level of technology. The inputs are generally abstractly discussed as capital (K) and labor (L) inputs. Paul Samuelson defines a production function as follows:

> The production function is the technical relationship telling the maximum amount of output capable of being produced by each and every set of inputs (or factors of production). It is defined for a given state of technical knowledge.[3]

Note that the function discusses a technical relationship which does not depend on the prices of the factor inputs. It can be expressed as a mathematical function,

$$Q = f(K,L), \text{ where}$$
$$Q = \text{Output}$$
$$K = \text{Capital}$$
$$L = \text{Labor}$$

[3]Samuelson, op. cit., p. 535.

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This general representation says that output is a function of (depends on) capital and labor inputs. The assumptions behind this statement are that only the most efficient production possibilities are considered, thus only the maximum possible outputs are given for any combinations of labor and capital, and that the technological possibilities are taken as fixed for that point in time.

An invention or a new method of production will <u>change</u> any given production function. The production function is usually shown as a set of curves, called isoquants, on a two-dimensional graph such as the following (Figure 5-a). Each isoquant shows that many different efficient combinations of the factor inputs can produce a given output. If capital (K) and labor (L) are shown on the axes, then each isoquant line such as A represents one possible amount of output, Q. For example, if A represents 1000 units of output, then the relationship represented in Figure 1 shows that 1000 units of output can be produced by using 100 units of capital and 20 units of labor in the most efficient way then known, <u>or</u> by using 75 units of capital and 30 units of labor in the most efficient way, or by any other indicated possible combination of capital and labor. However, 1100 units (shown by isoquant B) cannot be produced except by using more inputs than possible on line A.

ISOQUANTS ILLUSTRATING PRODUCTION FUNCTIONS

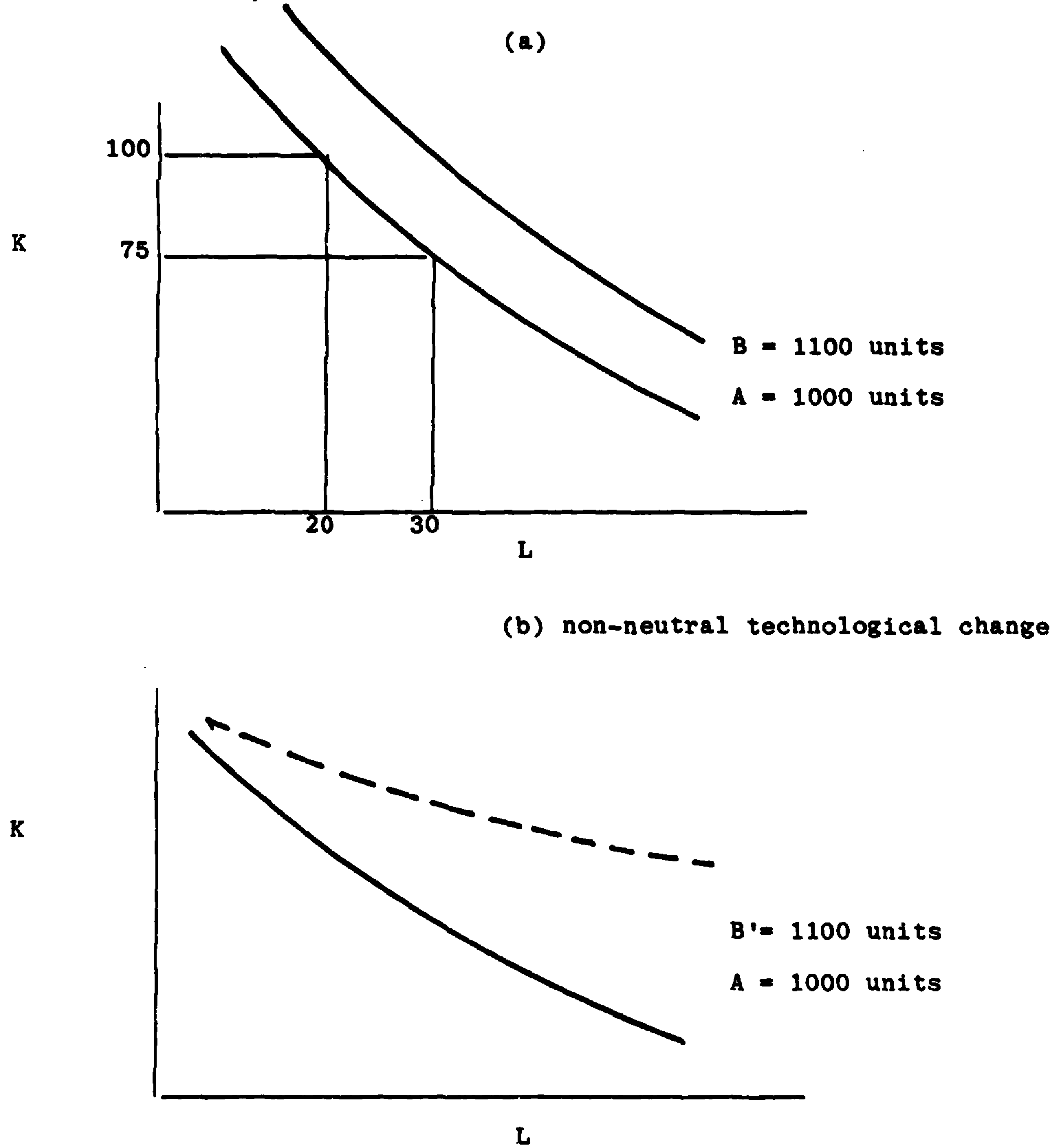

Figure 5

ACUMENICS

Thus we see that, in the general abstract case, capital can substitute for labor (or vice versa) in various efficient methods of production. (Of course the production method chosen will depend on the relative prices of the inputs, but that does not concern us here). More output requires an increase in inputs, given the technology.

When a technological change of any sort occurs, such as a new invention, a new method of production, a new management technique, etc., the production function will be shifted. Increases in output due to the change will now be possible at least for some factor input combinations. A useful concept in this regard is that technological change can be neutral or non-neutral, depending on whether the change affects the relationship between the inputs or not.

> A neutral change neither saves nor uses labor; it is one which produces a variation in the production relation, itself, but does not affect the marginal rate of substitution of labor for capital. A non-neutral technological change alters the production function and can be either labor-saving (capital-using) or capital-saving (labor-using). If the production function is altered such that the marginal product of capital rises relative to the marginal product of labor for each combination of capital and labor, there is said to occur a capital-using (labor-saving) technological change.[4]

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[4]Brown, op. cit. pages 20-21.

The nature of technological change may be intuitively understood by looking at Figure 5 (a) and (b). In Figure 5a, a neutral technological change would mean that the output (1100) previously possible from the various factor combinations shown by isoquant B can now be produced, say, with the factor combinations indicated by the old isoquant A. In other words, the same factor inputs now can produce more output than before, and if more of one factor is used, less of another is needed; the marginal rate of substitution between capital and labor remains the same.

A non-neutral technological change can be illustrated by Figure 5b, where before the change, 1100 units of output are possible from *any of the factor* combinations shown on isoquant B'. After the technological change, 1100 units are now possible from the various factor combinations shown on A; however, the marginal rate of substitution of capital for labor is different on the two isoquants, A and B'.

Murray Brown has found the production function to be a useful tool in the measurement and analysis of technological change. He develops the concept of 'an abstract technology,' and states, "It is relatively easy to define a technological change in terms of a change in the characteristics of an abstract technology."[5] That is, if a production function relationship is shown to change

[5]Page 12.

over time in certain ways as we shall see below, the changes can indicate and to some extent quantify the type and effect of the technological change that is occurring.

The four characteristics of interest in measuring and analyzing technological change are: (1) the efficiency of a technology (2) the degree of economies of scale that are technologically determined; (3) the degree of capital intensity of a technology and (4) the ease with which capital is substituted for labor.[6] Brown's definitions, which are useful, follow.[7]

> (1) Efficiency -- This characteristic ... enters only the relationship between inputs and outputs; it does not affect the relationship of inputs to inputs. For given inputs, and given the other characteristics of an abstract technology, the efficiency characteristic determines the output that results. If it is large, then output is large. ... One can think of ... (it) ... as a scale transformation of inputs into output.
>
> (2) Technologically determined economies of scale -- For a given proportional increase in all inputs, if output is increased by a larger proportion, the firm enjoys increasing returns (or economies of scale); if output is increased by the same proportion, there are constant returns to scale; and if output is increased by a smaller proportion, decreasing returns result (or diseconomies of scale).[8]

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[6] Ibid.

[7] Ibid. pages 13-19.

[8] Economies of scale are often further classified as internal economies, which depend on the operation of the individual firm, and external economies, which depend on the general development of the industry or the economy as a whole.

(3) Capital intensity -- Degrees of capital intensity are reflected in the size of the labor-capital ratios for given relative factor prices.[9]

(4) The ease with which capital is substituted for labor -- The elasticity of substitution ... ( ) ... tells us how rapidly diminishing returns set in to one factor of production ... (it) ... relates the proportional change in the relative factor inputs to a proportional change in the marginal rate of substitution between labor and capital ... Intuitively, it can be thought of as a measure of the ease of substitution of labor for capital; it can also be conceived of as a measure of the 'similarity' of factors of production from a technological point of view.[10]

Changes in the efficiency of technology and changes in economies of scale may be thought of as producing neutral technological change. Changes in the capital intensity of a technology and in the ease of substitution of capital for labor produce non-neutral technological change.[11]

Cobb-Douglas Production Function

The Cobb-Douglas Production Function and the Measurement of Technological Change:

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[9]Usually capital intensity is thought of as the quantity of capital relative to the quantity of labor, or the capital-labor ratio. Brown wishes to emphasize the necessity of eliminating the influence of relative factor price in the short run, on this ratio.

[10]The concept of "constant elasticity of substitution," whereby this measure does not vary over the possible production process, will be important below. The Cobb-Douglas and, of course, the CES production functions both assume a constant elasticity of substitution.

[11]*Ibid*. page 21.

The generalized expression of a Cobb-Douglas production function is

$$Q = AK^{\alpha} L^{\beta}$$ [12]

where, again, Q = output, K = capital, and L = labor. A, α and β are constants to be determined empirically, and depend, of course, on the technology. The Cobb-Douglas formulation of the production function is easily reformulated in logarithmic form:

$\ln Q = \ln A + \alpha \ln K + \beta \ln L$. One reason for the wide use of this formulation is that it can then be applied in a straightforward manner to the available data, using least squares regression techniques. Again, note that the Cobb-Douglas function is a special case of the CES production function, which will be discussed further below.

Of interest for our purposes is the interpretation of these parameters A, α , and β , as indicators of technological change. Following Brown's schema (pp. 40 ff), the interpretation follows.

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[12] More properly, in a Cobb-Douglas production function, the restriction that ($\alpha + \beta = 1$) is imposed, and the function can also be written $Q = AK^{\alpha} L^{(1-\alpha)}$. This is a "linearly homogeneous production function of degree one," which means that if K and L are increased by p percent, Q will also increase by exactly p percent (that is, p^1 percent!). In the more general case, if ($\alpha + \beta = r$), a linearly homogeneous production function of degree r will mean that if K and L are increased by p percent, Q will be increased by p percent. See Chiang, <u>op. cit.</u> p. 406 ff.

(1) Efficiency: This characteristic is indicated by A. A change in A would indicate neutral technological change. A proportional increase in A will increase output in the same proportion.

(2) Non-neutral technological change:

(a) Factor-saving or factor-using technological gains are indicated by the direction of change in the ratio, α/β . If α rises relative to β , then a capital-using technological change has occurred.[13]

(b) Variations in the elasticity of substitution between labor and capital, σ , would also result in a non-neutral technological change, but in a Cobb-Douglas function is always unity and thus unchanging.

Tinbergen Formulation of the Cobb-Douglas Production Function:

In order to capture a neutral rise in efficiency over time in a way that was easily quantified,[14] Professor Tinbergen suggested and applied the following formulation of the Cobb-Douglas Production function:

$$Q = AK^{\alpha} L^{\beta} e^{yt}$$

Where e is an estimate of "the productivity advance coefficient."[15] the term e^{yt} can be thought of as a 'trend term' and has proven useful to analysis.

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[13]If the reader does refer to Brown, op. cit., please note that he uses slightly different terminology than this section, and particularly, he reverses the exponents α and β. Exponents have been made consistent throught this paper.

[14]That is, this formulation can also be readily converted to logarithmic form and applied to time-series data using least squares regression techniques.

[15]Brown, op. cit. p. 111.

CES Production Functions

The generalized form of a constant elasticity of substitution (CES) production function is

$$Q = A\,[\,\delta K^{-\rho} + (1-\delta)L^{-\rho}]^{-v/\rho}$$

(Where $A > 0$; $\delta > 0$; $\rho > -1$). While this function assumes the elasticity of substitution is constant, it is not restricted to one or any particular value. However, this formulation is, according to Brown, statistically "relatively unmanageable,"[16] and it has not been used in the present study. It has already been noted that the Cobb-Douglas production function used is a special case of the CES production function, where the elasticity of substitution is constant and unitary.

Of interest for our purposes is the meaning of the coefficients in this formulation for understanding and attempting to measure technological change. Admittedly, the meanings are somewhat flawed in some cases. Again following Brown and Chiang the following interpretations are suggested.

(1) Efficiency is again represented by A: it indicates the state of technology.

(2) Capital intensity is represented by δ. δ has to do with the relative factor shares in the product.

[16]Ibid. p. 128. For one thing, it is difficult to generalize to more than two factors of production; also, the statistical application is considerably more cumbersome. The logarithmic form does not yield an expression that can be evaluated by direct application of least squares regression techniques. For further discussion of these and other problems, see Brown, esp. Chapter 9.

(3) The degree of returns to scale is represented by v. It should be noted that v can change for two reasons, an expansion in the scale of operations or a technological change that alters the rate of growth; v does not distinguish between the two causes.

(4) The ease of substitution of capital for labor is indicated by ρ. If the elasticity of substitution is σ, $\rho = -(1-1/\sigma)$[17]

Summary

Although the abstractions necessary to quantify a production function necessarily entail some deficiencies in the final formulation,[18] the concept of a production function has proved fruitful for the analysis and measurement of the economic effects of technological change. In particular, the Tinbergen version of the Cobb-Douglas production function has been found both quantifiable and useful. This formulation was found to be relevant to the present study since the data exploration indicated that its use was appropriate. The Tinbergen-Cobb-Douglas production function formulation was used throughout.

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[17]Chiang, p. 419, shows that if $-1 < \rho < 0$, then $\sigma > 1$
if $\rho = 0$, then $\sigma = 1$
if $0 < \rho < \infty$, then $\sigma < 1$.

[18]The reader is referred to the works referenced here, or other intermediate economics texts, for a full discussion of the deficiencies of the Cobb-Douglas production function. Of course it is clear that the pre-specification of a unitary elasticity of substitution might be a drawback; however, this specification often fits the data well. Other statistical problems, such as collinearity, can arise when it is applied to time series data; these may be reduced by the use of the trend term in the Tinbergen specification. And finally, any interpretation of the meaning of the coefficients can be open to discussion, given the present state of knowledge in this field. This section did not attempt to discuss many other interesting aspects of production functions, such as their use in examining factor shares of income.

VII. ANALYTIC APPROACH TO IMPACT ESTIMATES

As noted above, the major impacts of new communications technology can be measured either in terms of personnel or capital requirements. As such, it seems reasonable that the magnitude of such impacts could be estimated using a production function formulation. The two basic production function formulations were reviewed by the project team. The team determined that the Cobb-Douglas formulation would be used owing to the relative ease of computation. The basic data for estimating industry, capital and labor requirements exist in the form of forecast variables under each scenario. The capital requirements for the agency were forecast using the OS or cost model, FAA forecast, and extrapolation of the FAA master equipment log.

The Tinbergen formulation of the Cobb-Douglas Production function was used in the present effort.[19] The Tinbergen formulation provides a means to account for the effects of time in the computation of labor and capital coefficients. As such, the Tinbergen formulation is consistent with the data available, i.e. time-series forecasts for the estimation of capital and labor coefficients.

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[19] Murray Brown, On the Theory and Measurement of Technological Change. (Massachusets, 1968) pp.111ff. Also see preceding Chapter VI.

The general Tinbergen model is

$$Q = AK^{\alpha} L^{\beta} e^{yt}$$

where

Q = product
K = capital
L = labor
t = time
A, α, β, y are empirically determined coefficients.

The two major components of the airspace system are terminal areas and en route airspace. The users of such airspace are different. That is, terminal areas are used by general aviation, airtaxis, commuters, corporate aircraft as well as aircarriers. En route airspace is used predominately by aircarriers, commuters and corporate aircraft. As such, it was determined that separate production functions would be estimated for en route and terminal airspace. In addition two sets of production functions must be examined for each portion of airspace: system users and providers of service. The basic aggregate measure of product in a terminal area is total operations (TOPS). TOPS are comprised of local operations (LOPS) and itinerant operations. The user capital in the terminal area includes the active general aviation fleet, (GACAP) as well as the aircarrier fleet capital (TACAP). The labor component of the user includes the total pilots active in the terminal area (TPLT). The generic user production function in the terminal area can be specified as follows:

$$TOPS = A(TCAP)^{\alpha} \quad (TPLT)^{\beta} \quad e^{yt}$$

where TCAP = P(GACAP) + R(TACAP).

and P, R are the relative cost of the capital units. The agency or services providers generic production function also uses TOPS as the product. However, capital (CTERM) is defined as the consumed value of agency communication facilities in the area. Labor is defined as the array of government personnel, primarily controllers (TERM), necessary to manage TOPS. The generic agency production function is

$$TOPS = A\ (CTERM)^{\alpha} \quad (TERM)^{\beta}\ e^{yt}.$$

The use of en route airspace is dominated by aircarrier operations. As such the capital and labor attendant to such use is embodied in the aircarrier fleet and the transport pilots (TRANP). The measure of product in en route airspace is aircraft handled (AIRHAND). The estimate of en route product or workload is based on the number of IFR Departures (TIFRDEP) and overs (OVERS). As such the generic production function for en route space users is:

$$AIRHAND = A(TACAP)^{\alpha} \quad (TRANP)^{\beta} \quad e^{yt}.$$

where TRANP = transport pilots and TACAP = aircarriers fleet capital.

The agency and user production function employ the same measure of product, i.e., AIRHAND. The agency measure of capital is the consumed quantity of technology necessary to service AIRHAND (CCENT). The labor component of the production function is the number of agenc personnel necessary to perform center(en route facilities)functions (CENT). The generic agency en route production function is:

$$AIRHAND = A(CCENT)^{\alpha} \ (CENT)^{\beta} \ e^{yt}$$

It should be noted that user and agency production functions are estimated for each scenario. The effects of new technology are considered by estimating production functions constructed for the following time periods:

1981 - 1990

1991 - 2000

2001 - 2010

2011 - 2020

The actual estimates were prepared using a log linear form of the production function, i.e.,

$$\ln(TOPS) = \ln A + \alpha \ln(CTERM) + \beta \ln(TERM) + yt.$$

During the curve fitting exercise certain restrictions were imposed:

$$\alpha + \beta = 1,$$

$$\alpha > 0,$$

$$\beta > 0,$$

The log linear user production function and appropriate statistics for each scenario are shown in Tables 12 - 14.

It has been assumed in this analysis that the largest individual unit effects of technology will accrue to the agency. In addition, new technology adopted by users will be compatible with agency investments. That is, users will not invest in new

TABLE 12

USER PRODUCTION FUNCTION COEFFICIENTS

STAGFLATION

TERMINAL

ln (TOPS) = ln A + α ln (TCAP) + β ln (TPLT) + γt				
YEARS	INTERCEPT	TCAP	TPLT	$e^{\gamma t}$
1991 - 2000	1.2185	.2879	.7120	.0026
2001 - 2010	1.4937	.2744	.7255	-.0016
2011 - 2020	2.0060	.2365	.7634	-.0042

CENTER

ln (AIRHAND) = ln A + α ln (TACAP) + β ln (TRANP) + γt				
YEARS	INTERCEPT	TACAP	TRANP	$e^{\gamma t}$
1991 - 2000	6.2161	.0111	.9888	-.0169
2001 - 2010	4.6011	.1254	.8745	-.0134
2011 - 2020	.6652	.4070	.5929	-.0050

TABLE 13

USER PRODUCTION FUNCTION COEFFICIENTS

RAPID GROWTH

TERMINAL

$$\ln(\text{TOPS}) = \ln A + \alpha \ln(\text{TCAP}) + \beta \ln(\text{TPLT}) + \gamma t$$

YEARS	INTERCEPT	TCAP	TPLT	$e^{\gamma t}$
1991 - 2000	1.4506	.2870	.7329	.0001
2001 - 2010	1.5950	.2544	.7455	.00005
2011 - 2020	1.6870	.2464	.7535	.00003

CENTER

$$\ln(\text{AIRHAND}) = \ln A + \alpha \ln(\text{TACAP}) + \beta \ln(\text{TRANP}) + \gamma t$$

YEARS	INTERCEPT	TACAP	TRANP	$e^{\gamma t}$
1991 - 2000	-4.1450	.7357	.2642	.0013
2001 - 2010	-3.4733	.6871	.3128	.00006
2011 - 2020	-3.0496	.6550	.344044	.00003

TABLE 14

USER PRODUCTION FUNCTION COEFFICIENTS

BALANCED GROWTH

TERMINAL

ln (TOPS) = ln A + α ln (TCAP) + β ln (TPLT) + yt

YEARS	INTERCEPT	TCAP	TPLT	e^{yt}
1991 - 2000	1.117	.2879	.7120	.0066
2001 - 2010	1.3506	.2744	.7256	.0029
2011 - 2020	1.8958	.2365	.7634	.0000

CENTER

ln (AIRHAND) = ln A + α ln (TACAP) + β ln (TRANP) + yt

YEARS	INTERCEPT	TACAP	TRANP	e^{yt}
1991 - 2000	1.6980	.31945	.68055	-.0040
2001 - 2010	2.4275	.27002	.7299	-.0061
2011 - 2020	4.2089	.1455	.8544	-.0090

technology that cannot be employed in the airspace system. As such, the characteristics of the technology forcasted in previous sections of this effort will weigh most heavily in the coefficients of the agency production functions. The one technology characteristic that is likely to alter the division of labor in function performance is speed in data processing. That is, system speed will allow greater substitution of capital for labor in many of the functions specified in preceding sections of this work. The agency production functions will be specified based upon the technology forecast parameters, rather than forecasts of activity measures. In particular, production function estimates were determined for one scenario, i.e., stagflation.

It was assumed that the continued presence of existing agency technology beyond 1990 would represent conditions under the stagflation scenario. As such, agency production functions were estimated for the time period 1971-1981. As indicated before the functions of interest are

$$AIRHAND = A\,(CCENT)^{\alpha}\,(CENT)^{\beta}\,e^{yt}$$

$$TOPS = A\,(CCTERM)^{\alpha}\,(TERM)^{\beta}\,e^{yt}$$

The estimates were based on the log linear form of the relationship.

$$\ln(AIRHAND) = \ln A + \alpha \ln(CCENT) + \beta \ln(CENT) + \gamma t$$

$$\ln(TOPS) = \ln A + \alpha \ln(CTERM) + \beta \ln(TERM) + \gamma t.$$

As noted above, the coefficients for the agency production function were altered based upon the relative increase in speed of VLSI data processing equipment projected in the technology forecast. The basic data processed are shown in Table 15. If stagflation is taken as the base case, i.e., stagflation = 1.00 then equivalent values for balanced growth and rapid growth are 1.05 and 1.15, respectively. That is, the net efficiency under balanced growth will be 5% greater than under stagflation. Under rapid growth the speed will be 15% greater than under stagflation. As such, one would expect similar differences in the production function capital coefficients for the balanced and rapid growth scenario when compared to the stagflation scheme. The agency log linear production function coefficients for each scenario are presented in Table 16. The application of the production functions will be described in the next section.

TABLE 15

VLSI DATA PROCESSING CHARACTERISTICS

SPEED (MIPS)

YEARS	BALANCED GROWTH	STAGFLATION	RAPID GROWTH
1980	3.1	3.1	3.1
1985	7.8	6.9	9.8
1990	15.6	13.2	20.99
2000	41.7	37.78	47.22

YEARS	BALANCED GROWTH	STAGFLATION	RAPID GROWTH
1980	1.0	1.0	1.0
1985	1.13	1.0	1.42
1990	1.18	1.00	1.59
2000	1.10	1.00	1.24
Average	1.10	1.00	1.31
Net Relative 50% Efficiency	0.05	0.00	.15

The Use of Production Functions in Estimating Impact Magnitude.

The preceding section has identified means of relating aviation product to the factors of production. Product is defined as either operations for terminal areas or aircraft handled for en route facilities. The equations developed provided for user and agency factors of production. The following equations have been developed according to the generic format for selected time periods under each scenario:

I) Terminals

$$TOPS = A(TCAP)^{B} (TPLT)^{C} e^{yt}$$

$$TOPS = D(CTERM)^{E} (TERM)^{F} e^{zt}$$

II) Centers

$$AIRHAND = G(TACAP)^{H} (TRANP)^{I} e^{wt}$$

$$AIRHAND = J(CCENT)^{K} (CENT)^{L} e^{rt}.$$

In as much as the dependent variables for the user and agency are the same, the factors of production can be examined. For example, for terminal product,

$$A(TCAP)^{B} (TPLT)^{C} e^{yt} = D(CTERM)^{E} (TERM)^{F} e^{zt}.$$

If the user factors of production, and the agency capital investment are provided, then one can estimate the agency labor, i.e., number of controllers. Or, if CTERM, TERM, and TPLT are specified the number of aircraft serviced can be estimated. Since the major

TABLE 16

AGENCY PRODUCTION FUNCTION COEFFICIENTS TERMINAL: 1991-2020

ln (TOPS) = ln A + α ln (CTERM) + β ln (TERM)			
SCENARIO	INTERCEPT	ln (CTERM)	ln (TERM)
STAGFLATION	5.836028	.186336	.338924
BALANCED GROWTH	5.836928	.195653	.329607
RAPID GROWTH	5.836928	.204970	.320270

CENTER

ln (AIRHAND) = ln A + α ln (CCENT) + β ln (CENT)			
SCENARIO	INTERCEPT	ln (CCENT)	ln (CENT)
STAGFLATION	2.109721	.440310	.319192
BALANCED GROWTH	2.109721	.462326	.297176
RAPID GROWTH	2.109721	.484341	.275161

individual impact will accrue to the agency, the relationships will be used to estimate the impact of

1) varying capital intensity on the number of controllers

2) varying number of controllers on capital intensity.

VIII. SPECIFIC EFFECTS

As noted above, the primary effect of communication technology will be to change the division of labor between man and machine. As such, the functions performed by man and machine will be automated further.

It seems reasonable that the technology adopted by the agency will influence that used by the industry. That is, industry will use technology compatible with that adopted by the agency. Such industry use will be accomplished voluntarily and/or by regulation. Therefore, the primary impacts of concern here are those occurring to the agency.

The initial result of technological use is to shift responsibility in the performance of funtions. As the machine-man division of labor changes so do the relative composition of the factors of production. Therefore, the net and measurable effects of technological change are:

- o changes in the level and nature of agency capital investment;
- o changes in the magnitude and composition of the agency work force

The present effort will examine the agency impacts for the three principle components of the airspace system:

1) terminal areas,
2) en route facilities, and
3) flight service stations.

A change in the level of capital investment will be estimated based upon the system concept, innovation lag factor, and nature of the technology developed in the technology forecasts. Estimates were prepared based upon an examination of the agency's current agency and historic capital stock, current agency estimates, and other relevant published documents. Capital requirements by year were developed for each scenario.

The agency staff impacts were estimated using production function constructs. Current and historic capital and labor coefficients were estimated. The coefficients were modified based upon a change in the relative efficiency of technology across scenarios. Staff estimates were computed based upon the adjusted production function coefficients. The results are reported in terms of staff magnitude for each scenario, as well as for cross scenario conditions. That is, staff levels have been developed for the following generic cases:

scenario technology = scenario capital = scenario activity
scenario technology = scenario capital ≠ scenario activity

For example, the effects on staff level are estimated where balanced growth activity occurs in conjunction with an investment in rapid growth activity. In addition, staff productivity measures were calculated to place the impact measurement in the appropriate context. The productivity measures estimates vary with the component of the airspace system considered:

System Component	Productivity Measure
terminal areas	total annual operations per terminal staff
en route	total annual aircraft handles per center employee
FSS	total flight services per FSS employee.

An increase or decrease in productivity is measured by changes in the activity per employee measures. The activity per employee measures indicate also the impact of the technology on operations efficiency.

Estimates of the communications load are presented also. Communications load estimates consider the magnitude and composition of messages for the terminal and center components of the airspace system.

IX. CAPITAL COSTS

Introduction

The effects of new communications technology on the air traffic control system have been estimated by assuming that the products of the system (aviation operations) are related to the capital and labor employed according to the following relationship:

$$Q \quad = AK^{\alpha} L^{\beta}$$

where Y represents units of operation, K and L represent capital consumed and labor hours employed respectively, A is a coefficient of efficiency and α and β indicate the elasticity of output with respect to capital and labor. The form of the relationship is that of a Cobb Douglas production function.[20]

The first requirement for using the function in the present context is to estimate the values of its coefficients. Historical data for the period 1970-1980 were available from the FAA on aviation's operations and labor hours. Estimates of capital consumption during the same decade have been prepared in order to calculate values for the coefficients.

The effects of changes in communications technology can be represented as improvements in both the amount of capital employed

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[20]Meghnad Desai, Applied Econometrics (New York: McGraw-Hill Book Company, 1976), pp. 111-112. See also Chapter VI.

to support air traffic control functions and the efficiency with which capital is used. Improvements will be reflected in reduced manpower requirements for the air traffic control system. The plan for the present forecast and assessment effort is therefore to project aviation operations and air traffic control capital investment over the forecast period (1980-2020), and then to derive future manpower requirements using a Cobb-Douglas production function. Aviation operations have been projected by the FAA to 1990, and these estimates have been extrapolated to 2020 for purposes of the present report. It has been necessary to construct projections of capital consumption as well.

This section of the report describes the sources of data and assumptions used to estimate capital consumption during the historical period (1970-1980) and the forecast period (1980-2020). The historical data is described first. Projections for the forecast period are then presented for each of three economic scenarios, identified as stagflation, balanced growth, and rapid growth.

Historical ATC Capital Growth (1970-1980)

Since the focus of this technology forecast and assessment is communications, capital consumption has been estimated for communications related facilities and equipment (F&E) in the air traffic control system. The categories of F&E that have been identified with communication functions are adopted from a recent series of reports on the subject prepared for the FAA.[21] All air traffic control (ATC) facilities and equipment have been assigned to one of the following three areas: terminals, en route centers and flight service stations. The rate of capital consumption for the period 1970 to 1980 has been calculated from historical data on replacement costs and an assumed aggregate useful life of 14 years. The total for all communications related facilities and equipment increased from $125.7 million in 1970 to $275.1 million in 1980. Details for terminals, en route centers and flight service stations are shown in Table 17.

The sources of information for historical F&E costs are summarized in Tables 18, 19, and 20. Terminal facilities and equipment (Table 18) are classified according to function as control (e.g. air traffic control towers), communications (e.g. remote transmitter/receiver facilities), surveillance (e.g. airport surveillance radars), and navigation (e.g. inner, middle and outer radio marker beacons). Facilities and equipment at en route centers (Table 19) are assigned to similar categories under the headings: centers (e.g. air route traffic control centers), communications (e.g. remote center air/ground communications facilities), surveillance

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[21] W. M. Kolb and I. Gershkoff, "FAA Communications Cost Model User's Guide (Revised)," prepared by ARINC Research Corporation for the Office of Aviation Systems Plans, (April 1980).

TABLE 17

ANNUAL CAPITAL CONSUMPTION
AIR TRAFFIC CONTROL, SELECTED FACILITIES AND EQUIPMENT
1970 - 1980
(1979 DOLLARS IN THOUSANDS)

Year	Terminals	En Route Facilities	FSS	Total
1970	36,747	83,968	4,948	125,663
1971	41,524	89,585	5,512	136,621
1972	46,923	95,577	6,139	148,639
1973	53,024	101,970	6,838	161,832
1974	59,918	108,791	7,616	176,325
1975	67,708	116,068	8,483	192,259
1976	72,806	121,340	11,121	205,267
1977	78,289	126,852	14,580	219,721
1978	84,184	132,615	19,114	235,913
1979	90,523	138,639	25,058	254,220
1980	97,339	144,937	32,851	275,127

Source: Tables 2, 3 and 4.

Table 18

Air Traffic Control, Selected Facilities and Equipment
Terminal Replacement Costs

Facilities Equipment	1972 Unit Costs	1972 Inventory	1972 Unit Costs	1975 Inventory	1978 Unit Costs	1979 Inventory
CONTROL						
ATCT	411,000	331	411,000	400	620,000	428
TRACON/TRACAB	661,000	34	611,000	76	881,000	76
TOWB	94,000	20	94,000	202	142,000	303
RBDE	100,000	193	100,000	300	151,000	101
ARTS	664,000	2	655,000	81	980,000	93
CST	687,000	47	687,000	29	1,039,000	5
CTRAC	2,200,000	2	2,000,000	0		
COMMUNICATIONS						
RTR	87,000	483	87,200	737	132,000	791
CKT	50,000	4	50,000	4	76,000	4
FDEP	20,000	72	20,000	106	30,000	211
CMLT	46,000	28	46,300	19	70,000	13
TELEY	100,000	6	100,000	8	151,000	5
SURVEILLANCE						
ASR	600,000	123	644,300	171	975,000	181
PAR	786,000	6	786,000	9	1,189,000	8
NAVIGATION						
FM	12,000	48	12,000	42	18,000	36
H	46,000	170	46,000	•213	699,000	207
HH	35,000	47	85,000	13	130,000	9
LOC	123,000	323	123,000	586	186,000	667
GS	79,000	299	74,100	555	120,000	599
MM	12,000	292	12,000	534	18,000	577
OM	12,000	306	12,000	542	18,000	612
LOM/LMM	18,500	286	18,500	366	28,000	378
LM	7,400	18	7,400	50	11,000	65

(1) Weight average of ARTS II (@ $250,000) and ARTS III (@ $1,078,000).

(2) Four units assigned t CKT per 1972 Aviation Cost Allocation Study.

(3) Nineteen units assigned to en route facilities per 1972 Aviation Cost Allocation Study.

(4) All 123 ASR's are of the types ASR 2-7 having a weighted average cost of $600,000.

(5) Includes all H and HH facilities, those assigned to both en route and FSS facilities. The 1972 Aviation Cost Allocation Study assigned them as follows:

Terminals	H	101	@	$46,000	HH	0	@	$85,000
En Route Facilities	H	58	@	$46,000	HH	47	@	$85,000
FSS	H	11	@	$46,000	HH	0	@	$85,000

(6) Includes RTR's at FSS facilities. Cost is a weighted average cost per 1972 Aviation Cost Allocation Study: FSS 103 units (@ $40,000);

(7) Includes CMLT's at FSS facilities. Cost is a weighted average cost per 1972 Aviation Cost Allocation Study: FSS 4 units (@ $108,000); Terminals 24 units (@ $38,000).

Sources: C. Paul F. Dienemann, et. al., "Aviation Cost Allocation Study: FAA Airport and Airway System cost Element." Prepared for the Office of Policy Review - FAA (Feb. 1972).
Table 2: "Airport Systems Costs".
Table 3: "Terminal Central Systems Costs".
Table 4: "En Route Central Systems Costs".
Table 5: "Flight Service Systems Costs".
Table 6: "Support Systems Costs".

S.A. Klein, S.C. Novikoff and E.M. Bosek, "FAA Communications Cost Model and Projections 1975-2000". Prepared for the Office of Aviation Policy - FAA - by Computer Sciences Corporation (Dec. 1975).
Table B-7: "F & E Average Replacement Costs by Facility Type".
Table 3-2: "Distribution of Facilities by Class by ARTCC -

W.M. Kolb and I. Gershkoff, "FAA Communications Cost Model User's Guide (Revised)". Prepared by ARINC Research Corporation for the Office of Aviation System Plans (April, 1980).
Appendix A: "Facilities and Equipment Cost Allocations".
Appendix D: "Facility Category Descriptions".

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Table 19

Air Traffic Control, Selected Facilities and Equipment
En Route Center Replacement Costs

Facilities Equipment	1972 Unit Costs	1972 Inventory	Unit Costs	1975 Inventory	1978 Unit Costs	1979 Inventory
CENTERS						
ARTCC	13,618,000	25	13,618,000	25	20,599,000	23
CTRB	1,100,000	24	1,100,000	24	1,644,000	25
CCC	—	—	7,500,000	16	11,345,000	20
EDPS (EVS '72)	1,100,000	0	1,100,000	5	49,372,000	1
COMMUNICATIONS						
RCAG	161,000	459	161,000	525	244,000	559
LNKR	33,000	0	33,000	10	50,000	8
LCOT	33,000	106	33,000	108	50,000	84
TROPO	405,000	2	405,000	3	613,000	3
CKT	50,000	1	50,000	1	76,000	1
FDEP	20,000	19	20,000	19	30,000	19
SURVEILLANCE						
ARSR	2,180,000	91	2,180,000	108	3,298,000	102
RMLR	110,000	495	110,000	521	166,000	518
RMLT	108,000	215	108,000	247	163,000	213
BVEC	—	—	80,000	98	80,000	204
CD	—	—	133,000	37	201,000	107
NAVIGATION AIDS						
VOR (VARIOUR TYPES)	248,000	885	248,000	924	374,000	931
VOT	8,000	73	8,000	65	12,000	66
SRA	93,000	13	93,000	18	—	—
MRL	64,000	13	64,000	—	—	

Sources: C. Paul F. Dienemann, et. al., "Aviation Cost Allocation Study: FAA Airport and Airway System Cost Element." Prepared for the Office of Policy Review - FAA (Feb. 1972).
Table 2: "Airport Systems Costs."
Table 3: "Terminal Central Systems Costs."
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S.A. Klein, S.C. Novikoff and E.M. Bosek, "FAA Communications Cost Model and Projections 1975-2000." Prepared for the Office of Aviation POlicy - FAA - by Computer Sciences Corporation (Dec. 1975).
Table B-7: "F & E Average Replacement Costs by Facility Type."
Table B-2: "Distribution of Facilities by Class by ARTCC -

W.M. Kolb and I. Gershkoff, "FAA Communications Cost Model User's Guide (Revised)." Prepared by ARINC Research Corporation for the Office of Aviation System Plans (April, 1980).
Appendix A: "Facilities and Equipment Cost Allocations."
Appendix D: "Facility Category Descriptions."

Table 20

Air Traffic Control, Selected Facilities and Equipment
Flight Service Station Replacement Costs

Facilities Equipment	1972 Unit Costs	1972 Inventory	Unit Costs	1975 Inventory	1978 Unit Costs	1979 Inventory
STATIONS						
FSS	77,000	334	76,500			
IFSS	1,590,000	8	1,590,000		116,000	
IFSR	—	—	795,000		2,405,000	
IFST	—	—	159,000		1,203,000	
CRES	—	—	2,250,000		794,000	
IATSC	2,250,000	2	—		241,000	
AFTN	2,700,000	1	4,992,000		3,403,000	
WMSC	4,992,000	1	20,000		—	
OAW		—			7,551,000	
					30,000	
COMMUNICATIONS						
12CO	158,000	24	158,000	35	239,000	904
LRCO	11,700	484	11,700	587	18,000	581
COMCO	28,000	14	28,000	17	42,000	18
DF	22,000	6	35,900	239	54,000	205
LDA	—	—	100,000	3	17,000	10
SFO	—	—	27,000	77	41,000	128
SSO	—	—	50,000	4	76,000	3

Sources: C. Paul F. Dienemann, et. al., "Aviation Cost Allocation Study: FAA Airport and Airway System Cost Element." Prepared for the Office of Policy Review - FAA (Feb. 1972).
Table 2: "Airport Systems Costs."
Table 3: "Terminal Central Systems Costs."
Table 4: "En Route Central Systems Costs."
Table 5: "Flight Service Systems Costs."
Table 6: "Support Systems Costs".

S.A. Klein, S.C. Novikoff and E.M. Bosek. "FAA Communications Cost Model and Projections 1975-2000." Prepared for the Office of Aviation Policy - FAA - by Computer Sciences Corporation (Dec. 1975).
Table B-7: "F & E Average Replacement Costs by Facility Type."
Table B-2: "Distribution of Facilities by Class by ARTCC -

W.M. Kolb and I. Gershkoff, "FAA Communications Cost Model User's Guide (Revised)." Prepared by ARINC Research Corporation for the Office of Aviation System Plans (April, 1980).
Appendix A: "Facilities and Equipment Cost Allocations."
Appendix D: "Facility Category Descriptions."

(e.g. air route surveillance radars), and navigation (e.g. VHF omnidirectional range facilities). Flight service station F&E costs are assigned either to communications (e.g. remote communications outlets) or to "stations". Under the latter reading are included the weather message switching center and the domestic and international flight service centers (Table 20).

Unit F&E costs are shown in Tables 18, 19, and 20 as they appear in the service reports in terms of either 1972 or 1978 replacement costs. In order to treat the capital cost information from different years on a comparable basis all cost data has been converted to 1979 dollars using the latest revisions to the Communications Equipment Price Index from the Bureau of Economic Analysis of the Department of Commerce.

Facilities and equipment replacement costs have been converted to estimated values for capital consumed (Table 17) by assuming that the average useful life for all units is 14 years. This is consistent with depreciation assumptions adopted in previous studies.[22] Capital cost estimates for the years not reported in the contractors' studies are estimated by interpolation and extrapolation, assuming constant proportional increases or decreases.

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[22] S. A. Klein, S. C. Novikoff and E. M. Bosek, "FAA Communications Cost Model and Projections, 1975 - 2000," prepared for the Office of Aviation Policy of FAA by Computer Sciences Corporation (December, 1975), pp. 3-1, 3-2, and 3-3.

Forecast Period (1980-2020)

Stagflation Scenario: Capital Projections

The basic assumptions concerning ATC facilities and equipment under the stagflation scenario are that no radical new technology is introduced; that conventional technologies and their improvements will determine the shape of the ATC system during the forecast period (1980-2020); and that growth in the replacement values of ATC facilities and equipment will slow down in relation to growth in GNP. Under these assumptions capital consumption has been projected to grow in the stagflation scenario from its 1980 value of $275.1 million to $1329.0 million in 2020. The increase represents an annual compound growth rate of four percent. Details for individual years and for terminals, en route centers and flight service stations appear in Table 21.

Capital growth for the stagflation scenario has been projected for the period 1980 to 1990 by estimating, first, additions to terminal facilities to match demands upon airport capacity and, second, improvements in facilities and equipment throughout the ATC system. The FAA has forecast the number of airports that will exceed their operating capacity over the next decade, and these forecasts form the basis of the additions to terminal capacity from 1980 to 1990.[23] The airports identified in the FAA forecasts have been

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[23]Office of Aviation Policy, Federal Aviation Administration, Terminal Area Forecasts: 1980-1991 (Washington, D.C.; November, 1979), Tables 2, 12, 13, and 14.

TABLE 21

STAGFLATION SCENARIO
ANNUAL CAPITAL CONSUMPTION
AIR TRAFFIC CONTROL, SELECTED FACILITIES AND EQUIPMENT
1980 - 2020
(1979 DOLLARS IN THOUSANDS)

Year	Terminals	En Route Facilities	FSS	Total
1980	97,340	144,936	32,851	275,127
1981	104,796	150,722	36,257	291,775
1982	112,824	156,738	40,016	309,578
1983	121,467	162,994	44,166	328,627
1984	130,772	169,501	48,745	349,018
1985	140,790	176,267	53,800	370,857
1986	151,575	183,303	59,378	394,256
1987	163,187	190,619	65,535	419,341
1988	175,688	198,228	72,330	446,246
1989	189,146	206,141	79,830	475,117
1990	203,636	214,369	88,108	506,113
1991	215,352	218,974	95,523	529,849
1992	227,742	223,679	103,561	554,982
1993	240,844	228,484	112,276	581,604
1994	254,701	233,392	121,724	609,817
1995	269,354	238,406	131,968	639,728
1996	284,851	243,528	143,073	671,452
1997	301,240	248,760	155,113	705,113
1998	318,571	254,104	168,167	740,842
1999	336,899	259,563	182,318	778,780
2000	356,282	265,139	197,661	819,082

TABLE 21
(Continued)

Year	Terminals	En Route Facilities	FSS	Total
2001	368,964	265,217	209,849	844,030
2002	382,097	265,294	222,789	870,180
2003	395,698	265,372	236,527	897,597
2004	409,783	265,450	251,112	926,345
2005	424,370	265,528	266,597	956,495
2006	439,475	265,606	283,036	988,117
2007	455,119	265,684	300,489	1,021,292
2008	471,319	265,762	319,018	1,056,099
2009	488,095	265,839	338,689	1,092,623
2010	505,469	265,917	359,574	1,130,960
2011	510,307	265,917	372,153	1,148,377
2012	515,191	265,917	385,173	1,166,281
2013	520,122	265,917	398,648	1,184,687
2014	525,101	265,917	412,594	1,203,612
2015	530,126	265,917	427,029	1,223,072
2016	535,200	265,917	441,968	1,243,085
2017	540,323	265,917	457,430	1,263,670
2018	545.495	265,917	473,433	1,284,845
2019	550,716	265,917	489,995	1,306,628
2020	555,987	265,917	507,137	1,329,041

assigned to three groups: towered airports ranked among the first 100 in operation, other towered airports, and non-towered airports. These airports are expected to exceed practical annual capacity during the decade, to reach saturation or other constraints or to exceed the initial criteria for tower candidacy. Additions to terminal facilities and equipment for the purpose of meeting forecast demand have been assumed as shown in Table 22a.

Increases in terminal area facilities will be accompanied by increases at enroute centers and flight service stations to provide for larger volumes of traffic. In the period from 1975 to 1979, for example, en route center F&E replacement values increased on average at 89% of the rate of growth of capital in the terminal areas (Table 17). Similarly, the growth in Flight Service Station F&E replacement costs was 221% of the growth of terminal area capital investment for the same years. It has been assumed, therefore, that each one percent increase in growth of terminal area capital from 1980 to 1990 will be accompanied by a 0.89 percent increase in en route center F&E investments and by a 2.21 percent increase in the F&E replacement costs of flight service stations. These additions are assumed to be in the form of conventional technology such as is represented in the F&E replacement cost estimates for 1975 and 1979 in Tables 18 through 20. The additions to facilities and equipment at the en route centers and flight servfce stations that were assumed for the stagflation capital projects are listed in Tables 22b and 22c.

TABLE 22a

STAGFLATION SCENARIO
SUMMARY OF IMPROVEMENTS AND ADDITIONS TO TERMINAL FACILITIES AND EQUIPMENT: (1980 - 1990)
(1979 DOLLARS IN THOUSANDS)

	Total Replacement Value
A. Additions to Facilities at Airports Exceeding PANCAP Limits by 1990	
1. Non-Towered Airports	17,986
2. Towered Airports Not Ranked Among the First 100 in Operations	222,945
3. Towered Airports Ranked Among the First 100 in Operations (52)	170,820
	411,751
Total Additions	
B. Improvements to Facilities by 1990	
1. Automation at Top-Ranked Airports (152)	212,800
2. Automation at Medium Sized Airports (189)	113,400
3. Vortex Advisory Systems	1,292
4. Terminal Information Processing Systems	12,344
5. Discrete Address Beacon Systems (90)	198,000
6. Upgraded Airport Surveillance Radars (181)	333,633
7. Microwave Landing Systems (152) Total	204,925
	1,076,394
Total Improvements	

Source: Figure 1

TABLE 22b

STAGFLATION SCENARIO
SUMMARY OF IMPROVEMENTS AND ADDITIONS TO
EN ROUTE FACILITIES AND EQUIPMENT:
1980 - 1990
(1979 DOLLARS IN THOUSANDS)

		Total Replacement Value
A.	Additions	
	1. Increases in Facilities and Equipment Propotional to Additions to Terminal Areas	524,054
B.	Improvements	
	1. Remote Maintenance Monitoring Systems	98,056
	2. Upgrading Common Digitizers	10,754
	3. Direct Access Radar Channel	8,933
	4. Upgrading Air Route Surveillance Radars	168,198
	5. Discrete Address Beacon Systems	66,000
	6. Electronic Tabular Display Subsystems	45,310
	7. Additional Data Processing Capacity to Meet New Functional Requirements	27,600
Total Improvements		448,013

Sources: Figure 2

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TABLE 22c

STAGFLATION SCENARIO
SUMMARY OF IMPROVEMENTS AND ADDITIONS
TO FLIGHT SERVICE STATION FACILITIES
AND EQUIPMENT
1980 - 1990
(1979 DOLLARS IN THOUSANDS)

A. Additions	
Increases in Facilities and Equipment Proportional to Additions in Terminal Areas	232,590
Total Additions	232,590
B. Improvements	
1. Replacement of Flight Service Stations with Automated Flight Service Stations	435,240
2. Aviation Weather Processors - Direct User Access Terminals	787,039
Total Improvements	1,222,279

Source: Figure 3

Currently the FAA is considering a range of possible improvements to facilities and equipment in the air traffic control system. It has been assumed that in the stagflation scenario the FAA will implement the improvements under consideration for the period 1980 to 1990. The MITRE Corporation has recently surveyed and described the FAA's development plans and this survey[24] has been used to identify the areas in which new technologies will be implemented. In the terminal areas, improvements have been projected in terms of the installation of the following systems:

- Vortex advising systems;
- Low level wind shear alert systems;
- Terminal information processing systems;
- Wake vortex advisory systems;
- Discrete address beacon systems;
- Microwave landing systems; and
- Upgraded airport surveillance radars.

In addition, a number of processors will be added to the data systems at the largest terminals to automate certain data analysis and communication functions. Seven additional processors are assumed for each of the major airports in the stagflation scenario, including analysis of wind shear and vortex data, aircraft location and

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[24]M. Kay and J. Matney, "Definition, Description and Interfaces of the FAA's Development Programs" a report in three volumes prepared by the MITRE Corporation for the Office of Systems Engineering Management of the FAA (September, 1978).

conflict data, digitization of radar data, control of data displays and data entry, and communication of traffic advisories to aircraft. The facilities and equipment required for these terminal area improvements are assigned a replacement cost of $1.1 billion for purposes of the stagflation scenario capital projections, as detailed in Table 22a.

Improvements to facilities and equipment at en route centers have been projected in terms of implementation of the following systems:

- Remote maintenance monitoring systems;
- Direct access radar channels;
- Upgrading air route surveillance radars;
- Upgrading common digitizers;
- Discrete address beacon systems; and
- Electronic tabular display subsystems.

As in the case of the terminal area projections, processors will supplement the data systems of the en route centers to automate several data analysis and communication functions. Six processors have been assumed for the projections to 1990, automating the detection of minimum safe altitudes, flight path conflicts, and flight plan conflicts, the metering of traffic, and the formulation and communication of conflict resolution advisories. The facilities and equipment for these improvements have been assigned a replacement cost of $448.0 million for the purposes of the stagflation capital projections. The details of the cost projections for en route center improvements are listed in Table 22b.

Improvements assumed for the flight service stations consisted of the installation of sixty automated flight service stations, and an automated weather information system with direct user access for all stations. These improvements total $541.00 million over the 1980's, as shown in Table 22c.

Beyond 1990 no comprehensive description of the FAA's capital programs has been discovered. Consequently, it is necessary to base capital projections on assumptions about the rate of growth of total capital investment. Total replacement costs for facilities and equipment in the FAA's air traffic control system grew more rapidly during the 1970's than the gross national product.[25] However, the F&E annual growth rate exhibited a slight declining trend to the extent any trend can be identified. For purposes of capital projections annual growth rates in F&E replacement costs from 1970 to 1980 shown in Table 17, have been fitted to a Linear model, using time as the independent variable. The trend has been extrapolated through the forecast period (1980-2020). For the decades after 1990 the annual growth rate at the mid-point of each decade was adopted as representative of the growth in ATC facilities and

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[25]For example, compare Table 17 of this report with Table 23 of the FAA Aviation Forecasts: FY 1980-1981, Office of Aviation Policy (September, 1979).

equipment investment during that decade. The annual growth rates in total ATC facilities and equipment are therefore assumed to be:

Stagflation Scenario
Total F&E Growth Rates

Decade	Annual Rate of Increase
1990-2000	1.04932
2000-2010	1.03279
2010-2020	1.01627

The rate for the period 1980-1990 forecast by this method is 1.06585, which corresponds closely to the increases resulting from aggregation of the individual improvements and additions actually assumed for the stagflation scenario and shown is Table 22a.

The growth rates beyond 1990 for facilities and equipment in the terminal areas, the en route centers, and the flight service stations have been assumed to bear the same relation to each other as they did in the period 1975 through 1979. That is, each percentage increase in terminal area F&E replacement costs has been accompanied by a 0.89 percent increase in en route center F&E costs, and 2.21 percent increase in flight service station F&E costs.

Finally, the projected F&E values shown in Table 21 represent the amount of capital consumed annually, assuming an average depreciation period of 14 years for all conventional ATC technologies.

Balanced Growth Scenario: Capital Projections

The capital projections for both the balanced growth scenario and the rapid growth scenario are based upon the assumptions about conventional technologies adopted in the stagflation scenario. The projections differ in two principle respects. First, the balanced growth and rapid growth scenarios assume that a satellite - aided communication system will replace conventional navigation and communication technologies. Second, total investments in ATC facilities and equipment grows faster in the balanced growth and rapid growth scenarios than in the stagflation scenario.

For the balanced growth scenario (Table 23) it is assumed that conventional technologies are employed to the year 2000. The decade from 2000 to 2010 will see the gradual replacement of conventional communication and navigational equipment with a satellite-aided system. By 2010 the replacement will be complete. The facilities and equipment affected by the change can be identified by reference to Tables 18, 19 and 20 as follows:

- all the navigation aids associated with the terminal areas (Table 18);
- all but five of the air route terminal control centers and associated equipment (F&E replacement costs under the heading "centers" in Table 19);
- a proportion of the surveillance facilities and equipment associated with the en route centers (18/23, see Table 19);
- all of the navigation aids associated with the en route centers (Table 19);

- all of the communication facilities and equipment associated with the flight service stations (Table 20).
- all of the 318 flight service stations themselves, but no other facilities and equipment categories under the heading "stations" in Table 20.

The projections for capital growth of conventional technology have been reduced to eliminate the replacement values originally associated with these F&E categories and the subsequent growth attributable to them. The reductions can be seen under the headings for terminal areas, en route Facilities and flight service stations from 2000 to 2010 in Table 23. Reductions have been assumed at constant annual proportional rates.

In place of conventional communication and navigation facilities, a satellite system will be implemented in the balanced growth scenario between 2000 and 2010. The system itself will consist of 24 orbiting satellites which locate aircraft by altitude, latitude, longitude and velocity (the GPS system); one communication and data satellite in geosynchronous orbit (the S/D satellite); and associated ground stations and data processing facilities. In Phase I form orbiting satellites will provide limited aircraft positioning information, using communication and data channels leased from commercial satellites. In phase II a system of six orbiting GPS satellites will replace the original four, and an experimental set of geosynchronous satellites will provide communication and data channels. During the course of Phase I and Phase II, the largest 100 terminal areas will receive additional data processing and communication equipment, a network of calibration stations will be established to maintain

TABLE 23

BALANCED GROWTH SCENARIO
ANNUAL CAPITAL CONSUMPTION
AIR TRAFFIC CONTROL, SELECTED FACILITIES
AND EQUIPMENT
1980 - 1990
(2979 DOLLARS IN THOUSANDS)

Year	Terminals	En Route Facilities	FSS	Satellite System	Total
1980	97,340	144,936	32,851	-0-	257,127
1981	106,004	152,244	37,200	-0-	106,004
1982	115,438	159,921	42,125	-0-	317,484
1983	125,713	167,985	47,702	-0-	341,400
1984	136,902	176,455	54,017	-0-	367,374
1985	149,087	185,352	61,169	-0-	395,608
1986	162,356	194,698	69,267	-0-	426,321
1987	176,806	204,516	78,437	-0-	459,759
1988	192,543	214,828	88,821	-0-	496,192
1989	209,680	225,660	100,580	-0-	535,920
1990	228,342	237,039	113,896	-0-	579,277
1991	245,235	251,468	127,678	-0-	624,381
1992	263,377	266,775	143,127	-0-	673,279
1993	282,862	283,013	160,445	-0-	726,320
1994	303,788	300,241	179,860	-0-	783,889
1995	326,262	318,516	201,623	-0-	846,401
1996	350,399	337,905	226,020	-0-	944,324
1997	376,322	358,473	253,368	-0-	988,163

TABLE 23
(Continued)

Year	Terminals	En Route Facilities	FSS	Satellite System	Total
1998	404,162	380,294	284,026	-0-	1,068,482
1999	434,062	403,442	318,394	-0-	1,155,898
2000	466,174	428,000	356,920	-0-	1,251,094
2001	494,746	451,538	397,892	-0-	1,344,176
2002	525,068	476,370	443,567	-0-	1,445,005
2003	557,250	505,568	494,485	-0-	1,554,303
2004	591,403	530,206	551,248	17,429	1,690,286
2005	627,650	559,364	614,527	25,582	1,827,123
2006	666,118	590,126	685,070	37,550	1,978,864
2007	706,945	622,580	763,711	55,115	2,148,351
2008	750,273	656,819	851,379	80,898	2,339,369
2009	796,257	692,940	949,111	118,742	2,557,050
2010	845,059	731,048	1,058,062	117,286	2,808,455
2011	872,417	729,154	936,087	217,791	2,755,449
2012	900,660	727,265	828,174	272,155	2,728,254
2013	929,818	725,382	732,701	340,090	2,727,991
2014	959,920	723,502	648,234	424,983	2,756,639
2015	990,996	721,628	573,505	531,066	2,817,195
2016	1,023,079	719,759	507,391	663,630	2,913,859
2017	1,056,200	717,895	448,898	829,284	3,052,277
2018	1,090,393	716,035	397,149	1,036,288	3,239,865
2019	1,125,693	714,180	351,365	1,294,965	3,486,203
2020	1,162,136	712,330	310,859	1,161,211	3,803,536

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the accuracy to the position measurements of the GPS satellites, and a control center including data processing facilities will be constructed. It is assumed that the Phase I and II programs will be implemented between 2000 and 2010 and that the F&E replacement values will total $1.2 billion in 1979 dollars. Details are shown in Table 23a.

Phase III of the satellite-aided communication and navigation system will be in place by the year 2010. Phase III is the system in its completed form. Additional F&E investments for phase III will include the full complement of 24 GPS satellites, a new S/D satellite, a system of ground stations to allow the satellites and the aircraft to link with the earth, and an expansion in the capacity of the control center (see Table 23a for details). It has been assumed that the F&E costs for the three phases are cumulative. The replacement costs for the facilities and equipment added for Phase III will be approximately $2.3 billion, bringing the total to $3.4 billion.

The rate of capital consumption for the satellite based technologies is more rapid than for conventional technologies. An average useful life of seven years has been assumed, which is consistent with the lives estimated for satellite systems currently in place.[26]

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[26]See for example "RCA Advances Data for Third Domestic Communications Satellite," New York Times (December 5, 1978), p. D7.

TABLE 23a

Capital Cost Assumptions for the Satellite Based Conunications and Navigation System

A. Additions to Facilities and Equipment in the First Decade	
o Phase I - Ground positioning satellite (GPS) system, including four orbiting satellites, delivery, spares and monitoring facilities:(1)	$355 million
o Phase II - GPS system, including six orbiting satellites, delivery, spares and monitoring facilities:	505 million
o Modifications to equipment at 100 largest terminal areas @ $10 million:	100 million
o Development of a 69-transponder surveillance/data (S/D) satellite for use in conjunction with the GPS system: (2)	100 million
o Network of calibration stations (1000 stations @ $50,000 (3):	60 million
o National Control Center for S/D satellite operations and GPS system:	100 million
TOTAL	$1220 million
B. Additions to Facilities and Equipment in the Second Decade	
o Phase III - GPS system, including a full complement of 24 orbiting satellites, with delivery, spares and monitoring facilities:	$2010 million
o Modification to equipment at 300 additional terminal areas, @ $10 million:	300 million
o Delivery of 69-transponder S/D satellite in fully operational form, with spare:	100 million

TABLE 23a (Continued)

Capital Cost Assumptions for the Satellite Based Communications and Navigation System

• Network of ground stations for interconnection of satellite, ground communications networks (1000 stations @ $100,000):	100 million
• Additional capacity for the S/S control center:	50 million
TOTAL	$2460 million

(1) GPS system costs estimates are based upon a contract between Hughes Communication Services, Inc. and the FCC to build and launch four space satellites for communication purposes. The contract includes maintenance, one spare satellite, and two moveable earth stations and extends for a term of five years. See New York Times, (December 5, 1979), page D2.

(2) The RCA Corporation's SATCOM 3 communication satellite has 24 transponders and costs $50 million. To account for the increase in the number of transponders, and the increased complexity of the tasks to be performed, the S/D satellite has been assumed to require $100 million for development and design and $100 million for final delivery, with one spare. See New York Times (December 11, 1980) page A21.

(3) Currently, small receivers for use with RCA's SATCOM system range in price from $10,000 to $40,000 (see New York Times (October 28, 1979) at pp. 34-34) Other reported earth station costs range up to $200,000 per unit. (See for example, New York Times (November 23, 1980). The calibration stations for the GPS system will perform both transmission and receiving functions, and will therefore be more expensive. Likewise the ground stations will perform a range of functions that will increase their costs above the minimum cost for receivers.

The rate of growth in the system has been assumed, for purposes of the balanced growth scenario, to be a function of growth in the Gross National Product. In the period 1970 to 1980 the compound annual growth for ATC facilities was approximately 104.7% of the annual growth for GNP.[27] The average compound annual rate of growth in GNP forecast by the FAA for the balanced growth scenario (i.e. the "baseline" case) is approximately 102.9%. The growth in ATC facilities and equipment in the balanced growth scenario has been projected at a rate proportional to the historical relationship of ATC facilities and equipment replacement costs to GNP. The annual rate used or total F&E replacement costs in the balanced growth scenario is approximately 107.7%.

The growth rates for the terminal areas, en route centers and flight service stations are assumed to bear the same relationship to each other as they did in the stagflation scenario. That is, for each one percent increase in terminal area replacement values, there will be a 0.89 percent increase in values for en route centers and a 2.21 increase in values for the flight service stations. The satellite facilities are assumed to grow at the same rate as the total of the conventional technologies.

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[27]See Table 23 of the FAA Aviation Forecasts: FY 1980-1981, Office of Aviation Policy (September, 1979) extrapolated to 2020 by Acumenics Research and Technology, Inc. See Scenario Volume.

Rapid Growth Scenario: Capital Projections

Capital cost projections for the rapid growth scenario adapt the methods employed in the balanced growth scenario with two modifications. First, it has been assumed that the satellite-based communication and navigation system will replace conventional technology at a very early point in the rapid growth scenario. The satellite system is assumed to be fully implemented by the year 2000. Phase I and Phase II will be implemented between 1980 and 1990, with a total replacement cost of facilities and equipment in 1990 of $1.1 billion. Starting in 1990, conventional navigation and communication facilities, identified in the same manner as in the balanced growth scenario, will be abandoned. In their place the Phase III satellite system will execute ATC navigation and communication functions. The total replacement value of the Phase III satellite system is assumed to be $4.9 billion by the year 2000 in the rapid growth scenario, increased over the values used in the balanced growth scenario in order to relate the difference in GNP growth for the two sets of projections.

The second modification to the assumptions of the balanced growth scenario is that the replacement costs of the ATC facilities and equipment will increase at a compound annual rate of approximately 109.3%. This rate is the product of the average compound increase in GNP assumed for the rapid growth scenario[28] (i.e. 104.3%) and the historical relationship of increases in F&E replacement costs to increases in GNP between 1972 and 1979 (approximately 104.7%).

Growth in conventional categories of ATC facilities and equipment has been apportioned among the terminal areas, en route centers, and flight service stations by the same method used in the stagflation scenario. That is, for each one percent increase in terminal area replacement costs, there is an increase of 0.89 percent in en route center replacement costs, and 2.21 percent for the flight service stations.

Capital consumption has been calculated on the basis of 14 years of useful life for conventional technologies, and seven years useful life for the satellite systems.

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[28]See Table 23 of FAA AVIATION FORECASTS: FY 1980-1981 Office of Aviation Policy (December, 1979) and its extrapolation to 2020. See Scenario Volume.

TABLE 24

RAPID GROWTH SCENARIO
ANNUAL CAPITAL CONSUMPTION
AIR TRAFFIC CONTROL, SELECTED FACILITIES
AND EQUIPMENT
1980 - 2020
(1979 DOLLARS IN THOUSANDS)

Year	Terminals	En Route Facilities	FSS	Satellite System	Total
1980	97,340	144,936	32,851	-0-	275,127
1981	107,212	153,795	38,026	17,429	316,462
1982	118,086	163,197	44,017	21,942	347,242
1983	130,062	173,172	50,951	27,623	381,808
1984	143,213	183,758	58,977	34,775	420,723
1985	157,782	194,990	68,268	43,780	464,820
1986	173,784	206,909	79,023	55,115	514,831
1987	191,409	219,557	91,472	69,386	571,824
1988	210,822	232,978	105,882	87,352	637,034
1989	232,204	247,219	122,562	123,387	725,372
1990	255,754	262,331	141,870	174,286	834,241
1991	276,101	272,441	132,742	200,402	881,686
1992	298,067	282,940	124,201	230,432	935,640
1993	321,781	293,844	116,209	264,961	996,795
1994	347,381	305,168	108,732	304,664	1,065,945
1995	375,018	316,929	101,736	350,317	1,144,000
1996	404,854	329,143	95,190	402,811	1,231,998
1997	437,063	341,827	89,065	463,171	1,331,126

TABLE 24
(Continued)

Year	Terminals	En Route Facilities	FSS	Satellite System	Total
1998	471,835	355,001	83,354	532,576	1,442,746
1999	509,373	368,682	77,972	612,380	1,568,407
2000	549,898	382,890	72,955	704,143	1,709,886
2001	599,206	414,445	83,882	769,325	1,866,858
2002	652,934	448,600	96,445	840,541	2,038,520
2003	711,481	485,571	110,890	918,349	2,226,291
2004	775,277	525,588	127,499	1,003,360	2,431,724
2005	844,794	568,902	146,595	1,096,241	2,656,532
2006	920,544	615,787	168,551	1,197,719	2,902,601
2007	1,003,086	666,536	193,796	1,308,591	3,172,009
2008	1,093,029	721,466	222,822	1,429,727	3,467,044
2009	1,191,038	780,924	256,195	1,562,076	3,790,233
2010	1,297,834	845,282	294,567	1,706,676	4,144,359
2011	1,409,273	911,752	337,504	1,864,662	4,523,191
2012	1,530,281	983,448	386,700	2,037,273	4,937,702
2013	1,661,679	1,060,783	443,068	2,225,862	5,391,392
2014	1,804,359	1,144,198	507,651	2,431,908	5,888,116
2015	1,959,291	1,234,174	581,648	2,657,028	6,432,141
2016	2,127,526	1,331,224	666,432	2,902,988	7,028,170
2017	2,310,207	1,435,906	763,574	3,171,716	7,681,403
2018	2,508,574	1,548,820	874,876	3,465,319	8,397,589

TABLE 24
(Continued)

Year	Terminals	En Route Facilities	FSS	Satellite System	Total
2019	2,723,973	1,670,614	1,002,402	3,786,102	9,183,091
2020	2,957,868	1,801,984	1,148,516	4,136,579	10,044,947

X. AGENCY LABOR IMPACTS

The primary impact of automation on labor is to add or delete personnel. This section of the report will present estimates of the agency labor requirements for each scenario, as well as specified contingencies. These estimates are based on the production functions developed in Chapter VII.

Estimates of terminal staff (TERM) and center staff (CENT) are presented for the years 1990 to 2020 for the stagflation, balanced growth and rapid growth scenarios. The estimates of TERM, as well as CENT are then compared for all scenarios. In addition, estimates for the following options have been prepared:

(1) Staff levels under stagflation capital investment with balanced and rapid growth activity measures;

(2) Staff levels under the balanced growth investment with stagflation and rapid growth aviation activity measures;

(3) Staff levels under the rapid growth investment scenario and stagflation and balanced growth aviation activities.

The Scenarios

The official FAA estimates of staff for the period 1970-1990 are shown in Table 25. The historic data 1970-1990 indicates that the center workforce increased from 10,597 to 10,982 or 3.5%. The terminal staffing increased from 8,569 to 11,859 or 38.3% during the 1970-1979 period. Estimates of staffing from 1980 to 1992 incorporate planned technological shifts. From 1970 to 1992 the increase in terminal staff is from 8,569 to 16,175 or 88.7%. The increase for center staff between 1970 and 1992 is 10,597 to 15,121 or 42.6%.

TABLE 25

CONTROLLER STAFFING

F.Y.	TERMINAL	CENTERS	FSS
1970	8,569	10,597	4,545
1971	9,249	11,328	4,581
1972	9,399	10,772	4,457
1973	9,949	10,682	4,330
1974	10,472	10,764	4,471
1975	10,832	10,813	4,664
1976	11,092	11,000	4,892
1977	11,385	10,981	5,054
1978	11,610	10,954	4,966
1979	11,859	10,982	4,989
1980	12,653	11,532	5,035
1981	12,653	11,688	5,068
1982	13,363	11,833	5,200
1983	13,695	12,338	5,200
1984	13,983	12,734	5,200
1985	14,307	13,198	5,200
1986	14,597	13,538	5,220
1987	14,867	13,849	5,240
1988	15,000	14,131	5,240
1989	15,396	14,358	5,240
1990	15,659	14,613	5,153
1991	15,916	14,894	4,770
1992	16,175	15,121	4,415

A comparison of center and terminal staff with terminal total aircraft operations and center IFR aircraft handles for the 1970-1992 period is shown in Table 26. The terminal staff is expected to increase 88.7% and the operations workload 75.1%. Center staff is expected to increase 46.6% but workload is estimated to enlarge by 103.7%. The tentative conclusions drawn from the FAA forecast and staff level projections is that ceteris paribus the staff magnitude will increase with more aviation activity. However, technological change will cause the center staff levels to grow at a slower rate than terminal staff.

The preceeding statement obtains only when new technology is substituted for extant technology on a continuing basis. If the extant technology is replaced with the same genre of equipment, one would expect labor utilization to be less efficient. Inefficient labor utilization would result in a staff growth rate proportional to activity levels.

The stagflation scenario assumes that the agency capital to 2020 is based on extant technology. As such, the level of capital may increase, but will not impede an increase in agency staff proportional to activity levels. The projected agency impact for 1990 to 2020 is shown in Table 27. It is anticipated that the number of terminal personnel will increase from 15,540 to 17,696 or 13.9%. The size of the center workforce is expected to increase from 14,370 in 1990 to 21,924 in 2020 or 52.5%.

TABLE 26

COMPARISON OF AVIATION ACTIVITY AND STAFF LEVEL INCREASES

FY	STAFF		TERMINAL AIRCRAFT OPERATIONS (MILLIONS)	CENTER IFR AIRCRAFT HANDLES (MILLIONS)
	TERM	CENT		
1970	8,589	10,597	56.2	21.6
1992	16,175	15,121	98.4	44.0
% CHANGE	88.7	42.6	75.1	103.7

TABLE 27

AGENCY STAFF 1980-2000: STAGFLATION SCENARIO

OBS	YEAR	STERM	SCENT
21	1990	15539.4	14369.7
22	1991	15801.5	14768.3
23	1992	16027.5	15123.0
24	1993	16217.2	15433.1
25	1994	16371.0	15698.0
26	1995	16489.4	15917.9
27	1996	16573.2	16093.7
28	1997	16623.4	16226.3
29	1998	16641.5	16317.5
30	1999	16628.8	16368.9
31	2000	16586.8	16382.7
32	2001	16708.7	16841.0
33	2002	16804.8	17277.3
34	2003	16876.0	17691.2
35	2004	16923.4	18083.0
36	2005	16948.1	18453.0
37	2006	16951.2	18801.6
38	2007	16933.8	19129.3
39	2008	16897.3	19436.8
40	2009	16842.9	19725.0
41	2010	16771.6	19994.2
42	2011	16919.9	20253.7

It is expected that terminal staff will increase with activity and center staff will decline under the balanced growth scenario. That is, centers will be more automated than terminals. The expected staffing levels for centers and terminals under the balanced growth scenario is shown in Table 28. The terminal staff is expected to increase from 17,062 in 1990 to 25,131 in 2020 or 47.5%. Owing to automation, the center staff is expected to decrease from 13,434 in 1990 to 4071 in 2020 or -69.7%.

The rapid growth scenario is expected to result in increased terminal staff to accomodate growth. Increased automation will result in decreased center staff. The estimated staff levels under the rapid growth scenario are shown in Table 29. Under rapid growth, terminal staff is expected to increase from 21,636 in 1990 to 31,147 or 43.9%. Center staff is expected to decrease from 10,983 in 1990 to 2,172 in 2020 or-79.4%.

A comparison of terminal and center staff levels across scenarios is shown in Tables 30 and 31. The continued discussion of the staff levels in the context of aviation activity is in a succeeding section.

The Stagflation Option

The following section includes the staff estimates for the following conditions:

(a) The agency capital investment is for extant technology i.e., the capital investment under Stagflation.

(b) Aviation activity levels during the forecast period reflect rapid or balanced growth levels.

TABLE 28

AGENCY STAFF-BALANCED GROWTH

OBS	YEAR	BTERM	BCENT
1	1990	17062.1	13434.3
2	1991	17687.9	13477.4
3	1992	18307.0	13478.4
4	1993	18917.0	13437.9
5	1994	19515.6	13356.5
6	1995	20100.3	13235.6
7	1996	20668.7	13076.8
8	1997	21218.6	12882.0
9	1998	21747.6	12653.6
10	1999	22253.5	12394.1
11	2000	22734.3	12106.0
12	2001	23352.2	11894.8
13	2002	23948.5	11656.3
14	2003	24520.8	11392.7
15	2004	24850.3	10828.8
16	2005	25280.7	10428.2
17	2006	25647.0	9980.9
18	2007	25935.1	9481.8
19	2008	26127.2	8925.2
20	2009	26201.2	8304.9
21	2010	26130.6	7616.4
22	2011	26558.5	7652.1
23	2012	26897.0	7604.3
24	2013	27134.3	7463.5
25	2014	27258.4	7223.4
26	2015	27258.0	6882.4
27	2016	27123.1	6445.4
28	2017	26845.9	5924.4
29	2018	26421.5	5338.2
30	2019	25848.8	4711.4
31	2020	25131.1	4071.2
32	2021	.	.

TABLE 29

AGENCY STAFF-RAPID GROWTH

OBS	YEAR	RTERM	RCENT
1	1990	21636.4	10982.8
2	1991	22467.4	11118.1
3	1992	23250.4	11168.1
4	1993	23982.1	11132.7
5	1994	24659.5	11013.8
6	1995	25280.1	10815.2
7	1996	25841.7	10541.1
8	1997	26342.7	10199.0
9	1998	26781.8	9796.5
10	1999	27158.3	9342.5
11	2000	27471.5	8846.5
12	2001	27984.3	8380.1
13	2002	28457.6	7919.6
14	2003	28891.5	7467.5
15	2004	29286.0	7026.2
16	2005	29641.3	6597.4
17	2006	29957.9	6182.7
18	2007	30236.2	5783.1
19	2008	30476.8	5399.8
20	2009	30680.3	5033.2
21	2010	30847.5	4683.7
22	2011	31021.1	4364.9
23	2012	31160.3	4061.5
24	2013	31265.9	3773.5
25	2014	31339.0	3500.9
26	2015	31380.3	3243.4
27	2016	31391.0	3000.9
28	2017	31371.9	2772.9
29	2018	31324.2	2559.0
30	2019	31246.8	2358.2
31	2020	31147.3	2171.7
32	2021	.	.

TABLE 30

TERMINAL STAFF-ALL SCENARIOS

OBS	YEAR	STERM	BTERM	RTERM
1	1990	15541.4	17062.1	21636.4
2	1991	15803.5	17687.9	22467.4
3	1992	16029.5	18307.0	23250.4
4	1993	16219.3	18917.0	23982.1
5	1994	16373.0	19515.6	24659.5
6	1995	16491.4	20100.3	25280.1
7	1996	16575.2	20668.7	25841.7
8	1997	16625.5	21218.6	26342.7
9	1998	16643.6	21747.6	26781.8
10	1999	16630.8	22253.5	27158.3
11	2000	16588.9	22734.3	27471.5
12	2001	16710.8	23352.2	27984.3
13	2002	16806.9	23948.5	28457.6
14	2003	16878.2	24520.8	28891.5
15	2004	16925.6	24850.3	29286.0
16	2005	16950.2	25280.7	29641.3
17	2006	16953.3	25647.0	29957.9
18	2007	16936.0	25935.1	30236.2
19	2008	16899.4	26127.2	30476.8
20	2009	16845.0	26201.2	30680.3
21	2010	16773.7	26130.6	30847.5
22	2011	16922.0	26558.5	31021.1
23	2012	17056.4	26897.0	31160.3
24	2013	17177.4	27134.3	31265.9
25	2014	17285.6	27258.4	31339.0
26	2015	17381.6	27258.0	31380.3
27	2016	17465.9	27123.1	31391.0
28	2017	17539.1	26845.9	31371.9
29	2018	17601.9	26421.5	31324.2
30	2019	17654.7	25848.8	31246.8
31	2020	17698.2	25131.1	31147.3
32	2021	.	.	.

TABLE 31

CENTER STAFF-ALL SCENARIOS

OBS	YEAR	SCENT	BCENT	RCENT
1	1990	14369.7	13434.3	10982.8
2	1991	14768.3	13477.4	11118.1
3	1992	15123.0	13478.4	11168.1
4	1993	15433.1	13437.9	11132.7
5	1994	15698.0	13356.5	11013.8
6	1995	15917.9	13235.6	10815.2
7	1996	16093.7	13076.8	10541.1
8	1997	16226.3	12882.0	10199.0
9	1998	16317.5	12653.6	9796.5
10	1999	16368.9	12394.1	9342.5
11	2000	16382.7	12106.0	8846.5
12	2001	16841.0	11894.8	8380.1
13	2002	17277.3	11656.3	7919.6
14	2003	17691.2	11392.7	7467.5
15	2004	18083.0	10828.8	7026.2
16	2005	18453.0	10428.2	6597.4
17	2006	18801.6	9980.9	6182.7
18	2007	19129.3	9481.8	5783.1
19	2008	19436.8	8925.2	5399.8
20	2009	19725.0	8304.9	5033.2
21	2010	19994.2	7616.4	4683.7
22	2011	20253.7	7652.1	4364.9
23	2012	20496.3	7604.3	4061.5
24	2013	20722.6	7463.5	3773.5
25	2014	20933.7	7223.4	3500.9
26	2015	21130.2	6882.4	3243.4
27	2016	21313.2	6445.4	3000.9
28	2017	21483.3	5924.4	2772.9
29	2018	21641.3	5338.2	2559.0
30	2019	21787.9	4711.4	2358.2
31	2020	21923.8	4071.2	2171.7
32	2021	.	.	.

In essence, this section considers the impacts if the agency invests technology on the stagflation level and balanced or rapid growth aviation activity occurs.

Estimates of terminal staff requirements are shown in Table 32. If stagflation investment occurs with stagflation growth the terminal staff will increase from 15,541 in 1990 to 17,698 in 2020 or 13.8%. If stagflation investment occurs with balanced growth activity the terminal staff will increase from 19,512 in 1990 to 56,812 in 2020 or 191.2%. In similar, if the stagflation investment occurs with rapid growth activity the terminal staff will increase from 33,522 in 1990 to 138,112 in 2020 or 312%.

Estimates of center staff requirements are shown in Table 33. If the stagflation capital investment occurs with stagflation aviation activity levels, the number of center staff will increase from 14,370 in 1990 to 21,924 in 2020 or 52.6%. If the stagflation capital investment is coupled with balanced growth activity measures then the center staff will increase from 18,812 in 1990 to 67,936 in 2020 or 261.1%. In similar, if stagflation capital is used in conjunction with rapid growth activity the number of center staff would increase from 34,737 in 1990 to 245,218 in 2020 or 605.9%.

TABLE 32

TERMINAL STAFF-ACTIVITY ALL SCENARIOS-STAGFLATION CAPITAL

OBS	YEAR	STERM	STERMB	STERMR
1	1990	15541.4	19511.7	33522
2	1991	15803.5	20419.5	35633
3	1992	16029.5	21335.9	37772
4	1993	16219.3	22258.4	39936
5	1994	16373.1	23183.9	42120
6	1995	16491.5	24109.7	44320
7	1996	16575.3	25032.7	46532
8	1997	16625.6	25949.7	48753
9	1998	16643.6	26857.8	50980
10	1999	16630.9	27753.6	53207
11	2000	16588.9	28634.2	55433
12	2001	16710.8	29838.2	58322
13	2002	16807.0	31044.4	61263
14	2003	16878.2	32249.3	64251
15	2004	16925.6	33449.3	67286
16	2005	16950.3	34641.1	70364
17	2006	16953.3	35821.2	73483
18	2007	16936.0	36986.0	76641
19	2008	16899.5	38132.4	79835
20	2009	16845.0	39256.9	83062
21	2010	16773.8	40356.4	86320
22	2011	16922.1	42011.6	90870
23	2012	17056.5	43673.7	95557
24	2013	17177.5	45339.1	100384
25	2014	17285.6	47004.5	105349
26	2015	17381.6	48666.6	110455
27	2016	17465.9	50321.9	115702
28	2017	17539.2	51967.2	121091
29	2018	17602.0	53599.3	126621
30	2019	17654.8	55215.3	132295
31	2020	17698.2	56812.2	138112
32	2021	.	.	.

TABLE 33

CENTER STAFF-ACTIVITY ALL SCENARIOS-STAGFLATION CAPITAL

OBS	YEAR	SCENT	SCENTB	SCENTR
1	1990	14369.7	18811.5	34737
2	1991	14768.3	19959.7	37579
3	1992	15123.0	21116.4	40507
4	1993	15433.1	22276.0	43517
5	1994	15698.0	23432.5	46603
6	1995	15917.9	24579.8	49761
7	1996	16093.7	25711.9	52984
8	1997	16226.3	26822.6	56268
9	1998	16317.5	27906.4	59607
10	1999	16368.9	28957.3	62996
11	2000	16382.7	29970.1	66430
12	2001	16841.0	31847.4	71954
13	2002	17277.3	33758.5	77782
14	2003	17691.2	35697.5	83921
15	2004	18083.0	37658.6	90380
16	2005	18453.0	39636.0	97167
17	2006	18801.6	41623.8	104292
18	2007	19129.3	43616.0	111763
19	2008	19436.8	45607.1	119587
20	2009	19725.0	47591.6	127775
21	2010	19994.2	49563.7	136334
22	2011	20253.7	51539.5	145331
23	2012	20496.3	53494.9	154724
24	2013	20722.6	55425.1	164521
25	2014	20933.7	57326.4	174733
26	2015	21130.2	59194.6	185368
27	2016	21313.2	61026.7	196436
28	2017	21483.3	62819.4	207945
29	2018	21641.3	64570.1	219905
30	2019	21787.9	66276.4	232325
31	2020	21923.8	67936.3	245214
32	2021	.	.	.

The Balanced Growth Option

This section considers the agency impacts if the balanced growth scenario capital is in place and rapid growth or stagflation aviation activity prevail. Estimates of terminal staff for the above contingency are included in Table 34. If stagflation activity levels occur then the number of terminal staff (BTERMS) will decrease from 13,503 in 1990 to 7,575 in 2020, a change of 43.8%. If the rapid growth scenario activity levels prevail, then the number of terminal staff (BTERMR) will increase from 29,765 in 1990 to 62,647 in 2020, an increase of 110%.

The estimates for center staff are included in Table 35. If stagflation activity levels prevail the number of center staff (BCENTS) will decrease from 10,059 in 1990 to 1,200 in 2020, a change of 87.9%. If rapid growth activity occurs, then the center staff (BCENTR) will decline from 25,981 in 1990 to 16,161 in 2020, a change of 37.7%.

The Rapid Growth Impacts

This section presents the agency impacts if the rapid growth scenario technology is adopted and activity levels are at the balanced growth or stagflation scenario levels. Estimates of terminal staff requirements are presented in Table 36. The number of term staff (RTERMS) for stagflation activity levels will decrease from 9,592 in 1990 to 3,541 in 2020, a change of 63.1%. If balanced growth activity levels prevail, the terminal staff level (RTERMB)

TABLE 34

TERMINAL STAFF BALANCED GROWTH CAPITAL-RAPID AND STAGFLATION ACTIVITY

OBS	YEAR	BTERMS	BTERM[illegible]	BTERMR
1	1990	13503.1	17062.1	29765.9
2	1991	13590.6	17687.9	31355.8
3	1992	13643.2	18307.0	32937.7
4	1993	13661.7	18917.0	34506.5
5	1994	13647.6	19515.6	36058.7
6	1995	13602.2	20100.3	37590.9
7	1996	13527.2	20668.7	39099.5
8	1997	13424.4	21218.6	40581.6
9	1998	13295.8	21747.6	42034.3
10	1999	13143.4	22253.5	43455.0
11	2000	12969.2	22734.3	44841.2
12	2001	12865.8	23352.2	46517.7
13	2002	12742.4	23948.5	48176.4
14	2003	12600.6	24520.8	49814.7
15	2004	12334.7	24850.3	50985.8
16	2005	12122.7	25230.7	52390.0
17	2006	11884.2	25647.0	53691.6
18	2007	11616.4	25935.1	54866.0
19	2008	11315.7	26127.2	55855.0
20	2009	10977.2	26201.2	56625.1
21	2010	10594.7	26130.6	57106.3
22	2011	10426.2	26558.5	58711.7
23	2012	10229.0	26897.0	60167.3
24	2013	10002.1	27134.3	61442.0
25	2014	9744.6	27258.4	62502.7
26	2015	9456.1	27258.0	63315.7
27	2016	9136.6	27123.1	63847.7
28	2017	8786.7	26845.9	64068.5
29	2018	8407.9	26421.5	63952.6
30	2019	[illegible]82.9	[illegible].3	63451.9
31	[illegible]	[illegible]	25[illegible]	63647.5
[illegible]	[illegible]			

TABLE 35

CENTER STAFF BALANCED GROWTH CAPITAL-RAPID AND STAGFLATION ACTIVITY

OBS	YEAR	BCENTS	BCENT	BCENTR
1	1990	10059.4	13434.3	25961.2
2	1991	9751.9	13477.4	26592.3
3	1992	9417.1	13470.4	27133.8
4	1993	9060.2	13437.9	27586.6
5	1994	8686.1	13356.5	27951.3
6	1995	8299.9	13235.6	28232.1
7	1996	7905.8	13076.8	28429.8
8	1997	7508.1	12882.0	28548.2
9	1998	7110.5	12653.6	28590.6
10	1999	6716.2	12394.1	28561.3
11	2000	6328.0	12106.0	28463.4
12	2001	6000.0	11894.8	28547.3
13	2002	5676.8	11656.3	28569.9
14	2003	5360.6	11392.7	28534.0
15	2004	4924.7	10820.8	27730.3
16	2005	4587.6	10428.2	27320.6
17	2006	4250.6	9980.9	26760.9
18	2007	3912.3	9481.8	26050.5
19	2008	3570.8	8925.2	25135.4
20	2009	3224.6	8304.9	23989.8
21	2010	2872.6	7616.4	22581.0
22	2011	2806.0	7652.1	23299.7
23	2012	2713.7	7604.3	23794.4
24	2013	2594.3	7463.5	24013.9
25	2014	2448.0	7223.4	23912.2
26	2015	2276.2	6882.4	23454.1
27	2016	2082.2	6445.4	22623.7
28	2017	1871.2	5924.4	21429.4
29	2018	1650.0	5338.2	19907.9
30	2019	1426.3	4711.4	[illegible]23.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 36

TERMINAL STAFF RAPID GROWTH CAPITAL-BALANCE AND STAGFLATION ACTIVITY

OBS	YEAR	RTERMS	RTERMP	RTERM
1	1990	9591.32	12203.0	21636.4
2	1991	9503.63	12464.1	22467.4
3	1992	9386.30	12703.4	23250.4
4	1993	9241.38	12919.0	23982.1
5	1994	9072.50	13109.4	24659.5
6	1995	8880.41	13273.1	25290.1
7	1996	8667.97	13408.9	25841.7
8	1997	8437.61	13515.7	26342.7
9	1998	8191.75	13592.6	26781.8
10	1999	7932.86	13639.2	27158.3
11	2000	7663.24	13654.9	27471.5
12	2001	7455.21	13768.9	27984.3
13	2002	7240.63	13860.9	28457.6
14	2003	7021.83	13930.7	28891.5
15	2004	6797.82	13978.0	29286.0
16	2005	6572.31	14002.7	29641.3
17	2006	6345.71	14005.1	29957.9
18	2007	6119.12	13985.4	30236.2
19	2008	5893.52	13943.8	30476.8
20	2009	5669.80	13880.8	30680.3
21	2010	5448.75	13797.1	30847.5
22	2011	5239.10	13711.7	31021.1
23	2012	5030.80	13606.6	31160.3
24	2013	4827.38	13482.7	31265.9
25	2014	4628.29	13340.7	31339.0
26	2015	4433.90	13181.6	31380.3
27	2016	4244.51	13096.5	31391.0
28	2017	4060.39	12216.3	31371.9
29	2018	3881.78	12512.1	31324.2

will decrease from 12,203 in 1990 to 12,166 in 2020, a small change of 0.3%.

Center staff requirements are shown in Table 37. If stagflation activity occurs then center staff (RCENTS) levels will decrease from 3,945 in 1990 to 132 in 2020, a change of 96.6%. The center staff level (RCENTB) for balanced growth activity levels will decline from 5,392 in 1990 to 490 in 2020, a change of 90.9%.

Flight Services Station Personnel

The impact of technology on flight service station staff is shown in Table 38. The staff level estimates are for congruent activity and capital. If the existing technology is continued in use under the stagflation scenario, the flight service personnel (SFSS) will increase from 4,714 in 1992 to 22,698 in 2020; a net increase of 382 percent. If the agency went in balanced growth technology, the number of flight service staff (BFSS) will decrease from 4,191 in 1992 to less than 100 in 2020. If rapid growth activity occurs in conjunction with the use of rapid growth technology, the workforce (RFSS) is expected to increase from 1,690 in 1992 to 3,800 in 1992, then decrease to 109 by 2020.

Two non-congruent condition sets of staff estimates are shown in Tables 39 and 40. The data in Table 39 contrasts the following conditions: balanced growth activity with balanced growth technology (BFSS), and stagflation activity with balanced growth technology (BFSSS). As noted above, for the balanced growth, congruent condition staff is expected to diminish from 4,191 in 1992 to less than 100 in 2020.

If balanced growth technology is used with stagflation activity, the FSS will be fully automated by 2003.

If rapid growth technology is fully employed with either balanced growth (RFSSB) or stagflation activity (RFSSS), their flight service stations could be fully automated by 1992.

TABLE 37

CENTER STAFF RAPID GROWTH CAPITAL-BALANCE AND STAGFLATION ACTIVITY

OBS	YEAR	RCENTS	RCENTB	RCENT
1	1990	2944.77	5331.58	10992.8
2	1991	3762.79	5336.60	11118.1
3	1992	3561.34	5245.57	11168.1
4	1993	3344.66	5119.67	11132.7
5	1994	3117.05	4960.89	11013.8
6	1995	2882.87	4772.13	10815.2
7	1996	2645.99	4556.46	10541.1
8	1997	2410.46	4318.31	10199.0
9	1998	2179.69	4061.98	9796.5
10	1999	1956.64	3792.21	9342.5
11	2000	1743.83	3513.82	8846.5
12	2001	1554.68	3255.55	8386.1
13	2002	1382.75	3007.43	7919.5
14	2003	1227.09	2776.40	7467.5
15	2004	1086.67	2544.91	7026.2
16	2005	960.44	2321.45	6597.4
17	2006	847.33	2130.25	6182.7
18	2007	746.27	1941.43	5783.1
19	2008	656.22	1764.94	5399.8
20	2009	576.19	1600.62	5032.2
21	2010	505.22	1448.21	4683.7
22	2011	443.79	1311.33	4364.9
23	2012	389.33	1184.75	4061.5
24	2013	341.18	1068.11	3773.5
25	2014	295.66	960.95	3500.9
26	2015	261.19	862.53	3243.4
27	2016	228.21	773.23	3006.9
28	2017	199.22	691.67	2772.9
29	2018	173.75	617.61	2559.9
30	2019	151.43	550.49	2358.2
31	2020	131.94	489.96	2171.7
32	2021	.	.	.

TABLE 38

FSS PERSONNEL ALL SCENARIOS

OBS	YEAR	SFSS	BFSS	RFSS
1	1992	4714.5	4190.72	1689.73
2	1993	4744.4	3523.48	2386.52
3	1994	4705.9	2907.48	3048.19
4	1995	4602.9	2391.13	3549.68
5	1996	4442.9	1878.79	3800.46
6	1997	4234.0	1473.66	3771.95
7	1998	3985.7	1138.22	3497.88
8	1999	3708.4	866.30	3053.27
9	2000	3411.5	649.42	2525.66
10	2001	3673.4	503.36	2528.58
11	2002	3914.3	384.72	2479.60
12	2003	4129.3	290.43	2383.74
13	2004	4314.0	168.76	2248.29
14	2005	4465.0	115.19	2081.99
15	2006	4579.9	75.96	1894.22
16	2007	4657.0	48.10	1694.24
17	2008	4695.7	29.02	1490.58
18	2009	4696.5	16.52	1290.64
19	2010	4660.3	12.92	1100.36
20	2011	5629.6	24.72	927.93
21	2012	6750.3	59.62	771.43
22	2013	8036.7	119.35	632.48
23	2014	9502.3	192.73	511.62
24	2015	11159.8	245.82	408.44
25	2016	13021.4	245.30	321.90
26	2017	15097.9	192.29	250.54
27	2018	17398.2	120.42	192.62
28	2019	19930.2	61.85	146.08
29	2020	22698.4	26.87	109.85
30	2021	.	.	.

TABLE 39

BALANCED GROWTH CAPITAL-BALANCED GROWTH AND STAGFLATION

OBS	YEAR	BFSS	BFSSS
1	1992	4190.72	351.132
2	1993	3523.48	270.224
3	1994	2907.48	204.945
4	1995	2391.13	155.512
5	1996	1878.79	113.146
6	1997	1473.66	82.456
7	1998	1138.22	59.357
8	1999	866.30	42.230
9	2000	649.42	29.675
10	2001	503.36	21.616
11	2002	384.72	15.564
12	2003	290.43	11.095
13	2004	168.76	6.101
14	2005	115.19	3.949
15	2006	75.96	2.474
16	2007	48.10	1.491
17	2008	29.02	0.858
18	2009	16.52	0.466
19	2010	12.92	0.349
20	2011	24.72	0.639
21	2012	59.62	1.480
22	2013	119.35	2.846
23	2014	192.73	4.420
24	2015	245.82	5.429
25	2016	245.30	5.223
26	2017	192.29	3.952
27	2018	120.42	2.392
28	2019	61.85	1.188
29	2020	26.87	0.500
30	2021	.	.

TABLE 40

RAPID GROWTH CAPITAL-OTHER SCENARIO ACTIVITY

OBS	YEAR	RFSS	RFSSS	RFSSB
1	1992	1689.73	0.177478	2.11543
2	1993	2386.52	0.187452	2.44104
3	1994	3048.19	0.181836	2.57630
4	1995	3549.68	0.163128	2.50498
5	1996	3800.46	0.136331	2.26083
6	1997	3771.95	0.106913	1.90829
7	1998	3497.88	0.079229	1.51731
8	1999	3053.27	0.055850	1.14420
9	2000	2525.66	0.037675	0.82343
10	2001	2528.58	0.031040	0.72189
11	2002	2479.60	0.025264	0.62366
12	2003	2383.74	0.020319	0.53120
13	2004	2248.29	0.016154	0.44625
14	2005	2081.99	0.012697	0.36990
15	2006	1894.22	0.009870	0.30264
16	2007	1694.24	0.007589	0.24448
17	2008	1490.58	0.005774	0.19507
18	2009	1290.64	0.004347	0.15377
19	2010	1100.36	0.003239	0.11978
20	2011	927.93	0.002399	0.09261
21	2012	771.43	0.001760	0.07081
22	2013	632.48	0.001279	0.05356
23	2014	511.62	0.000921	0.04009
24	2015	408.44	0.000657	0.02969
25	2016	321.90	0.000464	0.02177
26	2017	250.54	0.000325	0.01580
27	2018	192.62	0.000226	0.01135
28	2019	146.08	0.000155	0.00806
29	2020	109.85	0.000106	0.00569
30	2021	.	.	.

XI. MEASUREMENT OF PRODUCTIVITY

The basic measure of technology and labor productivity is the system product divided by the labor necessary to provide the product. As noted previously, system product is a function of the factors of production (i.e., labor (L) and capital (C), or $Q = f(C,L)$. The formulation employed in estimating system product is $Q = AC^{\alpha} L^{\beta}$. Thus, the ratio of product to labor provides and indicates the average product as well as the general efficiency of the technology.

The system components, product and labor are:

System Component	Product	Labor
terminals	operations (TOPS)	terminal staff (TERM)
centers	aircraft handled (AIRHAND)	center staff (CENT)
FSS	contacts (CONT)	flight service staff (FSS)

The average product for each component is then:

System Component	Average Product
terminals	TOPS/TERM
centers	AIRHAND/CENT
FSS	CONT/FSS

Both the numerator and denominator of the average product for each system component has been estimated. The numerators are the forecast estimates provided in the scenario section. The denominator projections have been developed using the production function construct.

The average product measure (APM) indicates staff productivity since it indicates the level of product produced by each staff member. The APM also indicates the relative impact of technology since the average reports the productivity of staff for a given technological construct. Thus, the APM indicates for the same time period, whether more or less product is produced under a given technological regime. Thus, if the APM for a given time is the same across scenarios, the technology allows one to accommodate growth, but offers no unit labor savings. However, if the APM is greater under balanced growth then compared stagflation the technology is labor saving. An example of non-labor saving and labor saving APM's are shown in Table 41. The non-labor saving condition occurs when stagflation APM = balanced growth APM = rapid growth APM. The labor saving effect of technology is shown in Row B where stagflation APM ≠ balanced growth APM ≠ rapid growth APM. Under the Row A conditions, the relative effects of balanced and rapid growth technology compared to stagflation technology is 1.00 or

$$\frac{\text{Balanced growth APM}}{\text{Stagflation APM}} = \frac{6000}{6000} = 1.0$$

$$\frac{\text{Rapid growth APM}}{\text{Stagflation APM}} = \frac{6000}{6000} = 1.0$$

The relative efficiency of technology for balanced and rapid growth under row B conditions are:

$$\frac{\text{Balanced growth APM}}{\text{Stagflation APM}} = \frac{8000}{8000} = 1.33$$

$$\frac{\text{Rapid growth APM}}{\text{Stagflation APM}} = \frac{12,000}{6,000} = 2.0$$

TABLE 41

TOPS/TERM

	SCENARIO		
	Stagflation (S)	Balanced Growth (BG)	Rapid Growth (RG)
A	6000	6000	6000
B	6000	8000	12,000

The above indicates that for the given scenario activity levels the staff can produce 1.33 operations under balanced growth for each 1.00 generation for stagflation.

Comparative APM estimates are provided for two generic sets of conditions. A set of estimates is provided where the scenario activity and capital estimates are congruent. For example, stagflation activity and capital were used to estimate staff. The second set of estimates are noncongruent. The estimates examined the impact of using one scenario activity level with another scenario's capital. For example, estimating staff using stagflation activity and balanced growth capital, the second set of estimates provides impact measures for a non-optimal allocation of resources. As such, the second set of estimates provides a basis of comparing the efficiency of different scenario technology using a constant activity basis. Thus, the congruent and noncongruent conditions allow the calculation of a series of if - then estimates. The following provides a summary of the if - then relations.

Congruent

If	S capital	and	S activity	then	S workforce	
If	BG capital	and	BG activity	then	B workforce	
If	RG capital	and	RG activity	then	R workforce	

Noncongruent

If	S capital	and	BG activity	then	S workforce	B
If	S capital	and	RG activity	then	S workforce	R

```
If BG capital and  S activity  then  B workforce S
If RG capital and BG activity  then  B workforce R

If RG capital and  S activity  then  R workforce S
If RG capital and BG activity  then  R workforce B
```

when workforce equals TERM, CENT, FSS as appropriate

The following table provides a summary of the different conditions embodied in congruent and noncongruent estimates.

Congruent

Scenario Conditions	Stagflation (S)	Balanced Growth (BG)	Rapid Growth (RG)
Activity	S	BG	RG
Capital	S	BG	RG

Noncongruent

Scenario Conditions	Stagflation (S)		Balanced Growth (BG)		Rapid Growth (RG)	
Activity	BG	RG	S	RG	S	BG
Capital	S	S	BG	BG	RG	RG

XII. THE IMPACTS IN CONTEXT

The previous sections have presented the impacts of technological change in terms of agency workforce level. This section will view those staff estimates in the context of scenario variables for discrete years. The years of interest are 2000, 2010, and 2020.

Summary statistics for the stagflation, balanced growth, and rapid growth scenarios are presented in Tables 42, 43, and 44. The statistics in the summaries include: total operations, local operations, itinerant operations, aircraft handled, IFR departures, overs, total general aviation (GA) aircraft, single engine GA aircraft, multiple engine GA aircraft, total air carrier, total pilots, private pilots, transport pilots, student pilots, terminal staff, center staff, GNP, DPI and employment. In addition to the descriptive estimates, several descriptive statistics are also provided, including messages/operation, messages/aircraft handled, total operations /aircraft, total operations/terminal staff, total aircraft handled/ center staff, total operations/total pilots.

Stagflation Scenario

The stagflation scenario (Table 42) is a slow growth environment with the agency capital investment based on extant technology. Under the stagflation scenario total annual operations will be 99.9, 107, and 111 million in 2000, 2010, and 2020 respectively. The total aircraft handled will average from 44.4 million in 2000 to

TABLE 42

Stagflation Scenario

TIME/VARIABLE	2000	2010	2020
Total Operations (Millions)	99.918	107.048	110.964
Local Operations (Millions)	32.3	35.1919	37.0913
Itinerant Operations (Millions)	67.6176	71.8559	73.873
Aircraft Handled (Millions)	44.4683	47.3693	48.7322
IFR Departures (Millions)	18.0815	19.4167	20.0594
Overs (Millions)	8.44861	8.76848	8.90390
Total GA Aircraft (Thousands)	287.742	291.412	292.166
Single Engine GA Aircraft (Thousands)	226.229	228.890	229.438
Multi-Engine GA Aircraft (Thousands)	34.5468	40.6088	46.6708
Total Air Carrier	2317.25	2190.15	2063.05
Total Pilots (Thousands)	1153.81	1323.03	1492.25
Private Pilots (Thousands)	469.721	534.468	599.215
Transport Pilots (Thousands)	127.894	161.921	195.948
Student Pilots (Thousands)	256.77	284.486	312.202
Total Flight Service			
Terminal Staff	16588.9	16773.7	17698.2
Center Staff	16382.7	19994.2	21923.8
Messages/Operation	5.91	5.91	5.91
Messages/Handled	6.47	6.48	6.49
GNP (Billions 1972 $)	2006.8	2328.9	2702.8
DPI (Billions 1972 $)	1393.5	1617.2	1876.8
Employment (Millions)	113	118	123
Total Operations/Aircraft	344.47	364.60	377.13
Total Operations/Terminal Staff	6023.18	6381.9	6269.79
Total Aircraft Handled/Center Staff	2714.35	2369.15	2209.12
Total Operations/Total Pilots	86.60	80.91	74.36
2 * IFR Departures/Transport Pilots	141.38	119.91	102.37

48.7 million in 2020. The total general aviation fleet will increase from 287,242 aircraft in 2000 to 292,166 in 2020. The total number of pilots will change from 1,153,810 in 2000 to 1,492,250 in 2020.

The agency staff to accommodate this slow growth will include 16,589 terminal and 16,383 center personnel in 2000, and 17,698 terminal and 21,924 center staff in 2020.

The total operations/aircraft are expected to increase from 344 in 2000 to 377 in 2020. The average workload for agency terminal, i.e., operations/terminal staff will increase from 6,023 in 2000 to 6,269 in 2020. It is anticipated that the workload for center staff (aircraft handled/center staff) will deteriorate from 2,714 in 2000 to 2,209 in 2020.

Balanced Growth Scenario

The balanced growth (Table 43) scenario includes a mixed terrestrial and space based communication system. In addition, the balanced growth scenario expects modest growth in the economy and aviation. Total operations are expected to increase from 120.4 million in 2000 to 165 million in 2020. The number of aircraft handled at centers are expected to increase from 53.6 million in 2000 to 67.9 million in 2020. The GA fleet will increase from 362,471 in 2000 to 412,246 in 2020. The total pilot population will enlarge to 1,729,160 in 2020 from 1,275,200 in 2000.

TABLE 43

Balanced Growth Scenario

TIME/VARIABLE	2000	2010	2020
Total Operations (Millions)	120.385	144.341	164.959
Local Operations (Millions)	38.9481	49.7968	61.3843
Itinerant Operations (Millions)	81.437	94.544	103.575
Aircraft Handled (Millions)	53.5956	62.1904	67.9117
IFR Departures (Millions)	22.3817	26.8072	30.0088
Overs (Millions)	9.2829	9.9363	10.2766
Total GA Aircraft (Thousands)	362.471	396.647	412.246
Single Engine GA Aircraft (Thousands)	279.915	303.785	314.605
Multi-Engine GA Aircraft (Thousands)	42.0431	48.1430	51.9011
Total Air Carrier	3559.3	4001.51	4443.72
Total Pilots (Thousands)	1275.20	1502.18	1729.16
Private Pilots (Thousands)	514.813	600.963	687.113
Transport Pilots (Thousands)	151.517	196.753	241.989
Student Pilots (Thousands)	274.198	310.221	346.244
Total Flight Service			
Terminal Staff	22734.3	26130.6	25131.1
Center Staff	12106	7616.4	4071.2
Messages/Operation	5.9	5.9	5.9
Messages/Handled	6.51	6.6	6.63
GNP (Billions 1972 $)	2700	3600	4700
DPI (Billions 1972 $)	2000	2670	3640
Employment (millions)	126.6	144.1	158
Total Operations/Aircraft	328.89	360.27	395.88
Total Operations/Terminal Staff	5295.24	5523.96	6563.96
Total Aircraft Handled/Center Staff	4427.19	8165.33	16681
Total Operations/Total Pilots	94.4	96.09	95.4
2 * IFR Departures/Transport Pilots	147.72	136.25	124.01

Based upon the aviation activity levels, terminal staff will grow from 22,734 in 2000 to 25,131 in 2020. However, new technology will result in a reduction of center staff from 12,106 in 2000 to 4,071 in 2020.

The average number of operations per aircraft is expected to increase from 329 in 2000 to 396 in 2020. The workload for terminal staff (total operations/terminal staff) will increase from 5,295 in 2000 to 6,564 in 2020. At centers, the workload (air handles/ terminal staff) will increase from 4,427 in 2000 to 16,681 in 2020.

Rapid Growth Scenario

The rapid growth scenario (Table 44) embodies a predominately space based communication system. In addition, aviation activity will experience great levels of growth. Total operations are expected to increase from 150.4 million in 2000 to 222.7 million in 2020. Aircraft handled by centers are expected to increase from 71.1 million in 2000 to 108.4 million in 2020. Similarly, the GA fleet is expected to grow to 640,340 aircraft in 2020 from 457,952 in 2000. The cadre of pilots will increase to 2,550,690 in 2020 from 1,698,560 in 2000.

Terminal staff will increase from 27,471 in 2000 to 31,147 in 2020. However, center staff will decrease from 8,846 in 2000 to 2,172 in 2020.

TABLE 44

Rapid Growth Scenario

TIME/VARIABLE	2000	2010	2020
Total Operations (Millions)	150.437	186.562	222.687
Local Operations (Millions)	41.336	49.6006	57.8676
Itinerant Operations (Millions)	109.103	136.961	164.819
Aircraft Handled (Millions)	71.118	89.785	108.452
IFR Departures (Millions)	29.4194	37.3914	45.3634
Overs (Millions)	10.8517	13.0117	15.1717
Total GA Aircraft (Thousands)	457.952	566.564	640.34
Single Engine GA Aircraft (Thousands)	352.787	435.043	493.184
Multi-Engine GA Aircraft (Thousands)	51.6666	68.1547	83.5728
Total Air Carrier	4782.43	5770.71	6758.98
Total Pilots (Thousands)	1698.56	2124.63	2550.69
Private Pilots (Thousands)	665.257	822.017	978.777
Transport Pilots (Thousands)	230.303	312.521	394.739
Student Pilots (Thousands)	343.372	411.921	480.470
Total Flight Service			
Terminal Staff	27471.5	30847.5	31147.3
Center Staff	8846.5	4683.7	2171.7
Messages/Operation	2.37	2.11	1.93
Messages/Handled	6.33	6.31	6.3
GNP (Billions 1972 $)	3500	5500	8400
DPI (Billions 1972 $)	2440	3830	5830
Employment (Millions)	128	146	163.9
Total Operations/Aircraft	325.10	325.97	344.13
Total Operations/Terminal Staff	5476.11	6047.88	7149.48
Total Aircraft Handled/Center Staff	8039.11	19169.67	49938.76
Total Operations/Total Pilots	88.57	87.81	87.30
2 * IFR Departures/Transport Pilots	127.74	119.64	114.92

The average operations per aircraft will increase from 325 in 2000 to 344 in 2020. Terminal staff workload will increase from 5,476 operations per controller in 2000 to 7,149 operations per controller.

Comparative Measures of Effects

The previous sections present characteristic data for each scenario at three discrete time periods. Incorporated in the characteristic data were estimates for staff levels. However, the prior data considered factors for congruent capital and activity levels. That is, staff were estimated for the following conditions:

Activity	Capital Investment
Stagflation	Stagflation
Balanced growth	Balanced growth
Rapid growth	Rapid growth

However, staff estimates have also been provided for noncongruent activity and capital investment conditions:

Activity	Capital Investment
Balanced growth Rapid growth	Stagflation
Stagflation Rapid growth	Balanced growth
Stagflation Balanced growth	Rapid growth

The purpose of the noncongruent level estimates is to examine the marginal changes in staff for fixed capital investment of one sort and variations in activity levels of a different sort. That is, to determine the effects on staff levels if, for example, the agency invests in balanced growth technology but activity levels are not at balanced growth levels. However, the "raw staff" estimates do not show productivity gains or losses across congruent or noncongruent conditions.

The general trends in the staff estimate data presented previously are:

a. a general increase over time in the number of terminal staff for congruent conditions. The increase can be attributed to widespread system growth and use.

b. a general increase in center staff for stagflation, owing to the relative inefficiency of the extant technology, and a decline in the center staff for balanced and rapid growth scenarios.

Two descriptive statistics provide a means of assessing the impacts of technology: operations/terminal staff (O-T) and aircraft handles/center staff (A-C). The O-T, A-C measures serves as surrogates for the scenario conditions since the averages tend to normalize the growth in activity and staff among scenarios. In general, high productivity results in higher ratios, since each staff member is responsible for more workload. For example, an O-T ratio of 6,023 is more efficient than 5,250, since the proportions are 6,023 operations per staff compared to 5,250 operations per staff. The O-T, A-C measures indicate the consolidation of the productivity gains obtained by altering the factors of production.

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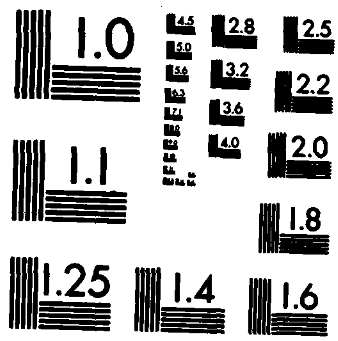

MICROCOPY RESOLUTION TEST CHART
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The relative efficiency of technology for each scenario and congruent conditions are shown in Table 45. The terminal data suggest, ceteris paribus, that the extant technology is as efficient as the new technology until 2012. The optimum efficiency of the balanced and rapid growth technology does not occur until 2020. It should be noted, that the stagflation scenario operations increase 11%, balanced growth 36%, and rapid growth 48% between 2000 and 2020. Thus, the efficiency of the stagflation technology obtains only for low growth rates in operation. The relative inefficiency of new technology in terminal areas is due to the inherent constraints of airports. Excess or increased traffic can be accommodated by other airports in the terminal area.

The center staff estimates of congruent conditions (Table 45) indicates that the stagflation technology is inefficient when compared to the balanced and rapid growth technology. The A-C measures for stagflagation, balanced growth and rapid growth in 2000 are 2714, 4427, 8039, respectively. In 2020 the AC measures for stagflation, balanced growth and rapid growth are 2207, 16,681 and 49,938. Another way of stating the relative efficiency is that in 2000 the balanced growth A-C is 63% greater than stagflation; the rapid growth A-C is 196% greater than stagflation. In 2020 the balanced growth A-C is 655% greater than stagflation; the rapid growth A-C is 2,160% greater than stagflation.

TABLE 45

Impact Measures - Congruent Conditions

Operations/Terminal Staff

YEAR	ACTIVITY LEVEL		
	STAGFLATION	BALANCED GROWTH	RAPID GROWTH
2000	6023	5295	5476
2010	6382	5524	6048
2020	6270	6564	7149

Aircraft Handled/Center Staff

YEAR	ACTIVITY LEVEL		
	STAGFLATION	BALANCED GROWTH	RAPID GROWTH
2000	2714	4427	8039
2010	2369	8165	19,170
2020	2209	16,681	49,938

The Terminal Capital Efficiency

The non-congruent effects of technology are examined in Tables 46, 47, and 48. The O-T and A-C measures presented indicate the efficiency if the technology in place is required to accommodate higher or lower aviation activity levels.

The terminal staff measures indicate that if balanced growth activity occurs using stagflation capital (Table 46) the relative productivity declines. That is, the operations per terminal staff decrease from 6,023 to 3,489 in 2000, 6,382 to 2,652 in 2010, and 6,270 to 1,953 in 2020. If rapid growth activity occurs, then terminal productivity also deteriorates from 6,023 to 1,802 in 2000, 6,382 to 1,240 in 2010, and 6,270 to 803 in 2020. The terminal based diminished productivity obtains also for center staff. That is, if balanced growth activity occurs with staff stagflation capital, then A-C decreases from 2,714 to 1,484 in 2000, 2,369 to 956 in 2010 and 2,209 to 717 in 2020. A similar pattern holds for center staff if rapid growth activity occurs during stagflation. The A-C deteriorates from 2,714 to 669 in 2000, 2,369 to 347 in 2010, 2,209 to 198 in 2020. One may conclude that continued investment in extant technology will not effectively accommodate reasonable growth in aviation activity. As such, the capital investment strategy for stagflation should not be pursued beyond 1990.

TABLE 46

Impact Measures - Stagflation

Operations/Terminal Staff

YEAR	STAGFLATION CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	6023	3489	1802
2010	6382	2652	1240
2020	6270	1953	803

Aircraft Handled/Center Staff

YEAR	STAGFLATION CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	2714	1484	669
2010	2369	956	347
2020	2209	717	198

The relative efficiency of balanced growth technology is shown in Table 47. These data indicate O-T and A-C measures if stagflation and rapid growth activity occur with balanced growth technology in use. In the current context center and terminal staff efficiencies will increase for stagflation activity and diminish for rapid growth aviation activity. If stagflation activity occurs then the O-T will increase from 5,295 to 9,283 in 2000, from 5,524 to 13,623 in 2010, and from 6,564 to 21,776 in 2020. As noted above rapid growth terminal activity will result in diminished efficiency. In particular, O-T will diminish from 5,295 to 2,685 in 2000, from 5,524 to 2,528 in 2010, and from 6,564 to 2,640 in 2020.

The preceding general trend holds for centers. That is, under balanced growth capital investment the efficiency of the technology increases if stagflation activity occurs and decreases if rapid growth activity obtains. With respect to center staff, the A-C measure with stagflation and balanced growth activity will increase from 4,427 to 8,469 in 2000, from 8,165 to 21,646 in 2010, and from 16,681 to 56,218 in 2020. If rapid growth activity occurs then the capacity per unit of balanced growth technology will decrease from 4,427 to 1,883 in 2000, from 8,165 to 2,754 in 2010, and from 16,681 to 4,202 in 2020.

Rapid growth technology will be the most efficient with respect to other scenario activity. That is, rapid growth technology employed in conjunction with stagflation or balanced growth

TABLE 47

Impact Measures - Balanced Growth

Operations/Terminal Staff

YEAR	BALANCED GROWTH CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	9283	5295	2685
2010	13,623	5524	2528
2020	21,776	6564	2640

Aircraft Handled/Center Staff

YEAR	BALANCED GROWTH CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	8469	4427	1883
2010	21,646	8165	2754
2020	56,218	16,681	4202

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activity will increase system productivity. The data for the rapid growth technology non-congruent conditions are shown in Table 48. If rapid growth technology is employed with stagflation at terminal the O-T increases from 5,476 to 19,631 in 2000, from 6,048 to 34,237 in 2010, from 7,149 to 62,888 in 2020. Similarly, if rapid growth technology is employed with balanced growth activity, then O-T increases from 5,476 to 11,017 in 2000, from 6,048 to 13,521 in 2010, from 7,149 to 18,304 in 2020. Similar trends hold with respect to center staff. If stagflation activity occurs with rapid growth technology, the A-C increases from 8,039 to 40,779 in 2000, from 19,170 to 177,792 in 2010, and from 49,938 to 821,606 in 2020. If balanced growth activity occurs with rapid growth technology then A-C increases from 8,039 to 20,238 in 2000, from 19,170 to 62,006 in 2010 and from 49,938 to 221,330 in 2020.

The relative efficiency of the technology for the non-congruent conditions defined in Tables 46 to 48 are shown in Tables 49, 50, and 51. Relative efficiency for a given technological level (i.e., stagflation, balanced growth, rapid growth), is defined as

$$\frac{\text{OT (activity} \neq \text{capital scenario)}}{\text{OT (activity = capital scenario)}}$$

or

$$\frac{\text{AC (activity} \neq \text{capital scenario)}}{\text{AC (activity = capital scenario)}}.$$

The tables are read as follows: if rapid growth activity occurs using stagflation capital then operations/terminal staff will be 30% of the O-T if stagflation activity obtains in year 2000 (See Table 49).

TABLE 48

Impact Measures - Rapid Growth

Operations/Terminal Staff

YEAR	RAPID GROWTH CAPITAL STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	19,631	11,017	5476
2010	34,237	13,521	6048
2020	62,888	18,304	7149

Aircraft Handled/Center Staff

YEAR	RAPID GROWTH CAPITAL STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	40,779	20,238	8039
2010	177,792	62,006	19,170
2020	821,606	221,330	49,938

TABLE 49

Relative Efficiency - Non-Congruent Conditions

Operations/Terminal Staff

YEAR	STAGFLATION CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	1.00	.57	.30
2010	1.00	.42	.19
2020	1.00	.31	.13

Aircraft Handled/Center Staff

YEAR	STAGFLATION CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	1.00	.54	.25
2010	1.00	.40	.14
2020	1.00	.32	.09

TABLE 50

Relative Efficiency - Non-Congruent Conditions

Operations/Terminal Staff

YEAR	BALANCED GROWTH CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	1.75	1.00	.51
2010	2.47	1.00	.45
2020	3.32	1.00	.40

Aircraft Handled/Center Staff

YEAR	BALANCED GROWTH CAPITAL		
	STAGFLATION	BALANCED GROWTH	RAPID GROWTH
2000	1.91	1.00	.42
2010	2.65	1.00	.33
2020	3.37	1.00	.25

TABLE 51

Relative Efficiency - Non-Congruent Conditions

Operations/Terminal Staff

YEAR	RAPID GROWTH CAPITAL		
	STAGFLATION ACTIVITY	BALANCED GROWTH ACTIVITY	RAPID GROWTH ACTIVITY
2000	3.58	2.01	1.00
2010	5.66	2.23	1.00
2020	11.48	3.02	1.00

Aircraft Handled/Center Staff

YEAR	RAPID GROWTH CAPITAL		
	STAGFLATION	BALANCED GROWTH	RAPID GROWTH
2000	5.07	2.51	1.00
2010	9.27	3.23	1.00
2020	16.45	4.43	1.00

or $\dfrac{\text{AC (activity} \neq \text{capital scenario)}}{\text{AC (activity} = \text{capital scenario)}}$.

The tables are read as follows: if rapid growth activity occurs using stagflation capital then operations/terminal staff will be 30% of the O-T if stagflation activity obtains in year 2000 (See Table 49).

XIII. COMMUNICATIONS LOAD

It is anticipated that both terminal area and en route activity will increase under the three socio-economic scenarios. As such, it is reasonable to assume that the message load will increase with shifts in activity level. The differences among scenarios will be the communication magnitude as well as the extent to which messages are automated.

The purpose of this section is to present estimates of the message load at terminal areas and en route centers for each scenario. The basic data for the analysis derives from a study of controller/pilot communications in fourteen terminal radar facilities.[29] The study examined tower voice tapes at selected terminals for discrete time periods. The terminals studied are shown in Table 52.

The reduced data included information on the number of messages per aircraft and message type per aircraft handled. Data were collected for both scheduled (AR) and non-scheduled operations. The types of messages concerned: advisories, vectors, altitude, speed, beacon assignment, radar contact and miscellaneous communication. A summary of the Jolitz data are presented in Table 53.

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[29]Gordon D. Jolitz, "A Sample of Controller/Pilot Communications from Fourteen Selected Terminal Radar Controllers," DOT-FA79-WA-4323, October 27, 1980.

TABLE 52

TERMINAL AREA RADAR CONTROL LOCATIONS

TCA Group I and II

Atlanta, Ga. (ATL)
Washington Nat'l (DCA)
Las Vegas, Nev. (LAS)
Pittsburgh, Pa. (PIT)

TRSA

Phoenix, Az. (PHX)
Baltimore, Md. (BAL)
Dayton, Oh. (DAY)
Burbank, Ca. (BUR)
Wichita, Ks (ICT)
Greensboro, N.C. (GSO)
Peoria, Ill. (PIA)

Stage II Radar Services

Fresno, Ca. (FAT)
Austin, Tx. (AUS)
Monterey, Ca. (MRY)

Source: Jolitz Study

TABLE 53

COMMUNICATIONS DATA SUMMARY

(BASE DATA)

SITE	AC HANDLED			MESSAGE COUNT			ADVISORIES			ADVISORY ALTITUDE		VECTORS		
	AR	GA	TOT	AR	GA	TOT	AR	GA	TOT	KWN.	UNKWN.	AR	GA	TOT
ATL	291	247	538	1750	1844	3613	23	136	159	83	76	407	368	775
DCA	237	235	472	1264	1419	2683	58	77	135	101	34	440	414	854
LAS	178	278	456	829	1518	2347	83	124	207	128	70	149	305	454
PIT	231	254	485	1523	1373	2896	151	125	276	139	137	391	287	678
SUB-TOTAL	937	1014	1951	5385	6154	11539	315	462	777	451	326	1387	1374	2761
% (MESSAGE COUNT)							5.8	7.5	6.7			25.8	22.3	23.9
PHX	150	136	466	778	2038	2916	165	303	468	168	300	102	322	424
BAL	99	352	451	560	1846	2406	72	263	335	153	182	127	298	425
DAY	47	185	232	234	864	1098	23	71	94	41	53	50	198	248
BUR	37	381	418	242	2328	2570	66	472	538	226	312	44	360	404
ICT	42	244	286	280	1904	2184	33	164	197	63	134	66	390	456
GSO	68	380	448	410	2472	2882	25	176	201	60	141	75	469	544
PIA	12	115	127	91	748	839	17	109	126	55	71	23	150	173
SUB-TOTAL	455	1793	2428	2596	12200	14806	401	1558	1959	766	1193	487	2187	2674
% (MESSAGE COUNT)							15.5	12.8	13.2			18.8	17.9	18.0
FAT	15	129	144	84	671	755	17	130	147	43	104	14	58	72
AUS	30	375	405	178	1795	1983	25	203	228	30	198	42	369	411
MRY	16	122	[illegible]	63	730	793	3	120	123	[illegible]	117	15	128	143
SUB-TOTAL	61	626	687	325	3196	3531	45	453	498	79	419	71	555	626
% (MESSAGE COUNT)							13.8	14.2	14.1			21.8	17.4	17.7
TOTAL	1453	3433	5066	8306	21550	29866	761	2473	3234	1296	1938	1945	4116	6061
% (MESSAGE COUNT)							9.2	11.5	10.8			23.4	19.1	20.2

Reference = A sample of Controller/Pilot Communications from Fourteen Selected Terminal Area Radar Control Facilities - Table 2 & 5. (Jolitz; DOT-FA79-WA-4323)

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TABLE 53
(Continued)

COMMUNICATIONS DATA SUMMARY
(BASE DATA)

SITE	ALTITUDE			SPEED			MISCELLANEOUS			BEACON ASSIGNMENT			RADAR CONTACT		
	AR	GA	TOT	AR	GA	TOT	AR	GA	TOT	AR	GA	TOT	AR	GA	TOT
ATL	465	549	1314	220	26	255	161	434	595	5	89	94	98	105	203
DCA	447	400	847	87	30	107	107	280	387	8	61	69	101	88	189
LAS	245	415	660	56	18	74	194	308	502	8	84	92	66	145	211
PIT	418	346	764	55	18	73	309	307	616	9	71	80	96	110	306
SUB-TOTAL	1575	1710	3685	427	82	509	771	1329	2100	30	305	335	361	448	809
% (MESSAGE COUNT)	29.2	27.8	31.1	7.9	1.3	4.4	14.3	21.6	18.2	.6	5.0	2.9	6.7	7.3	7.0
PHX	194	408	602	71	52	123	124	448	572	4	136	140	46	159	205
BAL	153	351	504	1	2	3	101	384	485	17	151	168	54	184	227
DAY	64	247	311	0	1	1	62	195	257	1	49	50	9	58	67
BUR	61	507	568	10	68	78	43	364	407	3	190	193	7	100	107
ICT	84	477	561	11	64	75	36	352	388	16	160	176	18	124	142
GSO	158	595	753	11	26	37	94	659	753	21	167	188	12	155	167
PIA	19	118	137	9	12	21	15	151	166	1	44	45	2	70	72
SUB-TOTAL	733	2703	3436	113	225	338	475	2553	3028	63	897	960	137	850	987
% (MESSAGE COUNT)	28.2	22.2	23.1	4.4	1.8	2.3	18.3	20.9	20.3	2.4	7.4	6.4	5.3	7.0	6.6
FAT	21	99	120	0	8	8	20	149	169	0	83	83	6	83	89
AUS	48	269	317	3	26	39	33	484	517	9	105	114	11	164	175
MRY	13	122	135	2	5	7	17	128	145	6	99	105	5	84	89
SUB-TOTAL	82	490	572	5	39	44	70	761	831	15	287	302	22	331	353
% (MESSAGE COUNT)	25.2	15.3	16.2	1.5	1.2	1.2	21.5	23.8	23.5	4.6	9.0	8.6	6.8	10.4	10.0
TOTAL	2390	4903	7593	545	346	891	1316	4643	5959	108	1489	1597	520	1629	2149
% (MESSAGE COUNT)	28.8	22.8	25.3	6.6	1.6	3.0	15.8	21.5	19.9	1.3	6.9	5.3	6.3	7.6	7.2

Table 53 shows how communications were distributed by message content and by user category. The numbers represent the total data collected for a 2 hour period studied for 2 days - one week day and one week-end day. The sites used in the study were grouped by airspace designation.

The first column shows the number of aircraft handled for each site during the days and times studied. The total is broken down into scheduled operations (AR) and general aviation (GA). For example, for every site studied there was a total of 1,453 aircraft handled concerning scheduled operations and 3,433 concerning general aviation, during the days and times studied, or a grand total of 5,066.

According to column 2, the total message count for every site during the days and times studied was 8,305 for scheduled operations, 21,550 for general aviation, or a total of 29,985. There were a total of 3,234 advisory communications, 1,296 of which the altitude was known and 1,938 of which the altitude was unknown. There were 6,061 vector communications or other navigational instructions, 7,593 altitude instructions, 891 speed control instructions, and 5,959 miscellaneous information exchanges. The chart also indicates that there were 1,597 Beacon assignment communications and 2,149 radar contact communications.

It was determined that the best measure for aggregated load forecasting was to employ the average messages (Total) for both scheduled and non-scheduled operations. In addition, the composition of messages per aircraft were modified to allow projections of en route communication load. The communication load for each aircraft handled used in the forecast are shown in Table 54.

Table 54, Communications Content per Aircraft-Terminal Area, indicates the average number of messages for each type of communication per aircraft, using the data obtained in the Communications Data Summary chart. In the Terminal Control area (TCA) there were an average of 5.74 messages concerning scheduled operations (AR), 6.07 messages concerning general aviation (GA), and an average of 5.91 messages for total operations. These averages are broken down into the various types of communications - Advisories, Vectors, Altitude, Speed, Miscellaneous, Beacon Assignment and Radar Contact. According to the second column, in the Terminal Radar Service Area (TRSA) there were an average of 5.70 messages concerning scheduled operations, an average of 6.80 messages concerning general aviation, and an average of 6.13 messages for all operations in the TRSA. The breakdowns for the different types of communications are then given. The third column shows that, in other terminal areas, there were an average of 5.32 messages concerning scheduled operations, an average of 5.10 messages concerning general aviation, and an average of 5.13 messages for total operations. Column 4 gives the average number of messages for the entire terminal area. In the terminal area as a whole, there were an average of 5.71

Table 54

COMMUNICATIONS CONTENT PER AIRCRAFT-TERMINAL AREA

INFORMATION/ A.C. HANDLED	TCA			TRSA			TCA			TRSA			ENROUTE
	AR	GA	TOT	AR	GA	TOT	AR	GA	TOT	AR	GA	TOT	AR
Messages	5.74	6.07	5.91	5.70	6.80	6.13	5.32	5.10	5.13	5.71	6.27	5.91	6.45
Advisories	.33	.46	.40	.88	.87	.81	.73	.72	.72	.52	.72	.64	.32
Vectors	1.48	1.36	1.42	1.07	1.22	1.10	1.16	.87	.91	1.34	1.20	1.20	1.00
Altitude	1.68	1.69	1.84	1.61	1.51	1.41	1.34	.78	.83	1.64	1.43	1.50	1.68
Speed	.46	.08	.26	.25	.13	.14	.08	.06	.07	.38	.10	.18	1.00
Miscellaneous	1.37	1.74	1.41	1.45	2.10	1.86	1.41	1.68	1.65	1.40	1.92	1.65	.45
Beacon Assignments	.03	.30	.17	.14	.50	.40	.24	.46	.44	.07	.43	.32	1.00
Radar Contact	.39	.44	.41	.30	.47	.41	.36	.53	.51	.36	.47	.42	1.00

messages concerning scheduled operations, an average of 6.27 messages concerning general aviation, and an average of 5.91 messages for total operations. Column 6 provides an estimate of the average number of messages in the en route area (6.45) and the breakdown of this estimated average into the various types of communications.

Based upon the data in Table 54 forecasts of communications load were derived using appropriate activity measures. That is, estimates of total annual operations for terminal areas and total annual aircraft handles were used to forecast communications load. The results of these forecasts are summarized below in Table 55 through 62.

Center Areas

The balanced growth scenario forecast for the communications load for en route center areas is shown in Table 55 for 1992 to 2020. Changes in communications load in the balanced growth scenario for en route center areas are projected as follows. Messages (BCMESS) are expected to increase from 290 million in 1992 to 454 million in 2020. Advisory communications (BCADV) will increase from 14 million in 1992 to 23 million in 2020. Vector communications (BCVEC) will increase from 45 million in 1992 to 70 million in 2020. Altitude instructions (BCALT) will increase from 75 million in 1992 to 118 million in 2020. Speed control instructions (BCSPEED) will increase from 45 million in 1992 to 70 million in 2020. Miscellaneous communications (BCMISC) will increase

TABLE 55

OBS	YEAR	BCMESS	BCADV	BCVEC	BCALT	BCSPEED	BCMISC	BCBEC	BCRAD
1	1992	289.524	14.3640	44.8874	75.411	44.8874	20.1993	44.8874	44.8874
2	1993	297.276	14.7486	46.0893	77.430	46.0893	20.7402	46.0893	46.0893
3	1994	304.958	15.1297	47.2803	79.431	47.2803	21.2762	47.2803	47.2803
4	1995	312.558	15.5068	48.4587	81.411	48.4587	21.8064	48.4587	48.4587
5	1996	320.065	15.8792	49.6224	83.366	49.6224	22.3301	49.6224	49.6224
6	1997	327.465	16.2463	50.7698	85.293	50.7698	22.8464	50.7698	50.7698
7	1998	334.750	16.6078	51.8992	87.191	51.8992	23.3547	51.8992	51.8992
8	1999	341.908	16.9629	53.0091	89.055	53.0091	23.8541	53.0091	53.0091
9	2000	348.931	17.3113	54.0979	90.884	54.0979	24.3440	54.0979	54.0979
10	2001	355.810	17.6526	55.1643	92.676	55.1643	24.8240	55.1643	55.1643
11	2002	362.537	17.9863	56.2073	94.428	56.2073	25.2933	56.2073	56.2073
12	2003	369.105	18.3122	57.2256	96.139	57.2256	25.7515	57.2256	57.2256
13	2004	375.509	18.6299	58.2185	97.807	58.2185	26.1983	58.2185	58.2185
14	2005	381.743	18.9392	59.1849	99.431	59.1849	26.6332	59.1849	59.1849
15	2006	387.802	19.2398	60.1244	101.009	60.1244	27.0560	60.1244	60.1244
16	2007	393.684	19.5316	61.0362	102.541	61.0362	27.4663	61.0362	61.0362
17	2008	399.385	19.8144	61.9201	104.026	61.9201	27.8641	61.9201	61.9201
18	2009	404.903	20.0882	62.7757	105.463	62.7757	28.2491	62.7757	62.7757
19	2010	410.238	20.3529	63.6028	106.853	63.6028	28.6213	63.6028	63.6028
20	2011	415.389	20.6084	64.4014	108.194	64.4014	28.9806	64.4014	64.4014
21	2012	420.355	20.8548	65.1714	109.488	65.1714	29.3271	65.1714	65.1714
22	2013	425.139	21.0922	65.9130	110.734	65.9130	29.6609	65.9130	65.9130
23	2014	429.741	21.3205	66.6265	111.933	66.6265	29.9819	66.6265	66.6265
24	2015	434.163	21.5399	67.3121	113.084	67.3121	30.2904	67.3121	67.3121
25	2016	438.408	21.7505	67.9702	114.190	67.9702	30.5866	67.9702	67.9702
26	2017	442.478	21.9524	68.6013	115.250	68.6013	30.8706	68.6013	68.6013
27	2018	446.377	22.1459	69.2058	116.266	69.2058	31.1426	69.2058	69.2858
28	2019	450.109	22.3310	69.7844	117.238	69.7844	31.4030	69.7844	69.7844
29	2020	453.677	22.5080	70.3376	118.167	70.3376	31.6519	70.3376	70.3376
30	2021	457.086	22.6771	70.8660	119.055	70.8660	31.8897	70.8660	70.8660

from 20 million in 1992 to 32 million in 2020. Beacon assignment communications (BCBEC) will increase from 45 million in 1992 to 70 million in 2020. Radar contact communications (BCRAD) will increase from 45 million in 1992 to 70 million in 2020.

In the rapid growth scenario for en route center areas, shown in Table 56, changes in communications load are projected as follows. Messages (RCMESS) are expected to increase from 356 million in 1992 to 683 million in 2020. Advisory communications (RCADV) will increase from 18 million in 1992 to 34 million in 2020. Vector instructions (RCVEC) will increase from 55 million in 1992 to 106 million in 2020. Altitude instructions (RCALT) will increase from 93 million in 1992 to 178 million in 2020. Speed control instructions (RCSPEED) will increase from 55 million in 1992 to 106 million in 2020. Miscellaneous communications (RCMISC) will increase from 25 million in 1992 to 48 million in 2020. Beacon assignment communications (RCBEC) will increase from 55 million in 1992 to 106 million in 2020. Radar contact communications (RCRAD) will increase from 55 million in 1992 to 106 million in 2020.

Changes projected in communications load for en route center areas in the stagflation scenario are shown in Table 57. Messages (SCMESS) are expected to increase from 260 million in 1992 to 316 million in 2020. Advisory communications (SCADV) will increase from 13 million in 1992 to 16 million in 2020. Vector communications (SCVEC) will increase from 40 million in 1992 to 49 million in 2020.

TABLE 57

OBS	YEAR	SCMESS	SCADV	SCVEC	SCALT	SCSPEED	SCMISC	SCBEC	SCRAD
1	1992	260.256	12.9119	40.3498	67.7876	40.3498	18.1574	40.3498	40.3498
2	1993	264.410	13.1180	40.9938	68.8696	40.9938	18.4472	40.9938	40.9938
3	1994	268.350	13.3135	41.6046	69.8958	41.6046	18.7221	41.6046	41.6046
4	1995	272.079	13.4985	42.1828	70.8671	42.1828	18.9823	42.1828	42.1828
5	1996	275.602	13.6733	42.7289	71.7846	42.7289	19.2280	42.7289	42.7289
6	1997	278.923	13.8380	43.2439	72.6498	43.2439	19.4598	43.2439	43.2439
7	1998	282.050	13.9932	43.7286	73.4641	43.7286	19.6779	43.7286	43.7286
8	1999	284.988	14.1389	44.1842	74.2294	44.1842	19.8829	44.1842	44.1842
9	2000	287.745	14.2757	44.6116	74.9475	44.6116	20.0752	44.6116	44.6116
10	2001	290.328	14.4039	45.0121	75.6203	45.0121	20.2554	45.0121	45.0121
11	2002	292.745	14.5238	45.3868	76.2499	45.3868	20.4241	45.3868	45.3868
12	2003	295.004	14.6359	45.7370	76.8382	45.7370	20.5817	45.7370	45.7370
13	2004	297.112	14.7404	46.0639	77.3873	46.0639	20.7288	46.0639	46.0639
14	2005	299.078	14.8380	46.3687	77.8993	46.3687	20.8659	46.3687	46.3687
15	2006	300.909	14.9288	46.6525	78.3762	46.6525	20.9936	46.6525	46.6525
16	2007	302.612	15.0133	46.9166	78.8199	46.9166	21.1125	46.9166	46.9166
17	2008	304.196	15.0919	47.1622	79.2324	47.1622	21.2230	47.1622	47.1622
18	2009	305.667	15.1649	47.3902	79.6156	47.3902	21.3256	47.3902	47.3902
19	2010	307.032	15.2326	47.6019	79.9712	47.6019	21.4209	47.6019	47.6019
20	2011	308.299	15.2954	47.7982	80.3010	47.7982	21.5092	47.7982	47.7982
21	2012	309.472	15.3537	47.9802	80.6068	47.9802	21.5911	47.9802	47.9802
22	2013	310.560	15.4076	48.1488	80.8899	48.1488	21.6669	48.1488	48.1488
23	2014	311.566	15.4575	48.3048	81.1521	48.3048	21.7372	48.3048	48.3048
24	2015	312.497	15.5037	48.4492	81.3946	48.4492	21.8021	48.4492	48.4492
25	2016	313.358	15.5465	48.5827	81.6189	48.5827	21.8622	48.5827	48.5827
26	2017	314.154	15.5860	48.7061	81.8263	48.7061	21.9177	48.7061	48.7061
27	2018	314.890	15.6224	48.8201	82.0178	48.8201	21.9691	48.8201	48.8201
28	2019	315.569	15.6561	48.9255	82.1948	48.9255	22.0165	48.9255	48.9255
29	2020	316.196	15.6873	49.0227	82.3581	49.0227	22.0602	49.0227	49.0227
30	2021	316.775	15.7160	49.1125	82.5089	49.1125	22.1006	49.1125	49.1125

Altitude instructions (SCALT) will increase from 68 million in 1992 to 82 million in 2020. Speed control instructions (SCSPEED) will increase from 40 million in 1992 to 49 million in 2020. Miscellaneous communications (SCMISC) will increase from 18 million in 1992 to 22 million in 2020. Beacon assignment communications (SCBEC) will increase from 40 million in 1992 to 49 million in 2020. Radar contact communications (SCRAD) will increase from 40 million in 1992 to 49 million in 2020.

Terminal Areas

In terminal areas, the projected change in the communications load in the balanced growth scenario is shown in Table 58. Messages (BTMESS) are projected to increase from 592 million in 1992 to 974 million in 2020. Advisory communications (BTADV) are expected to increase from 32 million in 1992 to 53 million in 2020. Vector communications (BTVEC) will increase from 120 million in 1992 to 198 million in 2020. Altitude instuctions (BTALT) will increase from 168 million in 1992 to 277 million in 2020. Speed control instructions (BTSPEED) will increase from 18 million in 1992 and to 30 million in 2020. Miscellaneous communications (BTMISC) will increase from 165 million in 1992 to 272 million in 2020. Beacon assignment communications (BTBEC) are expected to increase from 32 million in 1992 to 53 million in 2020. Radar contact communications (BTRAD) will increase from 42 million in 1992 to 69 million in 2020.

TABLE 58

OBS	YEAR	BTMESS	BTADV	BTVEC	BTALT	BTSPEED	BTMISC	BTBEC	BTRAD
1	1992	591.640	32.0346	120.130	168.182	18.0195	165.179	32.0346	42.0455
2	1993	606.477	32.8380	123.142	172.399	18.4714	169.321	32.8380	43.0999
3	1994	621.352	33.6434	126.163	176.628	18.9244	173.474	33.6434	44.1570
4	1995	636.250	34.4501	129.188	180.863	19.3782	177.633	34.4501	45.2157
5	1996	651.155	35.2571	132.214	185.100	19.8321	181.795	35.2571	46.2750
6	1997	666.051	36.0636	135.239	189.334	20.2858	185.953	36.0636	47.3335
7	1998	680.921	36.8688	138.258	193.561	20.7387	190.105	36.8688	48.3903
8	1999	695.750	37.6717	141.269	197.777	21.1903	194.245	37.6717	49.4441
9	2000	710.522	38.4716	144.268	201.976	21.6403	198.369	38.4716	50.4939
10	2001	725.221	39.2675	147.253	206.154	22.0880	202.473	39.2675	51.5386
11	2002	739.834	40.0587	150.220	210.308	22.5330	206.553	40.0587	52.5770
12	2003	754.343	40.8443	153.166	214.433	22.9749	210.603	40.8443	53.6082
13	2004	768.736	41.6236	156.089	218.524	23.4133	214.622	41.6236	54.6310
14	2005	782.999	42.3959	158.985	222.578	23.8477	218.604	42.3959	55.6446
15	2006	797.117	43.1603	161.851	226.592	24.2777	222.545	43.1603	56.6479
16	2007	811.079	43.9163	164.686	230.560	24.7029	226.443	43.9163	57.6401
17	2008	824.871	44.6631	167.487	234.481	25.1230	230.294	44.6631	58.6203
18	2009	838.484	45.4001	170.251	238.351	25.5376	234.094	45.4001	59.5877
19	2010	851.905	46.1268	172.976	242.166	25.9463	237.841	46.1268	60.5415
20	2011	865.124	46.8426	175.660	245.924	26.3490	241.532	46.8426	61.4809
21	2012	878.133	47.5470	178.301	249.622	26.7452	245.164	47.5470	62.4054
22	2013	890.922	48.2394	180.898	253.257	27.1347	248.735	48.2394	63.3143
23	2014	903.484	48.9196	183.449	256.828	27.5173	252.242	48.9196	64.2070
24	2015	915.811	49.5871	185.952	260.332	27.8927	255.683	49.5871	65.0830
25	2016	927.898	50.2415	188.406	263.768	28.2608	259.058	50.2415	65.9420
26	2017	939.738	50.8826	190.810	267.134	28.6214	262.363	50.8826	66.7834
27	2018	951.326	51.5100	193.163	270.428	28.9744	265.599	51.5100	67.6069
28	2019	962.659	52.1237	195.464	273.649	29.3196	268.763	52.1237	68.4123
29	2020	973.733	52.7233	197.712	276.797	29.6568	271.854	52.7233	69.1993
30	2021	984.545	53.3087	199.908	279.871	29.9861	274.873	53.3087	69.9676

Projected changes in communications load in the rapid growth scenario for terminal areas are shown in Table 59. Messages are expected to increase from 718 million in 1992 to 1316 million in 2020. Advisory communications (RTADV) are expected to increase from 39 million in 1992 to 71 million in 2020. Vector communications (RTVEC) will increase from 146 million in 1992 to 267 million in 2020. Altitude instuctions (RTALT) are expected to increase from 204 million in 1992 to 374 million in 2020. Speed control instructions (RTSPEED) will increase from 22 million in 1992 to 40 million in 2020. Miscellaneous communications (RTMISC) will increase from 200 million in 1992 to 367 million in 2020. Beacon assignment communications (RTBEC) will increase from 39 million in 1992 to 71 million in 2020. Radar contact communications (RTRAD) are expected to increase from 51 million in 1992 to 94 million in 2020.

Projected changes in communication load in the stagflation scenario for terminal areas are shown in Table 60. Messages (STMES) are expected to increase from 537 million in 1992 to 656 million in 2020. Advisory communications (STADV) will increase from 29 million in 1992 to 36 million in 2020. Vector communications (STVEC) will increase from 109 million in 1992 to 133 million in 2020. Altitude instructions (STALT) will increase from 153 million in 1992 to 186 million in 2020. Speed control instructions (STSPEED) will increase from 16 million in 1992 to 20 million in 2020. Miscellaneous communications

TABLE 59

OBS	YEAR	RTMESS	RTADV	RTVEC	RTALT	RTSPEED	RTMISS	RTBEC	RTRAD
1	1992	718.01	38.8772	145.789	204.105	21.8684	200.460	38.8772	51.0263
2	1993	739.36	40.0332	150.124	210.174	22.5187	206.421	40.0332	52.5435
3	1994	760.71	41.1892	154.459	216.243	23.1689	212.382	41.1892	54.0608
4	1995	782.06	42.3452	158.794	222.312	23.8192	218.342	42.3452	55.5780
5	1996	803.41	43.5012	163.129	228.381	24.4694	224.303	43.5012	57.0953
6	1997	824.76	44.6572	167.464	234.450	25.1197	230.264	44.6572	58.6125
7	1998	846.11	45.8132	171.799	240.519	25.7699	236.224	45.8132	60.1298
8	1999	867.46	46.9692	176.134	246.588	26.4202	242.185	46.9692	61.6470
9	2000	888.81	48.1252	180.469	252.657	27.0704	248.145	48.1252	63.1643
10	2001	910.16	49.2812	184.804	258.726	27.7207	254.106	49.2812	64.6815
11	2002	931.51	50.4372	189.139	264.795	28.3709	260.067	50.4372	66.1988
12	2003	952.86	51.5932	193.474	270.864	29.0212	266.027	51.5932	67.7160
13	2004	974.21	52.7492	197.809	276.933	29.6714	271.988	52.7492	69.2333
14	2005	995.56	53.9052	202.144	283.002	30.3217	277.949	53.9052	70.7505
15	2006	1016.91	55.0612	206.479	289.071	30.9719	283.909	55.0612	72.2678
16	2007	1038.26	56.2172	210.814	295.140	31.6222	289.870	56.2172	73.7850
17	2008	1059.61	57.3732	215.149	301.209	32.2724	295.830	57.3732	75.3023
18	2009	1080.96	58.5292	219.484	307.278	32.9227	301.791	58.5292	76.8195
19	2010	1102.31	59.6852	223.819	313.347	33.5729	307.752	59.6852	78.3368
20	2011	1123.66	60.8412	228.154	319.416	34.2232	313.712	60.8412	79.8540
21	2012	1145.01	61.9972	232.489	325.485	34.8734	319.673	61.9972	81.3713
22	2013	1166.36	63.1532	236.824	331.554	35.5237	325.634	63.1532	82.8885
23	2014	1187.71	64.3092	241.159	337.623	36.1739	331.594	64.3092	84.4058
24	2015	1209.06	65.4652	245.494	343.692	36.8242	337.555	65.4652	85.9230
25	2016	1230.41	66.6212	249.829	349.761	37.4744	343.515	66.6212	87.4403
26	2017	1251.76	67.7772	254.164	355.830	38.1247	349.476	67.7772	88.9575
27	2018	1273.11	68.9332	258.499	361.899	38.7749	355.437	68.9332	90.4748
28	2019	1294.46	70.0892	262.834	367.968	39.4252	361.397	70.0892	91.9920
29	2020	1315.81	71.2452	267.169	374.037	40.0754	367.358	71.2452	93.5093
30	2021	1337.16	72.4012	271.504	380.106	40.7257	373.319	72.4012	95.0265

TABLE 60

OBS	YEAR	STMESS	STADV	STVEC	STALT	STSPEED	STMISC	STBEC	STRAD
1	1992	536.990	29.0756	109.033	152.647	16.3550	149.921	29.0756	38.1617
2	1993	544.785	29.4977	110.616	154.863	16.5924	152.097	29.4977	38.7157
3	1994	552.257	29.9022	112.133	156.987	16.8200	154.183	29.9022	39.2467
4	1995	559.408	30.2894	113.585	159.019	17.0378	156.180	30.2894	39.7549
5	1996	566.241	30.6594	114.973	160.962	17.2459	158.088	30.6594	40.2405
6	1997	572.762	31.0125	116.297	162.816	17.4445	159.908	31.0125	40.7039
7	1998	578.976	31.3490	117.559	164.582	17.6338	161.643	31.3490	41.1455
8	1999	584.891	31.6692	118.760	166.263	17.8139	163.294	31.6692	41.5659
9	2000	590.513	31.9736	119.901	167.862	17.9852	164.864	31.9736	41.9654
10	2001	595.852	32.2627	120.985	169.379	18.1478	166.354	32.2627	42.3448
11	2002	600.915	32.5368	122.013	170.818	18.3020	167.768	32.5368	42.7046
12	2003	605.712	32.7966	122.987	172.182	18.4481	169.107	32.7966	43.0455
13	2004	610.252	33.0424	123.909	173.473	18.5864	170.375	33.0424	43.3682
14	2005	614.545	33.2749	124.781	174.693	18.7171	171.574	33.2749	43.6733
15	2006	618.602	33.4945	125.604	175.846	18.8407	172.706	33.4945	43.9615
16	2007	622.431	33.7018	126.382	176.935	18.9573	173.775	33.7018	44.2337
17	2008	626.042	33.8974	127.115	177.961	19.0673	174.783	33.8974	44.4903
18	2009	629.447	34.0817	127.806	178.929	19.1710	175.734	34.0817	44.7322
19	2010	632.653	34.2553	128.457	179.840	19.2686	176.629	34.2553	44.9601
20	2011	635.671	34.4187	129.070	180.698	19.3605	177.471	34.4187	45.1746
21	2012	638.509	34.5724	129.647	181.505	19.4470	178.264	34.5724	45.3763
22	2013	641.178	34.7169	130.188	182.264	19.5283	179.009	34.7169	45.5659
23	2014	643.685	34.8527	130.698	182.977	19.6046	179.709	34.8527	45.7441
24	2015	646.040	34.9802	131.176	183.646	19.6763	180.366	34.9802	45.9115
25	2016	648.250	35.0998	131.624	184.274	19.7437	180.984	35.0998	46.0685
26	2017	650.324	35.2121	132.045	184.864	19.8068	181.562	35.2121	46.2159
27	2018	652.268	35.3174	132.440	185.416	19.8660	182.105	35.3174	46.3541
28	2019	654.091	35.4161	132.810	185.935	19.9216	182.614	35.4161	46.4836
29	2020	655.799	35.5086	133.157	186.420	19.9736	183.091	35.5086	46.6050
30	2021	657.399	35.5952	133.482	186.875	20.0223	183.538	35.5952	46.7187

(STMISC) will increase from 150 million in 1992 to 183 million in 2020. Beacon assignment communications (STBEC) will increase from 29 million in 1992 to 36 million in 2020. Radar contact communications (STRAD) are expected to increase from 38 million in 1992 to 47 million in 2020.

Summary

To enable a summary comparison of the projections for the years 1992 through 2020, under the three scenarios, the total message loads forecast for the three scenarios are shown for center operations in Table 10 and for terminal operations in Table 11; they are also illustrated in Charts 1 and 2.

For center operations, total messages projected under the stagflation scenario (SCMESS) may be compared with total messages projected under the balanced growth scenario (BCMESS) and the rapid growth scenario (RCMESS) in Table 61. Chart 1 illustrates the three different projected paths of growth.

Similarly, for terminal operations, Table 62 compares total messages projected under the stagflation scenario (STMESS) to total messages projected under the balanced growth scenario (BTMESS) and under the rapid growth scenario (RTMESS). The three different projected paths of growth for terminal messages are illustrated in Chart 2.

TABLE 61

CENTER COMMUNICATION LOAD-ALL SCENARIOS

OBS	YEAR	SCMESS	BCMESS	RCMESS
1	1992	260.256	289.524	356.435
2	1993	264.410	297.276	368.112
3	1994	268.350	304.958	379.790
4	1995	272.079	312.558	391.467
5	1996	275.602	320.065	403.144
6	1997	278.923	327.465	414.821
7	1998	282.050	334.750	426.498
8	1999	284.988	341.908	438.175
9	2000	287.745	348.931	449.852
10	2001	290.328	355.810	461.529
11	2002	292.745	362.537	473.206
12	2003	295.004	369.105	484.883
13	2004	297.112	375.509	496.560
14	2005	299.078	381.743	508.237
15	2006	300.909	387.802	519.915
16	2007	302.612	393.684	531.592
17	2008	304.196	399.385	543.269
18	2009	305.667	404.903	554.946
19	2010	307.032	410.238	566.623
20	2011	308.299	415.389	578.300
21	2012	309.472	420.355	589.977
22	2013	310.560	425.139	601.654
23	2014	311.566	429.741	613.331
24	2015	312.497	434.163	625.008
25	2016	313.358	438.408	636.685
26	2017	314.154	442.478	648.362
27	2018	314.890	446.377	660.039
28	2019	315.569	450.109	671.717
29	2020	316.196	453.677	683.394
30	2021	316.775	457.086	695.071

TABLE 62

TERMINAL COMMUNICATION LOAD-ALL SCENARIOS

OBS	YEAR	STMESS	BTMESS	RTMESS
1	1992	536.990	591.640	718.01
2	1993	544.785	606.477	739.36
3	1994	552.257	621.352	760.71
4	1995	559.408	636.250	782.06
5	1996	566.241	651.155	803.41
6	1997	572.762	666.051	824.76
7	1998	578.976	680.921	846.11
8	1999	584.891	695.750	867.46
9	2000	590.513	710.522	888.81
10	2001	595.852	725.221	910.16
11	2002	600.915	739.834	931.51
12	2003	605.712	754.343	952.86
13	2004	610.252	768.736	974.21
14	2005	614.545	782.999	995.56
15	2006	618.602	797.117	1016.91
16	2007	622.431	811.079	1038.26
17	2008	626.042	824.871	1059.61
18	2009	629.447	838.484	1080.96
19	2010	632.653	851.905	1102.31
20	2011	635.671	865.124	1123.66
21	2012	638.509	878.133	1145.01
22	2013	641.178	890.922	1166.36
23	2014	643.685	903.484	1187.71
24	2015	646.040	915.811	1209.06
25	2016	648.250	927.898	1230.41
26	2017	650.324	939.738	1251.76
27	2018	652.268	951.326	1273.11
28	2019	654.091	962.659	1294.46
29	2020	655.799	973.733	1315.81
30	2021	657.399	984.545	1337.16

FIGURE 6

CENTER COMMUNICATION LOAD-ALL SCENARIOS   13:35 SATURDAY, FEBRUARY 21, 1981

PLOT OF SCMESS*YEAR   SYMBOL USED IS S
PLOT OF BCMESS*YEAR   SYMBOL USED IS B
PLOT OF RCMESS*YEAR   SYMBOL USED IS R

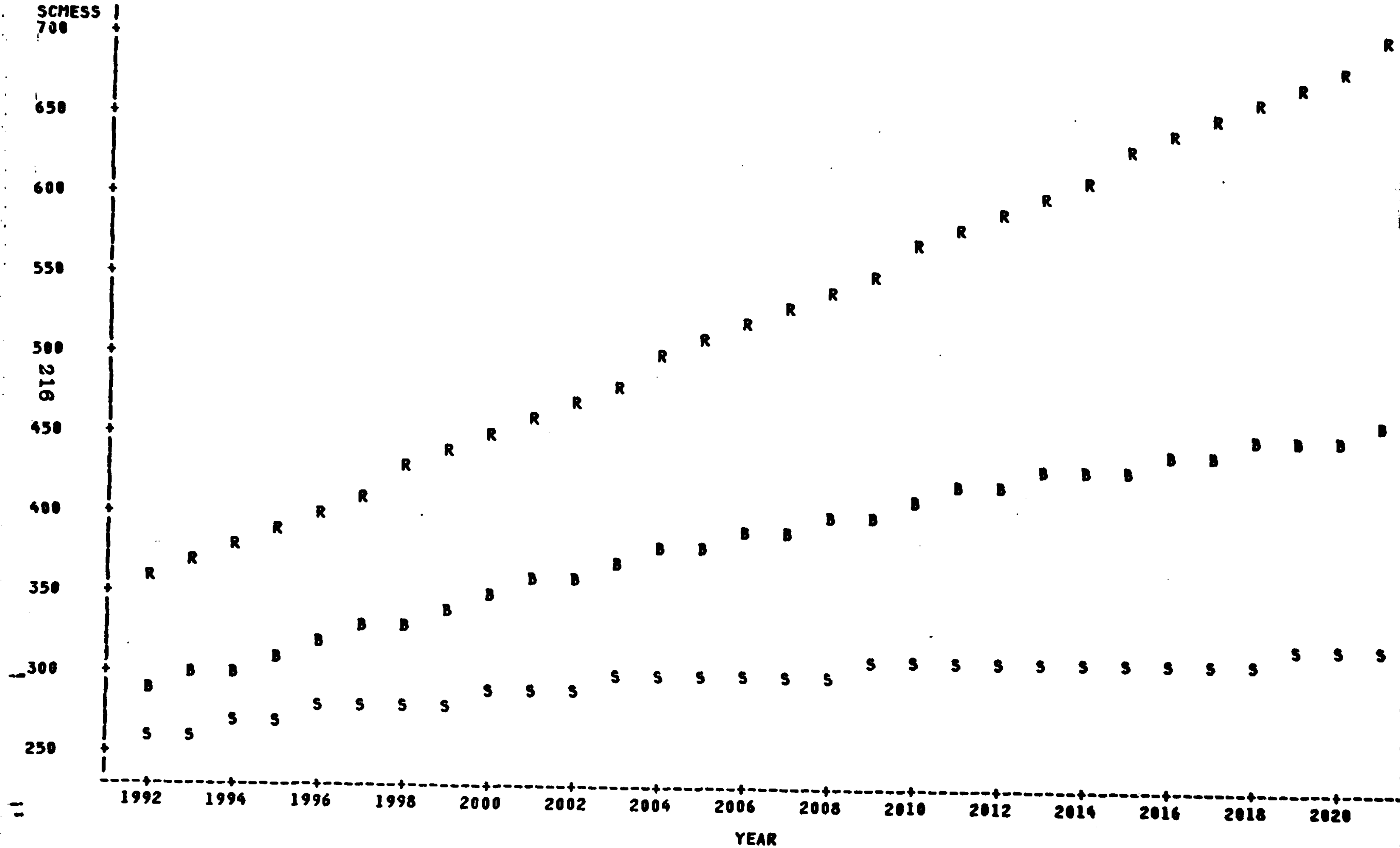
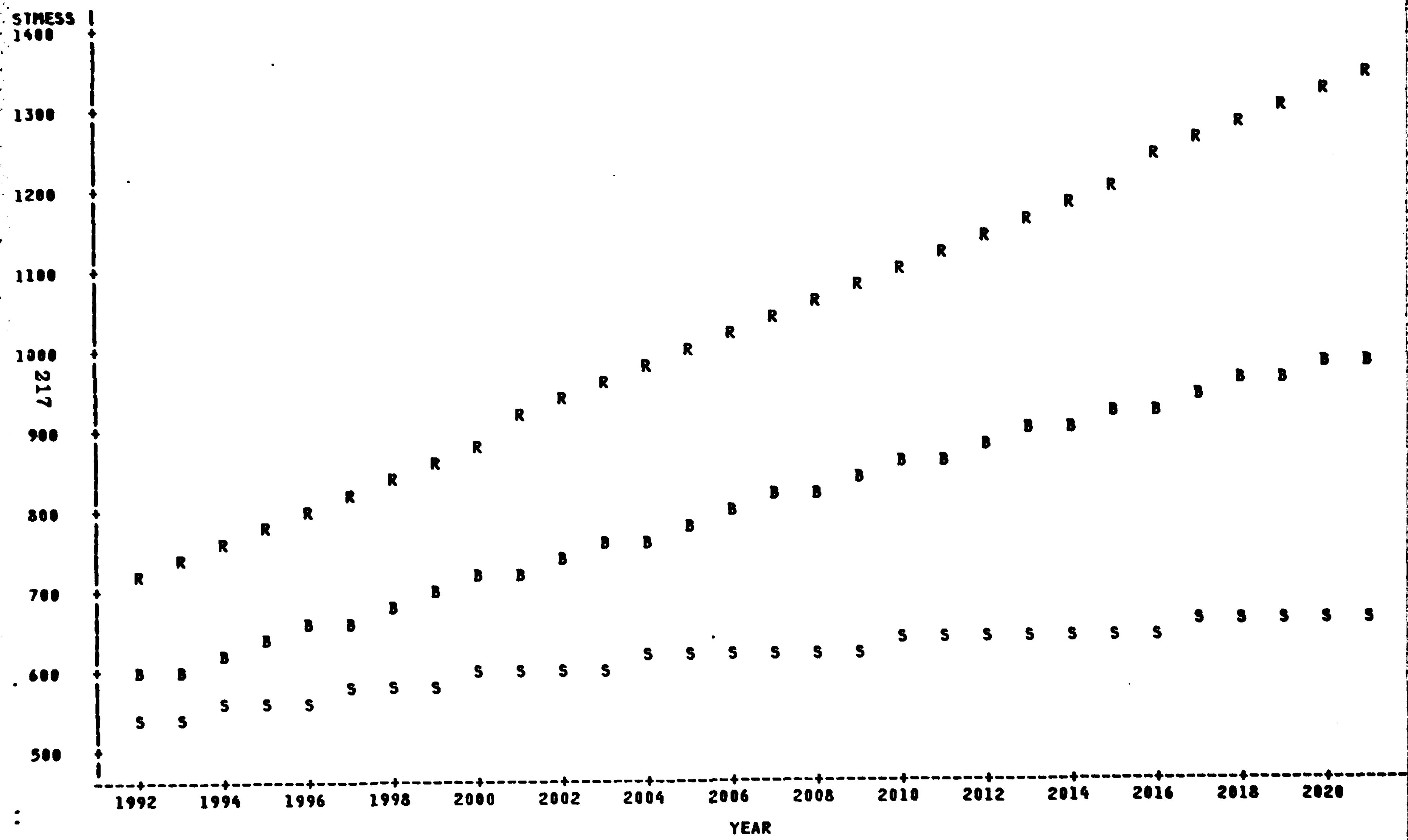


FIGURE 7

TERMINAL COMMUNICATION LOAD-ALL SCENARIOS   13:55 SATURDAY, FEBRUARY 21, 1981   1

PLOT OF STMESS*YEAR   SYMBOL USED IS S
PLOT OF BTMESS*YEAR   SYMBOL USED IS B
PLOT OF RTMESS*YEAR   SYMBOL USED IS R



APPENDIX A

ABBREVIATIONS AND ACRONYMS

APPENDIX A

ABBREVIATIONS AND ACRONYMS

ABDIS	Automated Service B Data Interchange System
ACD	Airport Traffic Control Tower Consolidated Display
ACD	Automatic Call Distribution
ADCOC	Air Defense Command Operation Control
AERA	Automated En Route Air Traffic Control
AFCD	Airport Facilities Consolidated Display
AFOS	Automation of Field Operations and Services
AFS	Airway Facilities Service
AFSS	Automated Flight Service Station
AFTN	Aeronautical Fixed Telecommunications Network
A/G	Air/Ground
A/G/A	Air-to-Ground-to-Air
AGL	Above Ground Level
AID	Airport Information Desk
AIRHAND	Aircraft Handled
AIRS	Airport Information Retrieval System
ALWOS	Automated Low-Cost Weather Observation System

ACUMENICS

ARO	Airline Reservation Office
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
ASR	Airport Surveillance Radar
ATARS	Automated Traffic Advisory and Resolution Service
ATCBI	Air Traffic Control Beacon Interrogator
ATCRBS	Air Traffic Control Radar Beacon System
ATCSCC	Air Traffic Control Systems Command Center
ATCT	Airport Traffic Control Tower
ATIS	Automated Terminal Information System
ATS	Automated Terminal Services
AUTOVON	Automated Voice Network
AV-AWOS	Aviation Automated Weather Observation System
AWP	Aviation Weather Processor
AWS	Air Weather Service
AWSDS	Advanced Wind Shear Detection System
AWSS	Airborne Wind Shear System
BCAS	Beacon-Based Collision Avoidance System

BDIS	Automatic Data Interchange System, Service "B"
BRITE	Bright Radar Indicator Tower Equipment
BUEC	Back-Up Emergency Communications
CAL	Commercial Airlines
CARF	Central Altitude Reservation Function
CCC	Center Computer Complex
CCENT	Consumed Quantity of Technolgoy Necessary to Service AIRHAND
CCP	Contingency Command Post
CCTV	Closed Circuit Television
CD	Common Digitizer
CDC	Computer Display Channel
CENT	Number of Agency Personnel Necessary to Perform Center Functions
CERAP	Combined Center/RAPCO
CFC	Central Flow Control
CFJC	Central Flow Jacksonville Computer
CKT	Control Circuit Equipment
CMA	Control Message Automation
CMLT	Communications Microwave Link Terminal
COMCO	Command Communications Outlet
CONUS	Conterminous United States
CRD	Computer Readout Device

CST	Combined Station/Tower
CTA	Calculated Time of Arrival
CTERM	Consumed Value of Agency Communications Facilities
CTRB	Center Building Maintenance
CWSU	Center Weather Service Unit
DABS	Discrete Address Beacon System
DARC	Direct Access Radar Channel
DCC	Display Channel Complex
DCS	Data/Communication System
DDD	Direct Distance Dialing
DEDS	Data Entry and Display Subsystem
DF	Direction Finder
DME	Distance Measuring Equipment
DR&A	Data Recording and Analysis
DTE	Data Terminal Equipment
DUAT	Direct User Access Terminal
EBCDIC	Extended Binary Coded Decimal Interchange Code
EDPS	Electronic Data Processing System
EFAS	En Route Flight Advisory Service
EMSAW	En Route Minimum Safe Altitude Warning System
ETABS	Electronic Tabular Display Subsystem

FAD	Fuel Advisory Departure
FAX	Facsimile
FDAD	Full Digital ARTS Display
FDEP	Flight Data Entry and Printout
F&E	Facilities and Equipment
FP	Flight Plan
FSAS	Flight Service Automation System
FSDPS	Flight Service Data Processing System
FSH	Flight Service Hub
FSS	Flight Service Station
FTS	Federal Telephone System
FWS	Flight Watch Specialist
FX	Foreign Exchange
GA	General Aviation
GPCAP	Active General Aviation Fleet
GPS	Global Positioning System
GOES	Geostationary Operational Environmental Satellite
GS	Glide Scope
H	Homing Radio Beacon
HH	Homing Radio Beacon - High Power
HSP	High Speed Printer
HUD	Head Up Display

LRCO	Limited Remote Communications Outlets
LSR	Limited Surveillance Radar
MIL	Military
MLF	Medium Low Frequency
MLS	Microwave Landing System
MM	Middle Marker
M&S	Metering and Spacing
MSAW	Minimum Safe Altitude Warning
MTBF	Mean Time Between Failure
MTBR	Mean Time Between Repair
MTD	Moving Target Detector
MTI	Moving Target Indicator
NADIN	National Airspace Data Interchange Network
NAFAX	National Facsimile Circuit
NAFEC	National Aviation Facilities Experimental Center
NAS	National Airspace System
NASCOM	National Aviation Systems Communications
NATCOM	National Communications
NAVAID	Navigational Aid
NDB	Nondirectional Beacon
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command

IATSC	International Aeronautical Telecommunications Switching Center
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IFSR	International Flight Service Receiving Station
IFSS	International Flight Service Station
IFST	International Flight Service Transmitter Station
ILS	Instrument Landing System
IM	Inner Maker
IOCE	Input/Output Control Element
LASS	Line Automatic Sensing and Switching
LCOT	VHF/UHF Link Terminal
LDA	Localizer - Type Directional Aid
LF	Low Frequency
LLWSAS	Low Level Wind Shear Alert System
LMM	Compass Locator at the ILS Middle Marker
LNKR	Link Repeater
LOC	ILS Localizer
LOM	Compass Locator at the ILS Outer Marker
LOPS	Local Operations
LORAN	Long Range Navigation

NOTAM	Notice to Airmen
NMC	National Meteorological Center
NWS	National Weather Service
OAG	Offical Airline Guide
OAW	Off-Airways Weather Station
OM	Outer Marker
ORD	Operational Readiness Demonstration
ORES	IFSS Residual Facility
OTC	Over the Counter
PAR	Precision Approach Radar--FAA and Military
PATWAS	Pilot Automatic Telephone Weather Answering Service
PDME	Precision DME
PIREP	Pilot Weather Report
PVD	Plan View Display
RBDE	Radar Bight Display Equipment
RCAG	Remote Communications Air-Ground
RCO	Remote Communications Outlet
RCCS	Radio Communications and Control System
RCS	Radio Communications Subsystem
RDF	Radio Direction Finder
RML	Radar Microwave Link
RMLR	Radar Microwave Link Repeater

RMLT	Radar Microwave Link Terminal
RMMS	Remote Maintenance Monitor System
RNAV	Area Navigation
R/T	Receiver/Transmitter
RTR	Remote Transmitter/Receiver
RVR	Runway Visual Range
RX	Receiver
SAC	Strategic Air Command
SAM	System Acquisition Management
SAMOS	Semi-Automated Meteorological Observation System
SCC	(ATC) System Command Center
SFO	Single Frequency Outlet
SFSS	Satellite Field Service Station
SMMC	System Maintenance Monitoring Console
SRAP	Sensor Receiver and Processor
SRG	Systems Requirements Group
SSO	Self-Sustained Outlet
STC	Sensitivity Time Control
SWL	Severe Weather Labs
SVSS	Small Voice Switching System
TAC	Air Carrier Fleet
TACAN	Tactical Air Navigation
TACAP	Air Carrier Fleet Capital

TAGS	Tower Automated Ground Surveillance System
TCAP	Total Aircraft Capital
TCDD	Tower Cab Digital Display
TCS	Technical Control Subsystem
TDP	Technical Data Package
TELEX	Telephone Exchange
TERM	Controllers
TIFRDEP	IFR Departures
TIPS	Terminal Information Processing System
TOPS	Total Operations
TOWB	Tower Building Maintenance
TPLT	Total Pilots Active in the Terminal Area
TRACAB	Terminal Radar Approach Control, Tower Cab
TRACO	Terminal Radar Approach Control
TRACON	Terminal Radar Approach Control, IFR Room
TRANP	Transport Pilots
TROPO	Tropospheric Scatter Station
TRSB	Time Reference Scanning Beam
TTS	Teletype Switching Facilities
TTY	Teletypewriter
TWEB	Transcribed Weather Broadcast
TX	Transmitter
VAS	Vortex Advisory System

VASI	Visual Approach Slope Indicator
VCS	Voice Communications Subsystem
VFR	Visual Flight Rules
VICON	Visual Confirmation of Voice Takeoff Clearance
VLF	Very Low Frequency
VMC	Visual Meteorological Conditions
VOR	Very High Frequency Omnirange Station
VORTAC	Colocated VOR and TACAN
VOT	Very High Frequency Onmidirectional Range Test
VRS	Voice Response System
VSCS	Voice Switching Control System
V.T.	Vacuum Tube
WAVE	Wind and Altimeter Voice Equipment
WBRR	Weather Bureau Romote Radar Recorder
WECO	Western Electric Company
WFMU	Weather and Fixed Map Unit
WMSC	Weather Message Switching Center
WSFO	Weather Service Forecast Office
WSR	Weather Service Radar
WVAS	Wake Vortex Avoidance System
WX	Weather