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THE AIR TRAFFIC CONTROLLER'S CONTRIBUTION TO ATC (AIR TRAFFIC CONTROL) SYSTEM CAPACITY IN MANUAL AND AUTOMATED ENVIRONMENTS. VOLUME II: APPENDICES

R. S. Ratner, et al

Stanford Research Institute

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Volume II – Appendices

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TABLES

GLOSSARY

A/G	air to ground
A/G/A	air-ground-air
ARTCC	air route traffic control center
ARTS	automated radar terminal system
ATC	air traffic control
ATCRBS	air traffic control radar beacon system
ATS	Air Traffic Service
CAS	collision avoidance system
CJ	control jurisdiction
DABS	discrete address beacon system
EB	eastbound
FL	flight level
G/A	ground to air
NAS	National Air Space System
N_H	average number of aircraft handled per hour
R-controller	radar controller
RNAV	area navigation
SRI	Stanford Research Institute
TAS	true air speed
TCA	terminal control area

TRACON	terminal radar control facility
TSC	Transportation Systems Cente.
VOR	very high frequency omnidirectional range
WB	westbound
3D	three dimensional
4D	four dimensional

Appendix A

DECISION-MAKING AND JUDGMENT

Appendix A

DECISION-MAKING AND JUDGMENT

The major emphasis this year was to analyze the controller-centered capacity constraints that might reduce the potential benefits of automation by limiting operationally attainable capacity. To start with, the following hypotheses were postulated as possibly limiting the capacity of an ATC system, and more particularly the capacity of a control sector:[1]

- The responsibilities imposed on a controller--both those explicitly prescribed and more particularly those he perceives as imposed on him because of the safety seeking character of his job. In this category are included the personal responsibility of a controller who may "cut corners" to expedite traffic, the sense of "total responsibility without complete control" that may cause him to be overly conservative in moving traffic, and his sense of perceived "fault" in considering the possibility of accident.

- The degree of trust of, and reliance on, technology (hardware and software), other controllers, supervision, and pilots. This category includes the controller's perception of the limitations and operational capabilities of his equipment and his perception of the cooperation and assistance he may expect from others in the system. Cases where too little trust and reliance are used by a controller, as well as where too much are used, are pertinent.

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1 R. S. Ratner, "Capacity Limitations Associated with Controller Judgmental Factors," Initial Briefing for FAA Subprogram Review, SRI Project 8181, Stanford Research Institute, Menlo Park, California, 8 Oct. 1971.

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- The controller's perception of the reliability of his equipment, his understanding of the possible failure modes for his equipment and procedures, and the degree to which his reliance on fail-safe concepts of operation is either implicit or explicit in his functioning. In this category we consider the basic reliance of an ATC controller on "backup:" A controller's prevailing mode of operation is to preserve one or more alternative "ways out" of every potentially difficult situation, especially those associated with equipment failure. Again, perceptions of reliability that are biased toward either good or bad performance are pertinent.

- Expected visibility of actions. One might reasonably expect the controller's decision-making processes to be affected by his judgments and expectations of the fact and consequences of his being observed, either visually or by voice communication links, by pilots, peer controllers in his own and adjacent sectors, area or team supervisors, and visiting observers. Effects on capacity operations are pertinent here.

- Latitude of reasonable decision objectives. In a complex decision-making role, such as ATC sector operation, a wide latitude of reasonable decision objectives and alternative actions appears to be possible. If so, capacity operations might be affected adversely by decision-making time requirements associated with the action selection process.

The first step in undertaking this year's effort was to define and develop measures of controller and system performance that were likely to be sensitive to the factors postulated, and to devise analytical or experimental methods to ascertain the existence and extent of each of the relationships.

Table A-1 summarizes the activities or tasks performed by the controller during routine ATC operations. The tasks are performed in conjunction with other people (e.g., data controller, pilot) and equipment. From this summary table, it is apparent that a significant number of his activities (such as detect significant deviation from planned path, detect significant closing rates, detect potential conflict, and so on) entail judgment and decision-making. These are the tasks that usually are so complex and ill-defined that they cannot be readily formulated into a routine algorithm. Specifically then, what kinds of decision-making are of interest here? Consider the following hypothetical situations.

Table A-1

TABULATION OF CONTROLLER OPERATIONAL TASKS

Component Control Activities	Controller Tasks
Information acquisition	Locate selected target(s). Identify selected target(s). Track selected target(s). Scan flight progress board (acquire flight progress data). Acquire aircraft status data: normal/emergency, altitude, climb/descend, speed, revise estimate. Acquire facility and environmental data. Monitor targets of significance to controlled aircraft. Acquire advance information on arriving aircraft.
Situation analysis/decision formulation (or situation evaluation/action selection)	Monitor flight progress (compare track with flight plan). Detect significant deviation from planned path or flight progress. Monitor and estimate separation between controlled aircraft. Estimate closing rates between controlled aircraft. Detect significant closing rates between controlled aircraft that may necessitate correct action (intervention). (Alternatively) detect potential conflicts that may necessitate intervention. Formulate control instructions or clearance amendment to: alleviate conflict, ensure required separation (or spacing), facilitate traffic flow, avoid hazard. Accept or transfer control responsibility. Request spacing modification or flow constraints. Refuse control responsibility. Coordinate with adjacent control jurisdiction; request authority for control action in adjacent airspace. Grant authority for control action.
Communications	Issue clearances, clearance amendments, and control instructions; assign beacon codes; obtain aircraft information. Coordinate arriving aircraft flight plans, revised estimates, and flight progress data. Coordinate aircraft location and identity. Coordinate workload and flow restrictions. Receive or give handoff. Coordinate aircraft movement. Enter data. Enter system commands. Enter information requests.
Data storage, retrieval, record finding	Mark flight progress strips (revise estimates, flight level and other data).

Obviously a basic element of any decision is that there are alternative choices involved: Shall I vector TWA 63 around slower traffic, or not? Shall I clear AA 10 through UA 56's altitude or wait? Is there a potential conflict situation on my radar PPI? All these decisions involve choice among two or more alternatives. Yet certainly some decisions are easier than others: If Navy 456 calls on frequency and I have no other traffic, shall I answer his call? Certainly. The decision is plain and well defined. The decision-making criterion is so simple that no judgment is involved. "Anyone" could make this decision. A computer could be programmed explicitly to do it. In some sense, this isn't a real decision at all: among the two alternatives (answer now or do not answer now) one is indisputably and <u>always</u> better than the other. "Better" means more in accord with the objective or criterion for making the decision in this particular ATC situation. We call this the situational control objective. It is immediately clear that one alternative "answer" has a higher value outcome than the other, and there is only one reasonable way to define "value" in this situation, i.e., as degree of responsiveness to users. Some controllers do not call these activities decisions, since they are so routine. The judgmental factors we are studying in the present project have no bearing on such routine processes. There is nothing to judge; the meaning of "value" (i.e., the situational control objective), the situation and the outcomes of the alternatives, are clear and indisputable. Nonjudgmental decisions are not of major concern to us in this project; their effects on capacity are felt entirely through the amount of time required to implement the (unambiguously) selected alternative.

1. <u>Decisions Involving Judgment</u>

Consider now another ATC situation: "TWA 68 was handed to me out of 200 climbing to 370. NAVY 456 under my control is level at 350 on the same airway.

Is there the potential of conflict?

What situation is likely to result?

What action (if any) should I take?

This sequence of decisions involves three specific judgmental elements:

- Uncertainty of situation--need to estimate/predict using incomplete information.
- Uncertainty of alternative outcomes--need to evaluate/predict the likely outcomes of possible alternative actions (including "no action").

- Uncertainty as to the relative weighting, or importance, in this particular ATC situation, among the various component elements of the control objectives--need to strike a balance or make tradeoff judgments to arrive at a specific measure of value, or situational control objective, against which to rank action alternatives.

Let us consider the ATC situation above to illustrate these elements of a decision. First, there is uncertainty of situation requiring some estimation, or assessment, of situation. Is a conflict likely to arise? Where? The assessment will be made on the basis of speeds, climb rate (through pilot reports of Mode C reporting), and so on. Second, there is uncertainty of alternative outcomes. If I wait for a while to allow the situation to become clearer (more imminent!) my control instructions may not be executed quickly enough. If I delay getting TWA 68 to its cleared altitude, I subsequently may have to delay another aircraft now level at 370, but currently far enough upstream to neglect. It is apparent that some actions have less or different uncertainties of outcome than others. Third, and most exemplary of human judgmental processes, the relative weightings among possible control objectives appropriate in this situation must be established by the controller. Consider the following reasonable goals for this situation:

- Avoid excessive penalties (delays) to traffic
- Keep your workload within bounds
- Limit risk of conflict materializing
- Strive for smooth control technique for professional pride
- Avoid visible mistakes
- Avoid hard-to-correct mistakes.

Which of these is important here? Possibly all of them! Perhaps others are listed as well. The controller must judge, on the basis of many complex factors (especially those that are the objects of our study: perceived responsibility, reliability, adequacy), the relative priorities and weight to give to each factor in assessing each possible alternative control action. These judgments are probably the most complex of controller mental processes, even though he may make them implicitly. Whereas many assessment and prediction tasks may be readily reduced to an algorithm (i.e., "automated" or programmed) or at least completely defined as a sequence of simple steps, the value-judgment decision elements are generally not well defined, at least not explicitly, and are subject to differences of opinion.

The key to automating decision processes seems to be in structuring the judgmental processes involved here. We will have to pursue this line of reasoning in order to evaluate the capacity effects of various judgmental factors, in relation to level of automation.

2. Decision Model[2]

As a first approach in trying to analyze judgment and decision-making for this project, we have focused on three general ATC decision classes. These are:

- Prediction and resolution of potential conflicts by R-controller (radar controller).
- Implementation by R-controller or prescribed sequencing/metering requirements.
- Situations caused by traffic or by facility outages, and decisions to invoke priorities of action or attention (including local flow control and need for assistance) by R-controller or area supervisor.

A general decision model described by Schrenk[2] was modified to facilitate the description and analysis of the judgmental and decision-making processes in these ATC situations. A diagram of the modified version of the model is presented in Figure A-1.

The model is divided into three phases: (1) deviation recognition, (2) situation assessment, and (3) action selection. A brief description of the steps in each phase is given below. Keep in mind that many of the decision elements are implicit in a controller's mental process; it is only for convenience of analysis that we are dissecting the decision process here.

a. Deviation Recognition

The first phase of ATC decision-making is concerned with recognizing that some deviation from the planned course of action is significant enough to cause a problem. The steps in deviation recognition are as follows.

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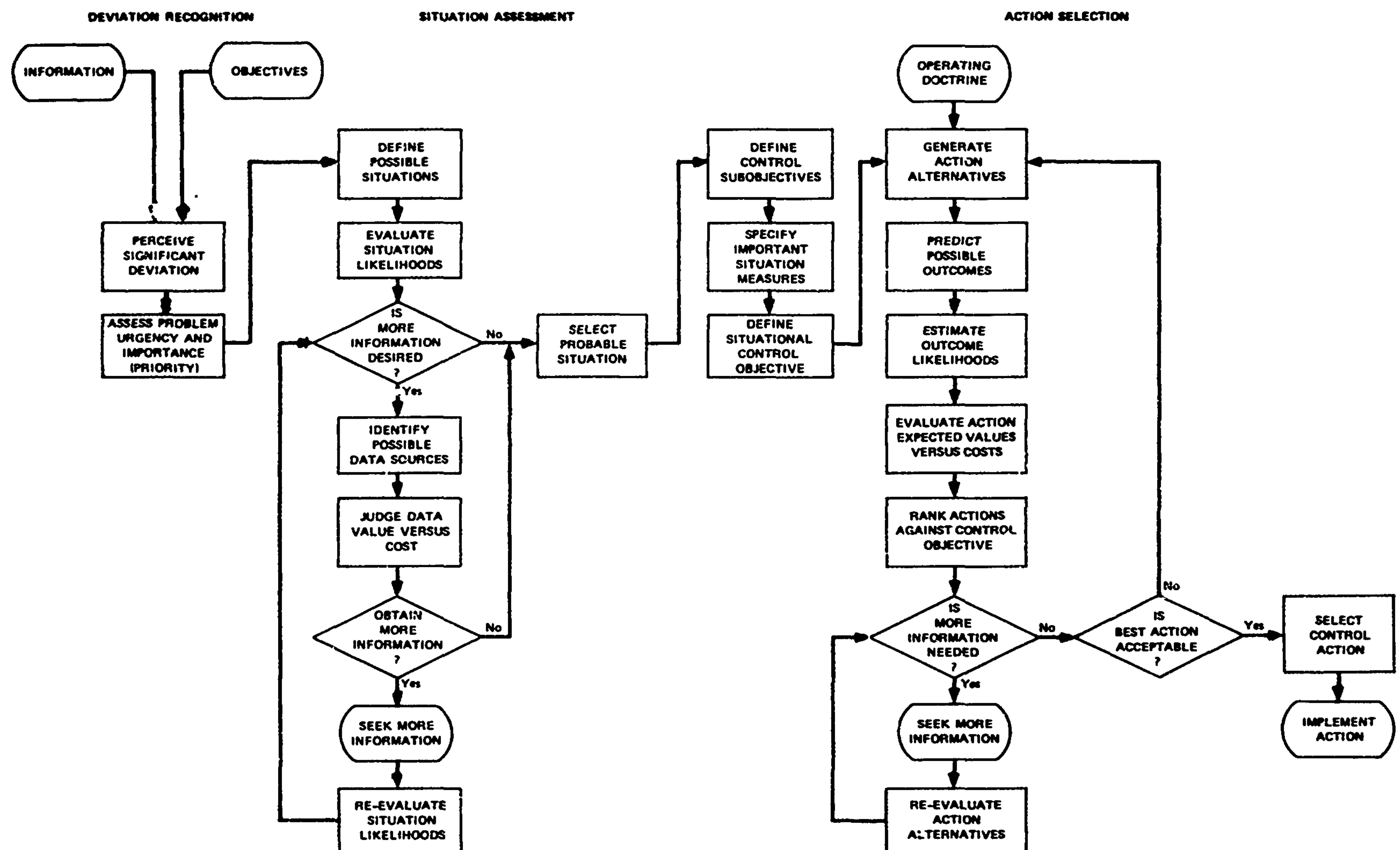
[2] L. P. Schrenk, "Aiding the Decision Maker—A Decision Process Model," Ergonomics, 1969, Volume 12, No. 4, pp. 543-557.



SOURCE. Reference 3.

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FIGURE A-1 ATC APPLICATION OF THREE-PHASE DECISION PROCESS MODEL

1) Objectives

Objectives specify the purpose, mission, or plan that the controller is trying to accomplish. They provide one of the primary factors in determining a deviation that could cause a problem. Objectives usually have many components and are ranked in some kind of order based on explicit or implicit priorities. Three categories of objectives exist for this project. They are (1) ATC organization related objectives (e.g., 7110-manual type objectives), (2) the particular facility management related objectives (e.g., letters of agreement, traffic-flow-pattern considerations), and (3) the controller related objectives--those involving his own perceptions, judgments, and personal goals. The specific objectives for each category must be defined for each decision class situation to be considered.

2) Information

Information on the current state of the ATC system and its environment is necessary if the controller is to determine that a deviation from the desired operating state exists. The controller receives aircraft information from flight progress strips, the radar display, and from voice communications with the pilot. He also receives facility information (e.g., equipment outage, equipment operating levels or conditions) and environmental information (such as weather reports and pertinent terrain hazards).

3) Perceive Significant Deviation

In the three general decision classes mentioned above, a problem requiring a decision occurs when the controller perceives an existing or forecasted situation that would prevent the objectives from being reasonably fulfilled.

4) Assess Problem Urgency and Importance

When a significant deviation, requiring a decision, is perceived by the controller, he must determine its priority in relation to other problems that are currently under consideration along with the time available before the incipient problem takes place.

b. Situation Assessment

The second phase of ATC decision-making is to perform an assessment to determine the probable situation that is producing the problem. The steps in situation assessment are as follows.

1) Define Possible Situations

The different alternative situations that could possibly generate the problem must be recognized and enumerated by the controller.

2) Evaluate Situation Likelihoods

The controller must assign probabilities to each alternative hypothesis. These probabilities indicate his belief in the likeliness of each of the situations and take into account the aircraft and the facility and environmental information available to him, as well as when the problem will occur.

3) Is More Information Desired?

More information is usually desired for nearly all problems containing uncertainty in order to increase the accuracy of the decision. The controller must determine if the expected value of the additional information is worth the time delay or is worth any possible risk caused by delaying action.

4) Identify Possible Data Sources

All of the possible sources of data that can possibly yield pertinent information concerning the problem must be specified.

5) Judge Data Value Versus Cost

The controller must determine the source from which to seek the desired data. Some of the parameters that must be considered in making this choice are (1) the time available before the problem develops, (2) the time required to obtain the data, (3) the reliability of the data, (4) the reliability of the data source, and (5) the usefulness of the information.

6) Obtain More Information

Although more information is desired, the controller must still evaluate the cost and value of data to determine if the additional information is worthwhile. It just might turn out that after thorough consideration the cost of additional information might be prohibitive.

7) Seek More Information

If the choice is made to seek more information, the controller takes the necessary steps to obtain the desired data from the source considered most cost effective.

8) Re-Evaluate Situation Likelihoods

The controller uses the additional information to revise his probabilistic assessment of the likeliness of the hypothesized alternative situations.

9) Select Probable Situations

On the basis of the assessment, the controller selects the alternative situation that he perceives to be the most likely cause of the problem.

c. Action Selection

The third phase of the ATC decision process is concerned with determining the action to take to alleviate the situation that is perceived to be the cause of the problem. The steps in action selection are as follows.

1) Define Control Subobjectives

The objectives previously mentioned usually are very broadly stated and are too all encompassing to define a specific basis for action. Consequently, for a specific situation the controller must determine subobjectives consistent with the major objectives that defined the basis for his actions. Some examples of these are:

- Avoid excessive delay to traffic.
- Strive for smooth control technique.
- Avoid visible mistakes.
- Limit risk of conflict materializing.
- Keep options open.
- Avoid "nonstandard" control to minimize personal responsibility.

2) Specify Important Situation Measures

The controller specifies the (performance) measures that are to be used as a basis for classifying the problem situation under consideration. These measures form the basis to determine the situational control objective as well as the procedure for evaluating the action alternatives. They specify the controller's value criteria for the situation.

3) Define Situational Control Objective

The measures of importance specified above determine the control objective that the controller is trying to achieve for the situation under consideration. This objective provides the basis for evaluating how well the action alternatives will be able to alleviate the problem situation.

4) Operating Doctrine

Operating rules or doctrine provide the guidelines that help to determine possible actions that are available to alleviate the situation causing the problem.

5) Generate Action Alternatives

A reasonable set of alternative ways of alleviating the probable situation must be generated by the controller. Some parameters considered by the controller in specifying the action alternatives are performance characteristics of the aircraft, time available for decision-making, and time to implement action.

6) Predict Possible Outcomes

All of the possible results for each action alternative must be determined.

7) Estimate Outcome Likelihoods

The controller must then use all available information on the aircraft, the facility, and the environment, along with experience and judgment, to estimate the probability of occurrences for each of the outcomes for each action alternative.

8) Evaluate Action Expected Values Versus Cost

The values of each possible outcome for each action alternative must be determined using the measures specified in "2)" above and then combined to obtain an expected value for each action alternative. The expected value must be considered along with the cost (usually in terms of time) of taking the action to determine the expected net value for each action alternative.

9) Rank Actions Against Control Objective

The controller evaluates each of the alternative actions against the situational control objective that he is trying to achieve, so as to determine its ranking in terms of how well it meets the criterion.

10) Is More Information Needed?

The controller compares the cost (mainly in terms of time) and value of obtaining additional information to determine if it is warranted.

11) Seek More Information

As in the situation assessment, if the choice is made to seek more information, the controller takes the steps to obtain the data from the source considered most cost effective.

12) Re-Evaluate Action Alternatives

The additional information is used to revise the estimates used with the action alternatives, as well as providing a basis for considering new action alternatives.

13) Is Best Action Acceptable?

The alternative that seems to offer the preferred course of action is reviewed to determine if the expected gain is worth the cost and to ensure that any possible adverse outcomes are acceptable or can be avoided. If these conditions are not met, then some new alternatives may have to be developed.

14) Select Control Action

The action alternative considered best by the measures and the ranking is selected.

15) Implement Action

The controller takes the necessary steps required to implement the action that seems most likely to alleviate problem situations.

Obviously this breakdown of the controller's decision-making process is too detailed for use in discussions with controllers. A more rudimentary breakdown of the decision-making process into the three basic phases (i.e., (1) deviation recognition, (2) situation assessment, and (3) action selection) is as detailed as will be needed there. However, this detailed structure facilitated subsequent analyses that were undertaken to ascertain the effects of the different levels of automation on decision-making and judgment.

Appendix B

AUTOMATION LEVELS--CONTROL AND OPERATING CONCEPTS

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Appendix B

AUTOMATION LEVELS--CONTROL AND OPERATING CONCEPTS

To explore the impact of controller judgment on system capacity, four levels of ATC system automation have been postulated, as shown in Table B-1. These four levels reflect distinctive stages in the evolutionary development and implementation of the National Airspace System. The increasing levels of ATC automation are necessarily accompanied by modifications in operating procedures, and will undoubtedly necessitate substantial revisions in control concepts and operational doctrine. The time-phasing of the four selected levels of ATC system automation, and the operational and control considerations associated with each of them, are discussed in parts 1 through 4 of this appendix. The remainder of the appendix is devoted to a discussion of the impact of automation on ATC functions and decisions.

1. Level I: Nonautomated Radar Control

This level is the "baseline" system and reflects current radar ATC practice in the domestic United States. System operation depends completely on the human controller; he makes all ATC decisions without computer assistance and communicates these decisions to pilots by voice radio. Computer assistance is limited to preparation and distribution of flight strips. Control is ground directed, either by assignment or approval of specific tracks and altitudes, or alternatively by direct navigational control of the aircraft (through the issuance by ATC of heading vectors and/or speed instructions). Clearances are issued with limited conflict search; conflicts are resolved in real time based on radar display information. Preferential routes and standard terminal arrival and departure procedures are used to facilitate preplanning and to reduce voice communications. Flow control and airport reservation procedures are in effect under certain conditions to control ATC workload level and to limit congestion and delay at a few busy airports.

2. Level II: Mechanized Tracking and Flight Data Handling

This level is the first stage of ATC automation and is exemplified by the Enroute NAS Stage A or ARTS III equipment operating with beacon

Table B-1

AIR TRAFFIC CONTROL AUTOMATION LEVELS

Automation Level and General Description	System Functions	System Hardware
Level I (2nd generation ATC) Nonautomated radar control	• Unaided human decision-making • Voice communications (A/G/A and intrasystem) • Manual radar tracking • Manual update and revision of flight strips • Computer generation and distribution of flight strips	• Remote radar/beacon sensors • Broadband radar display(s) • Flight strip tabular display • Sector strip printer • VHF/UHF voice radio • Telephone, intercom (intrasystem communications) • Central computer complex (flight strip processing)
Level II: (3rd generation ATC) Mechanized tracking and flight data handling	• Radar/beacon tracking • Automated handoff • Automatic altitude report • Alphanumeric data tag • Computer-processed flight plan updates and revisions • Computer-generated display of flight data and system status	• Radar/beacon tracking • Data filter group • Alphanumeric group • Central computer (configured for automatic track, alphanumeric tag, and flight plan correlation) • Plan view display • Computer readout device • Controller-computer interface: slew ball, display filter keys, category/function selection, alphanumeric keyboard, quick-action keys
Level III: (Upgraded 3rd generation ATC--Step I) Computer-aided decision processes	• Computer-aided metering, sequencing, and spacing • Computer-generated hazard alert (conflict, deviation, and the like) • Computer-generated action recommendations • Computer-formatted control instructions • Human review of computer-recommended actions • Controller-initiated G/A communications (voice or data) • Computer-assisted intra-system communications	• Level II hardware, and computer configured for - Metering, sequencing, and spacing - Conflict detection/resolution - Path surveillance • Two-way A/G/A data link: (1) discrete address beacon or (2) VHF data link • Airborne RNAV capabilities • Automatic airborne flight management • Airborne separation assurance • Airborne stationkeeping
Level IV (Upgraded 3rd generation ATC--Step II) Computer-generated control actions	• Computer-generated control actions • Computer-generated clearances • Automated A/G/A information transfer • Automated conformance check • Human monitoring of automated processes, human override	(Basically same as Level III)

tracking and flight data processing capability. This equipment is being deployed at all domestic enroute control centers and selected terminal facilities; implementation is scheduled for completion before 1975. Despite the automatic features, system operation and control are very similar to those associated with Level I. The human controller retains full responsibility for making and implementing ATC decisions, though the computer provides assistance in the organization and presentation of information (by mechanizing functions such as radar tracking, handoff procedures, and flight plan updating and revisions).

3. Level III: Computer-Aided Decision Processes

At this level of automation, the computer develops action recommendations to aid the human controller in formulating decisions, but the controller retains full responsibility for making and implementing each ATC decision. Level III operations reflect a transitional period in which controllers are learning to depend increasingly on computer-generated information in making their decisions. The attainable flow rate is expected to be a function of the controller's confidence in the effectiveness and reliability of the automated system, and of his ability to detect and cope with abnormal or emergency situations.

For investigating the implications of Level III automation over a broad set of ATC events, we assume a Level III system configuration using upgraded 3rd generation ATC system (post-1980) hardware and software, as shown in Table B-1.* Although the computer generates recommendations for action, the controller must review and approve each ground-to-air data link message before transmission. He may transmit override instructions, when needed, either through the data link or by voice. Two alternative override modes are postulated. In one, the controller must take positive action to transmit a computer-formatted message to an aircraft. In the other, the computer-formatted message will be automatically sent to an aircraft, after a specified review interval, unless the controller takes positive action to inhibit its transmission.

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* Specific Level III functions do not necessarily require upgraded 3rd generation equipment. For example, the terminal area metering, sequencing, and spacing program is being implemented essentially with ARTS III hardware.

We further make the following operational assumptions:

- Level III automation will be limited to airspace with high-density traffic--either en route or terminal. (This assumption implies a high degree of organization in the routing and scheduling of traffic.)

- All aircraft operating in Level III airspace will be under positive control or surveillance by the ATC facility responsible for that airspace. In those portions of Level III airspace where VFR operations are allowed, VFR aircraft will operate under "intermittent positive control" to avoid penetration of high-density airways or other restricted airspace, and to avoid conflict with IFR traffic. By definition, "pop-ups" are not allowed. (These assumptions imply that Level III is based on cooperation of the aircraft involved, both in the acquisition and exchange of information, and in the execution of required flight path maneuvers. There remain to be studied implications imposed by uncooperative aircraft, e.g., the intentional intruder or the disabled aircraft).

- All aircraft carry two-way data link with discrete address (DABS or universal air-ground digital communications system).

- All aircraft have three-dimensional (3D) RNAV capability. (This assumption implies the ability of aircraft to track specified three-dimensional flight paths; it implies the use of closely spaced parallel tracks and bypass procedures.)

- Some aircraft have airborne RNAV computer with stored flight plan capability. (This assumption implies the ability of certain aircraft to accept a clearance containing a complex routing and to track that path effectively.)

- Some aircraft have four-dimensional (4D) RNAV capability. (This assumption implies the ability of certain aircraft to adhere to a specified arrival schedule at designated waypoints; it also implies that ATC delegates responsibility for control of arrival time to appropriately equipped aircraft, and will not be responsible for transmitting vector and speed instructions to control that time.)

- Allowable sector operation rates will be coordinated with both local and central flow control functions.

4. Level IV: Computer-Generated Action Selection

Level IV reflects a fully automated ATC process, accompanied by a comparable level of automation in airborne flight path management and separation assurance functions. Conflict-free clearances (over some specified look-ahead time) and control instructions are generated in the computer and can be transmitted to the aircraft automatically without controller approval of individual messages.

Although Level IV automation could be implemented with the same type of hardware assumed for Level III operations,* the nature of the human controller's responsibilities is drastically changed. The controller acts as a system supervisor. He monitors the effectiveness of the computer-controlled process. He intervenes as necessary to make corrections in the process, by modifying ATC system parameters or operational data, or by overriding specific computer-generated actions. He may be called on to cope with situations that are not explicitly treated by the computer, or to deal with real-time revisions in flight plan necessitated by weather, aircraft malfunctions, or pilot requests. He may be alerted to situations requiring his intervention by the computer; alternatively, he may have to decide when his intervention is needed.

We assume that controller operational practices will be strongly dependent on the policies under which the ATC system is operated, and on the demonstrated integrity of the ATC system (in terms of equipment reliability, and equipment and procedural backup to cope with hardware or software failures). We believe the policy issues to be significant in interpreting the way in which judgmental factors will influence the allowable operations rate, or the size of jurisdiction to be controlled by a single control team. For example, to what degree will the controller in a Level IV system be held responsible for monitoring the movements of individual aircraft? To what degree is responsibility for air-to-air separation of individually controlled aircraft delegated to pilots (as in VFR), assuming employment of suitable air-derived separation assurance devices?

As noted under Level III, we assume that the transition between Levels III and IV will be a continuing process and that controllers will feel

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* Level IV automation could be implemented under even more advanced systems and equipment concepts, such as those being identified in the TSC "advanced generation air traffic management" studies.

able to operate in a Level IV mode only when they have developed sufficient confidence in the effectiveness and integrity of the system, and in their ability to undertake emergency duties consistent with their defined responsibilities. (At this time, we cannot estimate the duration of this transition period with confidence, except to say that it will cover many years, and will depend, in large measure, on the statutory responsibilities imposed on the agency--and the individuals--operating the ATC system.) It is likely that Level IV operations will first be applied in specific functional areas, such as the automatic transmission of traffic advisories to VFR aircraft, or to automatic metering, sequencing, and spacing control in selected terminal areas. Level IV operations may then be extended to other system functions in an evolutionary manner.

It may not be desirable or feasible to provide Level IV automation service throughout all airspace in a given geographical area. Consequently, Level IV service might be provided within airspace with intensive and organized traffic activity, while lesser levels of automation (and a higher degree of controller involvement in the movements of individual aircraft) are provided in portions of the airspace where flow is less intense and not highly organized, and where the greater flexibility afforded by human decision-making is advantageous.

5. Impact of Automation on ATC Functions and Controller Decisions

a. Introduction

The methodology for estimating sector relative capacity as a function of ATC automation level is discussed in Appendix C. This appendix deals with the first step in the process--the translation of an operational system description into terms that can be used as inputs for a quantitative analysis of relative capacity. Control concepts and operating procedures employed in the present day Level I system are identified. Changes in control concepts and operating procedures associated with automation levels II, III, and IV are postulated, and a qualitative assessment is made of the impact of the resulting system organization on controller functions and decision-making activities.

b. Methodology

The description of the Level I system is based on observations at selected ARTCC and terminal control facilities, on review of documents of operational doctrine, and on discussions with FAA operational and technical personnel. The descriptions of the Level II, III, and IV systems are based on available literature on various ATC automation programs;[1-18*] information gathered in discussions with FAA operational and technical personnel, both at field facilities and at FAA headquarters; on observations at selected facilities with functioning automation features; and by liberal amounts of SRI speculation on Level III and Level IV system operations. To date we have been unable to secure documentation on the advanced generation air traffic management ("fourth generation ATC") concepts that are being developed under Transportation Systems Center cognizance during the course of the study. Further, documentation available to us on the upgraded third generation system did not deal explicitly with controller functions. Consequently, assumptions regarding possible controller activities for Level III and IV systems are based on SRI's best judgment at this time; these assumptions are subject to modification as investigations proceed and additional information is received.

In section c below we present the results of our preliminary findings regarding the impact of automation on ATC functions and controller decisions for the four automation levels summarized earlier. The material is organized as follows.

For the Level I system, a number of discrete ATC functions and events were identified. These are: handoff or control transfer, "pointout" or coordination, conflict detection and resolution, traffic structuring, clearance generation and modification, surveillance, and workload management. For each of these functions, a set of controller decisions is identified, along with the information the controller must use to make these decisions, and the means by which he disseminates the results of his decisions. A tabular summary of this information is shown in Table B-2, along with notes that indicate the decision aids and mnemonic devices used in Level I. The information on each of the ATC functions is followed by remarks concerning items such as decision consequences, effects of failures, controller responsibilities and degree to which such responsibility is shared with other controllers, with supervisors, and with pilots.

The effects of introducing the automation features associated with Level II, III, and IV systems on ATC functions and controller decisions were then explored. The first step in this process was to construct a set of tables for each automation level that reflected the

* References are listed at the end of this appendix.

changes in controller decisions, information sources, decision dissemination, decision aids and mnemonic devices, and decision consequences brought about by the higher levels of automation. The information contained in these tables was then subjected to the following questions on automation impact.

(1) Is the function still performed?

(2) Are the same decisions needed?

(3) Are different decisions needed?

(4) Are new tasks added to accomplish the function or to make required decisions?

(5) Does automation change:

- The type of information provided to the controller?
- The time when the controller is made aware of the need for a decision?
- The quality of information provided to the controller?
- The presentation or display of information provided to the controller?

(6) Does automation change:

- The time required to make a decision?
- The time when the controller is made aware of the need for a decision?
- The time when a decision may be made?

(7) How is the decision or function affected by:

- Procedural changes applicable to the automation level under consideration?
- The degree to which responsibility for aircraft separation is vested in the controller?
- The degree to which responsibility for separation is distributed within the ATC system
  - Between controllers
  - Between controllers and machines.

Table B-2

ATC EVENTS AND CONTROLLER DECISIONS (LEVEL I SYSTEM)

ATC Event	Controller Decisions	Information Requirements and Sources							
		Aircraft Location and Beacon Code (radar)	Aircraft Report (pilot)	Traffic Situation (radar)	Aircraft Intent: Flight Strips	Aircraft Intent: Pilot Service Request	ATC Information (other sectors)	Clearance Modification and Control Instructions (to pilot via G/A radio)	Ad Inf (te G/A
Handoff	Locate and identify aircraft	X					X		
	Negotiate handoff conditions	X		X	X		X		
	Accept responsibility	X		X	X		X	*	
	Transfer control	X	O	X	X	O	X	X	
Pointout or coordination	Locate and identify aircraft	X					X		
	Assume responsibility for protection			X	X		X		
	Request coordination	X			X	O	X		
Block request	Assume responsibility for protection within blocked airspace			X			X		
Conflict detection/ resolution	Detect conflict		O	X	X		O		O
	Select control action		O	X	X		O	X	O
Traffic structuring	Establish plan (sequence, spacing, speed)	X	O	X	O	O	O		
	Select control actions and timing	X	O	X				X	O
Clearance generation (including amendments and modifications)	Probe potential conflicts	X	O	X	X	O	O		
	Develop conflict-free clearance		O	X	X		O	X	O
Surveillance	Detect potential hazard	X	O	O	O	O	O		X
	Transmit corrective instructions, if requested	X	O	O	O	O	O	X	O
Workload management	Establish priorities	X	O	X	X	O	X	O	O
	Delegate responsibilities (reroute, coordinate)	X	O	X	O		X		
	Request flow or spacing restrictions			X	X		X		
	Request help (add staff, cut load)			X	O		X		

Legend: X – primary interactions
O – as needed

* Change of A/G/A communication frequency is indication to pilot of control transfer in Level I system.

Note:
Level I system decision aids and
- Flight strips on tabular displ
- Target markers ("shrimp boats"
- Beacon IDENT to facilitate tar
- Video map to display selected
- Beacon code selection to displ
- Grease pencils for marking spe
- Weather clutter on radar as cu

Table B-2

TC EVENTS AND CONTROLLER DECISIONS (LEVEL I SYSTEM)

m Requirements and Sources				Decision Information and Dissemination					
Traffic Situation (radar)	Aircraft Intent: Flight Strips	Aircraft Intent: Pilot Service Request	ATC Information (other sectors)	Clearance Modification and Control Instructions (to pilot via G/A radio)	Advisory Information (to pilot via G/A radio)	ATC Control Information (to ATC sectors)	Request Service (other ATC sectors)	Request Assistance (supervisors and coordinators)	Exchange Information (ATC)
			X			X			
X	X		X			X		O	
X	X		X	*		X			
X	X	O	X	X		X	X	O	
			X			X			
X	X		X			X			
	X	O	X				X		
X			X			X			
X	X		O		O				
X	X		O	X	O				O
X	O	O	O						
X				X	O				O
X	X	O	O						
X	X		O	X	O	X		O	O
O	O	O	O		X				O
O	O	O	O	X	O	O			O
X	X	O	X	O	O				
X	O		X			O	X	X	O
X	X		X				X	X	
X	O		X				X	X	

Note:
Level I system decision aids and mnemonic devices:
- Flight strips on tabular display (planning, intent).
- Target markers ("shrimp boats" or "pucks") in ARTCCs to aid memory in radar tracking.
- Beacon IDENT to facilitate target identification.
- Video map to display selected routes, fixes, landmarks.
- Beacon code selection to display selected targets.
- Grease pencils for marking special data on scope faces.
- Weather clutter on radar as cue to detecting weather hazard (limited value).

- The degree to which responsibility for separation between aircraft is delegated to aircraft crews.

- The degree of airborne control, navigation, and guidance capabilities.

(8) Does automation allow the controller:

- To make more decisions in a given time?

- To reduce the number of decisions needed to move a given level of traffic?

- To increase the portion of his time available for decision-making?

- To handle more aircraft simultaneously?

- To provide service over a larger block of airspace?

- To reduce the minimum spacing used to separate aircraft?

The results of these questions are tabulated in the section c below. Table B-3 presents a summary of this information.

c. Results

The results of the investigations on the impact of automation on ATC functions and controller decisions are presented in Tables B-4 through B-7.

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Table B-3

IMPACT OF AUTOMATION ON ATC FUNCTIONS AND CONTROLLER DECISIONS

Functions and Events and Associated Controller Decisions (referenced to Level I)	Impact Areas																	
	Function Still Performed?			Same Decisions Needed?			Different or Additional Decisions Needed?			New Tasks Added			Information to Controller Changed?			Decision Timing Changed?		
	II*	III*	IV*	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Handoff or control transfer Locate and identify aircraft Negotiate handoff conditions Accept responsibility Transfer control	-	O	†	-	X	X	O	O	X	O	O	X	O	O	O	-	O	X
Pointout or coordination Locate and identify aircraft Assume responsibility for protection Request coordination	-	X‡	X	-	-	X	-	-	X	O	O	X	O	O	O	-	-	-
Conflict detection and resolution Detect conflict Select and implement control action	-	O	X	-	O	X	-	O	X	§	O	X	O	X	X	**	O	X
Traffic structuring Establish plan Select control actions	-	O	X	-	O	X	-	O	X	-	O	X	O	X	X	O	O	X
Clearance generation Probe potential conflicts Develop conflict-free clearance	-	O	X	-	O	X	-	O	X	O	O	X	O	X	X	-	O	X
Surveillance Detect potential hazard Transmit corrective instructions, if required	-	O	X	-	O	X	O	O	X	O	O	X	O	X	X	O	O	X
Workload management Establish priorities Delegate responsibilities Request flow or spacing restrictions Request help	-	-	O	-	-	O	-	O	O	-	O	O	-	O	O	-	O	O

Legend: - Essentially same as Level I
O Similar to Level I, but substantially modified.
X Extensively different from Level I.

* Automation level.

† Depends on degree to which controller is responsible for movements of individual aircraft.

‡ Need for coordination function will be determined by airspace structure and assignment of control jurisdiction to ATC sectors. If coordination is needed, it will be accomplished in a manner similar to Level II.

§ Controller has option of selecting path or route prediction display.

** Basically no change in decision timing, but some changes possible depending on way controller uses speed readout (ARTS environment) or path or route prediction data (NAS).

Table B-4

ATC INFORMATION FLOW AND DECISION CONSEQUENCES (LEVEL I SYSTEM)

(a) ATC Event: Handoff or Control Transfer

Controller Decisions	Information Needed and Sources	Decision Dissemination Information
Locate and identify aircraft	Aircraft location and track direction (radar display, other ATC sectors--voice message or physical gesture)	Acknowledge "radar contact" by voice message to transferring sector.
Negotiate handoff	Aircraft location and track direction (radar display) Traffic situation (radar display) Aircraft intent: plans of potentially conflicting traffic (flight strips, other ATC sectors)--voice message	With transferring sector, jointly establish action to ensure separation. Agree on control restrictions with transferring sector (voice messages).
Accept responsibility	Flight plans or intent of potentially conflicting traffic (other ATC sectors) Current traffic situation (radar display) Anticipated short-term workload (flight strips, other sectors, coordinators, supervisors)	Assume responsibility by verifying "my control" with applicable restrictions. (Voice message to transferring sector.) Refuse responsibility by advising transferring sector by voice message, or by advising coordinator or supervisor when flow restrictions are required.
Transfer control	Aircraft location (radar display) Altitude (pilot report via A/G radio) Intent (flight strip, pilot request--when applicable)	Handoff data: Aircraft identity, location, intent, to receiving sector (voice message, physical gesture, transfer of flight strips). Transfer communications (voice message to pilot via G/A radio). Transmit beacon code instructions (to pilot via G/A radio). Beacon code management procedures vary considerably among facilities.

Notes regarding consequences, failures and degree of joint responsibility, and general comments:

- If responsibility is not accepted, delay and additional workload will result at transferring sector.

  If responsibility is accepted with potential conflict, receiving sector must resolve conflict within available time; otherwise hazardous situation may result. (Handoff negotiation process is intended to ensure that separation is established between aircraft with potential conflicts, and to verify aircraft short-term intent.)

  Receiving sector assumes responsibility for workload management.

Table B-4 (continued)

(a) ATC Event: Handoff or Control Transfer (concluded)

- Misidentification could lead to faulty control decisions with possibly hazardous results. Misidentification might occur at initial radar contact or subsequently if controller attention is distracted.
- Misunderstanding of restrictions, or failure to comply with specified restrictions, could lead to faulty control decisions and possibly result in hazardous situation.
- Failure to request help could lead to overload situations, might result in decisions that impose user penalty, propagate additional workload, or create difficult or hazardous control situation.
- Identification and beacon code assignment procedures vary considerably among facilities.
- Early handoff can be used to reduce own sector workload, allow next sector more time to formulate plans.
- Failure to respond in timely fashion to initial aircraft call-in could induce additional communications load on transferring sector.

Table B-4 (continued)

(b) ATC Event: Pointout or Coordination

Controller Decisions	Information Needed and Sources	Decision Dissemination Information
Locate and identify aircraft	Location, altitude, and track direction of aircraft to be protected (radar display and information from sector in control--voice message)	(In ARTCC) Place "shrimp boat" with aircraft altitude status on radar target display.
Assume responsibility for protection	Current and anticipated traffic situation (radar display and flight strips) Intentions of aircraft to be protected (sector in control) Updated information on other potentially conflicting traffic (other ATC sectors)	Assume responsibility by verifying "pointout observed" or equivalent statement (voice message to sector in control).
Request coordination	Aircraft location and altitude (radar display and pilot report) Aircraft intent (flight plan or pilot service request)	Request protection by indicating aircraft location, altitude, intentions, and other required information (voice message between sectors).

Notes regarding consequences, failures, and degree of joint responsibility, and general comments:

- Acceptance of "pointout" (coordination target) implies joint responsibility for aircraft operations within specified airspace. Sector assumes responsibility for protecting "pointout" from other aircraft under control. Clear indication of pilot intent and positive separation should be established before pointout is accepted.
- Assumption of responsibility without direct communications could result in delays in required control actions leading to difficult or potentially hazardous situations.
- Coordination is practiced when two controllers share responsibility for a final approach path. Each controller is responsible for controlling his own aircraft and protecting the aircraft under the jurisdiction of the other controller.
- Coordination may be used to manage workload level [see Table B-4(g)].
- Two types of coordination procedures are noted. In the first type, (termed "pointout") two sectors negotiate directly with each other concerning movements and control of aircraft of mutual significance. As a result of this process, one sector may retain communications with an aircraft while that aircraft traverses airspace under the jurisdiction of the other. This is the type of coordination considered in the tables.

  In the second type, an external position, designated a "coordinator," assists in the transfer of control between one sector and another, modifies control (aircraft spacing, speed, traffic patterns) as required by local conditions, facilitates modification of control with adjacent facilities, and participates in the exchange of required ATC, facility status, and weather information. The coordinator performs decision-making duties above and beyond those performed by the radar controller. This type of coordination is to be further investigated in additional data collection efforts.

Table B-4 (continued)

(c) ATC Event: Conflict Detection and Resolution

Controller Decisions	Information Needed and Sources	Decision Dissemination Information
Detect conflict	Traffic situation (radar display) Aircraft altitude (pilot report, as needed) Aircraft intent and flight progress (flight strips) Estimates and revisions (other ATC sectors, as needed)	Advisory information on potential conflicts--to pilot via G/A radio, as needed.
Select and implement control action	Traffic situation (radar displa[illegible] Aircraft altitude, heading, speed (as needed, from pilot report) Aircraft intent (flight strips) Coordination information (other sectors, as needed)	Modify clearances or issue control instructions (speed, heading change) to pilot via G/A radio. Traffic advisory information--to pilot, as needed. Transmit clearance modification data, as needed--to other ATC sectors via interphone.

Notes regarding consequences, failures, and degree of joint responsibility, and general comments:

- Conflict Detection. Failure to detect conflict in time could restrict choice of control actions, require bolder actions later, or could result in hazardous situation.
- Conflict Resolution Action Selection: Choice of control action could induce user operational penalty (delay, interruption to flight profile, added distance, extra maneuvering) or degrade ATC system performance (restrict flow, cause delay or congestion, require rerouting or flight plan modification, create added workload. Delay in selecting or implementing action could require more intrusive control action later, run the risk of distracted attention, or result in peak workload requirements.

Table B-4 (continued)

(d) ATC Event: Traffic Structuring--Merging, Sequencing, and Spacing
Flow Organization--Merging, Sequencing, Spacing, Speed, Altitude, and Routing Control

Controller Decisions	Information Requirements and Sources	Decision Dissemination Information
Establish plan and control requirements: sequence, paths, inter-aircraft spacing, speeds, altitude objectives and restrictions	Aircraft location, altitude, track, and speed (radar display plus pilot reports as needed) Traffic situation (radar display) Aircraft intent (flight strips plus pilot reports, as needed) Control objectives of related ATC sectors: spacing, speeds, and sequence (explicitly stated, voice message or gesture, or inferred from radar display and based on control team experience)	Decisions are developed by controller, but are manifested only when control actions are communicated.
Select and execute control actions to implement plan	Aircraft location, track (radar display) Aircraft altitude, speed, heading (as needed from pilot reports) Traffic situation--relative aircraft positions, trends (radar display)	Transmit clearance modification or control instructions to pilot (via G/A radio). Transmit ATC clearance amendment data, or applicable control information (vector, speed, altitude) to other sectors, as needed.

Notes regarding consequences, failures, and degree of joint responsibility, and general comments:

- Planning procedure can require judgment; e.g., clustering of aircraft by speed class, imposition of delay or penalty to one aircraft to expedite movement and flow of other traffic.

  Faulty plan can result in inefficient utilization of airspace--restrictions in attainable flow rate, imposition of delay, propagation of congestion.

- Performance depends on two things: the quality of the plan and the quality of the execution; e.g., irregular spacing intervals can degrade flow rate and complicate next sector workload.

Table B-4 (continued)

(e) ATC Event: Clearance Generation, Amendment, and Modification

Controller Decisions	Information Requirements and Sources	Decision Dissemination Information
Probe for potential conflicts	Aircraft flight plans and updated flight progress data (flight strips mounted on flight progress board; revisions from other ATC sectors) Traffic situation (relative aircraft position and trends--radar display)	Decisions are manifested through the transmittal of a clearance.
Generate and transmit clearance	Traffic load on planned route (flight strips) Last assigned departure time, if appropriate (flight strips) Delays and ATC workload for alternative routes, as needed (coordination by voice with other sectors) Pilot preferences re: alternative routes and altitudes (via A/G/A radio) Traffic situation (radar display)	Clearance message (clearance limit, cleared route, assigned altitude, applicable restrictions, communications and beacon code instructions) to pilot via G/A radio. Clearance data to other sectors (via sector strip printer or voice messages where appropriate).

Notes regarding consequences, failures, and degree of joint responsibility, and general comments:

- See Table B-4 (d) for comments regarding planning procedures and execution.
- Approval of pilot service requests should be coordinated with adjacent (or downstream) sectors to ensure that decision does not interfere with or adversely affect existing traffic control plans.

Table B-4 (continued)

(f) ATC Event: Surveillance

Controller Decisions	Information Requirements and Sources	Decision Dissemination Information
Detect potential hazard Flight plan deviation Track deviation Altitude deviation Schedule deviation Penetrate restricted airspace Other hazards Weather (icing, turbulence) VFR traffic	Aircraft location and track--radar display. VFR traffic: relative location and velocities--radar display. [There is no means for controller to sense altitude deviation in Level I system. There is no requirement for conformance to schedule estimate under positive radar control in Level I system.]* Pilot reports on weather hazards (A/G radio). Weather clutter indications (radar display). [Controller has no reliable means to sense turbulence and icing hazards in Level I system.]	Transmit advisory message to pilot (G/A radio), covering traffic data, deviation advisory, weather hazard advisory.
Formulate and transmit corrective action (if requested by pilot)	Pilot request for corrective action (A/G radio). Knowledge of aircraft operating and performance characteristics (prior experience). Weather hazards on potential alternative paths (radar display and pilot reports, as applicable).	Transmit corrective instructions to pilot (via G/A radio) alternative altitude, alternative route, alternative heading, and deviation at pilot's discretion. Forward clearance modification and advisory data as needed to other sectors.

Notes regarding consequences, failures, and degree of joint responsibility, and general comments:

- Routine surveillance is given lower priority than services requiring separation between two controlled aircraft. Deviation (from track) is usually not closely monitored unless the aircraft is a traffic factor for other aircraft or is likely to penetrate restricted airspace.
- The pilot is responsible for navigating the aircraft in accordance with an accepted clearance.
- Under nonradar conditions, the pilot is responsible for reporting deviations in estimated flight plan fix times greater than ±3 minutes, or true airspeed deviations greater than ±10 knots.
- Under present rules, ATC responsibility is limited to detecting and advising the pilot of hazards (workload permitting) unless the pilot requests further assistance.

* Square brackets, [ ], indicate comments by authors.

Table B-4 (continued)

(g) ATC Event: Workload Management

Controller Decisions	Information Requirements and Sources	Decision Dissemination Information
Establish priorities for attention	Traffic situations, with urgency rating (radar display) Pilot reports, particularly if an emergency or urgent situation is indicated--e.g., aircraft malfunction (A/G radio, or relayed from one ATC sector to next) Estimates of aircraft and pilot performance (a priori knowledge based on experience)	No discrete indication of priority decisions made by controller. Priorities can be inferred by observing (1) control actions taken by controller (transmitted to pilot or other ATC sectors) and (2) tasks deleted or curtailed by controller (e.g., VFR traffic advisories). Priority decisions can be verified in follow-up discussions with controller.
Delegate responsibility Early handoff Rerouting Coordination	Traffic situation--current workload and workload complexity (radar display) Anticipated future short-term workload (flight strips, flight progress board, other sectors via interphone) Traffic situation on alternative routes and workload situation in associated sectors (via interphone with other ATC sectors or through coordinator or supervisor) Aircraft intentions (flight strips, pilot requests, other ATC sectors) Pilot approval of proposed flight plan changes	Early handoff may be used as a means of managing workload. Arranged by joint agreement between affected sectors. [See Table B-4(a) for specific procedures.] Rerouting decision may be made either by direct agreement between affected sectors, or through coordinator or supervisor (assumes pilot acceptance of route reassignment). Rerouting manifested by clearance modification (transmitted to pilot) and flight plan change (forwarded to ATC sectors via interphone and flight strips). Coordination decisions are usually developed by joint agreement between two affected sectors (direct verbal or interphone). [See Table B-4(b) for procedures and information.]
Request flow restrictions	Traffic situation--current workload (radar display) System and facility status, weather data (notes, interphone, overhead display) Anticipated short-term future workload (flight strips, flight progress board, supervisors, other sectors via interphone)	Refuse entry of additional aircraft to other sectors--direct or via interphone. Request speed and/or intrail spacing restrictions (to other sectors via coordinator, supervisor, or local flow control; direct or by interphones).

Table B-4 (continued)

(g) ATC Event: Workload Management (concluded)

Controller Decisions	Information Requirements and Sources	Decision Dissemination Information
Request help Add staff Cut load	Traffic situation--current workload (radar display) System and facility status, weather data (notes, interphone, overhead display) Anticipated short-term future work-load (flight strips, flight progress board, supervisors, other sectors via interphone)	Controller requests assistance from supervisor (direct or by interphone). Supervisors make decision to add staff (handoff, data positions) or to cut load (e.g., divide sector) to cope with sustained high traffic. Coordinator may provide temporary assistance to deal with short-term burst of traffic.

Notes regarding consequences, failures, and degree of joint responsibility, and general comments:

- Workload management is probably the most individual and subjective element in assessing human and decision-making limitations on capacity. The human operator probably is in the best position to judge whether he can assume more load, but may be reluctant to admit he cannot because of professional pride.
- One of the most significant decisions that can be made by a human controller is deciding when help is needed.
- Joint Responsibility: A key issue is the degree to which supervisory personnel are monitoring and anticipating load buildup so that route assignment and sector manning and configuration are adequate to cope with demand.
- Sectorization and manning practices differ considerably among facilities.
- Coordination can be used as a technique to reduce sector workload (e.g., for an aircraft likely to be in sector for only a brief period, well separated from other controlled traffic, and not interfering with normal sector flow patterns.

Table B-5

IMPACT OF AUTOMATION ON ATC FUNCTICNS AND CONTROLLER DECISIONS (LEVEL II SYSTEM)

(a) ATC Function or Event: Handoff or Control Transfer

1. Associated decisions (referenced to Level I).	Accept responsibility. Identify aircraft. Coordinate control restrictions and flight path intent. Transfer control.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	Is additional data entry needed to establish tracking? Confirm Mode C readout (as needed). Is target ready for handoff? How much data should be displayed for aircraft under control?
5. Are new tasks added?	Acknowledge receipt of handoff. Nondiscrete target, not already tracked, enter aircraft identification and associate with target. Search for arriving "silent-handoff" targets.
6. Are changes in information provided to controller?	Tabular presentation of displayed codes, arriving traffic. Synthetic target symbol. Alphanumeric tag and associated data: clearance altitude (used in ARTCC), altitude, speed (used in TRACONs); (new information, better resolution and presentation). Indication of working position control responsibility.
7. Is decision timing changed?	No reduction is anticipated in decision timing. Possible delay in time controller is aware of arriving handoff because of need to acquire visually blinking target. Limit on time by which handoff must be acknowledged.
8. Other factors to which decisions are sensitive.	Number of entry points. Consistency of handoff location. Anticipation (repetitive traffic, arrival list). Route structure, track assignment. Variations in local practice (sector manning, beacon code change, identification). Reliability of Mode C (altitude) indication.
9. Qualitative assessment of automation effects.	Some reduction in internal communications related to transfer of aircraft identity or location. No change with regard to planning and coordination decisions (unless accounted for by track assignment). Some increase in workload when data entry is required.

Table B-5 (continued)

(b) ATC Function or Event: Pointout or Coordination

1. Associated decisions (referenced to Level I).	Observe and establish pointout. Coordinate flight path intent. Negotiate control restrictions.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	No.
5. Are new tasks added?	No.
6. Are changes in information provided to controller?	Pointout target can be forced on console display together with indication of control responsibility. Target identity and altitude. Improved resolution. Availability of flight strip (local variation).
7. Is decision timing changed?	No significant effect in pointout decisions: • Pointout acquisition • Coordination of flight path intent and operating restrictions.
8. Other factors to which decisions are sensitive.	Instantaneous count; spatial distribution and intentions of traffic within sector.
9. Qualitative assessment of automation effects.	No change with regard to planning and coordination decisions.

Table B-5 (continued)

(c) ATC Function or Event: Conflict Detection and Resolution

1. Associated decisions (referenced to Level I).	Detect conflict. Select appropriate control action and time to act. Determine when situation is resolved.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	Is additional information needed to detect potential conflict?
5. Are new tasks added?	Select (as needed) appropriate functions to display path or route prediction (NAS).
6. Are changes in information provided to controller?	Improved resolution. Altitude and speed (used in TRACONs). Path or route prediction (NAS) up to eight minutes look-ahead). Updated fix estimates.
7. Is decision timing changed?	• No change in the time a controller becomes aware of potential crossing conflict (based on plan view display). Possible change in time controller may sense overtake conflict (if speed readout is available). • No change in time controller may make a decision (en-route controller may resolve conflict well in advance of look-ahead period provided in prediction display). • Updated fix postings may provide early indication of potential conflict.
8. Other factors to which decisions are sensitive.	System parameters (look-ahead time). False alarm incidence with considerable look ahead. Workload level (number of aircraft under control, route and altitude distribution). Separation standards (the use of digital symbols changes the allowable spacing between targets) (NAS). Track assignment may preclude conflict (RNAV airborne capability). Reliance on digital position and Mode C altitude.
9. Qualitative assessment of automation effects.	No change anticipated in timing of control actions to resolve conflicts. Some reduction in voice communications required to acquire altitude data for vertical separation. Allowable separation between targets changes when digital target is used (as contrasted with beacon target) (NAS).

Table B-5 (continued)

(d) ATC Function or Event: Traffic Structuring--Merging, Sequencing, and Spacing

1. Associated decisions (referenced to Level I).	Establish sequence. Plan spacing relations. Plan speed management. Select control actions and time to act.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	No.
5. Are new tasks added?	No.
6. Are changes in information provided to controller?	Improved resolution. Altitude and speed (used in TRACONs). Updated fix estimates.
7. Is decision timing changed?	Possible change in time controller may sense overtake if speed readout is available. (Controllers use change in relative separation in Level I system.)
8. Other factors to which decisions are sensitive.	Route structure or traffic flow organization. Traffic mix (speed, performance). Aircraft response accuracy.
9. Qualitative assessment of automation effects.	Alphanumerics assist controller in remembering aircraft identity, and can provide altitude and speed (if available) data. Possible increase in time available for decision-making due to reduction of other mental burdens. Reduction in some communications related to altitude and speed information.

Table B-5 (continued)

(e) ATC Function or Event: Clearance Generation, Amendment, and Modification

1. Associated decisions (referenced to Level I).	Probe potential conflicts. Develop conflict-free clearance.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	No.
5. Are new tasks added?	Keyboard entry of flight plan revisions, clearance revisions.
6. Are changes in information provided to controller?	Possible improved quality (currentness) of flight plan revision data.
7. Is decision timing changed?	Possibly change in time controller may be aware of potential conflict because of improved flight plan revision data.
8. Other factors to which decisions are sensitive.	Route structure, flow organization. Traffic mix. Environment (weather, facilities). Dimensions of airspace under control. Operations rate.
9. Qualitative assessment of automation effects.	No significant change anticipated in short-term clearance decisions.

Table B-5 (continued)

(f) ATC Function or Event: Surveillance

1. Associated decisions (referenced to Level I).	Detect potentially hazardous deviation. Transmit deviation advisory. Plan corrective action and transmit if requested.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	Is track position still correctly associated with target return?
5. Are new tasks added?	Establish and maintain tracks. Reposition track symbol by keyboard entry.
6. Are changes in information provided to controller?	Deviation from flight plan position (possibly, NAS).
7. Is decision timing changed?	If flight plan deviation indication is available, then possibly controller can sense deviation earlier.
8. Other factors to which decisions are sensitive.	Aircraft flight path (tracking may not be effective under certain maneuvering conditions, at certain speeds). Track reliability (track swap, multiple track, Mode C altitude garble).
9. Qualitative assessment of automation effects.	No significant change results from the availability of tracking capability. Surveillance gets lower priority than situations in which two aircraft are traffic factors for each other. Increase in workload for track maintenance.

Table B-5 (concluded)

(g) ATC Function or Event: Workload Management

1. Associated decisions (referenced to Level I).	Establish priorities. Delegate responsibilities. Request flow restrictions: Flow rate Delay Hold. Request help.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	No.
5. Are new tasks added?	Keyboard entries required to permit resectorization.
6. Are changes in information provided to controller?	Improved quality (currentness) of short-term workload (by means of updated flight progress strips).
7. Is decision timing changed?	No significant changes anticipated in timing of workload management decisions. R-controllers deal with workload on a real-time basis.
8. Other factors to which decisions are sensitive.	Traffic structure and flow organization. Traffic mix (aircraft performance, pilot proficiency). Adjacent sector workload and organization.
9. Qualitative assessment of automation effects.	No significant change in workload management anticipated through introduction of Level II automation. Alphanumeric data assistance may help average controllers to "keep picture" and keep up with workload.

Table B-6

IMPACT OF AUTOMATION ON ATC FUNCTIONS AND CONTROLLER DECISIONS (LEVEL III SYSTEM)

(a) ATC Function or Event: Handoff or Control Transfer

1. Associated decisions (referenced to Level I).	Accept responsibility. Identify aircraft. Coordinate control restrictions and flight path intent. Transfer control.
2. Is function still performed?	Yes, but substantially modified (assume discrete identification and automatic acquisition of all tracks).
3. Are same decisions needed?	No (identity and track transfer are mechanized; control restrictions and flight path intent are specified procedurally).
4. Are different or additional decisions needed?	Confirm validity of identity and aircraft data (i.e., altitude) (might be necessary until confidence is developed in reliability). Is voice communication circuit functioning?
5. Are new tasks added?	Search for arriving targets. Acknowledge arrival of aircraft in area of responsibility (keyboard entry). Monitor voice communication function.
6. Are changes in information provided to controller?	All handoff data displayed visually, requires visual acquisition. Handoff alert cue? (Could be visual and/or aural.)
7. Is decision timing changed?	Need to consider handoff acquisition time (time between handoff offer and acknowledgment by controller).
8. Other factors to which decisions are sensitive.	Number of entry points, route structure. Consistency of handoff location. Anticipation. Distribution of arriving aircraft (between entry points, latitude and longitude at specific entry points).
9. Qualitative assessment of automation effects.	Mechanization features and traffic management procedures change.

Table B-6 (continued)

(b) ATC Function or Event: Pointout or Coordination

1. Associated decisions (referenced to Level I).	Establish or observe pointout. Coordinate flight path intent. Negotiate control restrictions.
2. Is function still performed?	Maybe, depending on airspace structure and assignment of control responsibility.
3. Are same decisions needed?	Yes, if airspace structure requires shared responsibility.
4. Are different or additional decisions needed?	No.
5. Are new tasks added?	No.
6. Are changes in information provided to controller?	Same as Level II if pointout is required.
7. Is decision timing changed?	Same as Level II if pointout is required.
8. Other factors to which decisions are sensitive.	Same as Level II if pointout is required.
9. Qualitative assessment of automation effects.	Same as Level II if pointout is required.

Table B-6 (continued)

(c) ATC Function or Event: Conflict Detection and Resolution

1. Associated decisions (referenced to Level I).	Detect conflict. Select appropriate control action and time. Determine when situation is resolved.
2. Is function still performed?	Yes, but substantially modified. (Assume more highly structured routing and scheduling, conflict-free clearance generation. Conflicts arise primarily from unplanned deviations.)
3. Are same decisions needed?	Yes, but at rate commensurate with routing and scheduling strategy and navigational accuracy.
4. Are different or additional decisions needed?	No.
5. Are new tasks added?	Maybe, depending on implementation of conflict alerting and avoidance.
6. Are changes in information provided to controller?	Conflict alert indication. Identification of conflict pair. Location of potential conflict. Urgency of potential conflict. Recommended avoidance actions.
7. Is decision timing changed?	Depends on system parameters (look-ahead time, closest-point-of-approach criterion, maneuver intention) employed in conflict alleviation algorithms. If look-ahead time is set fairly short to avoid an unacceptable alarm rate, the controller may resolve many situations before an alert is indicated by the conflict avoidance system. Conflict avoidance system establishes limit times at which action must be taken to avoid hazard.
8. Other factors to which decisions are sensitive.	Aircraft maneuver intentions. Acceptable alarm rate. Degree to which controller exercises independent judgment as contrasted with degree to which he depends on computer. Airspace and route structure. Traffic organization. Reliability and quality of target position and path data. Assume controller still responsible for aircraft separation.
9. Qualitative assessment of automation effects.	Conflict avoidance feature may provide screen to detect conflicts not previously eliminated by clearance generation or detected by controller. Provides ATC backup comparable to airborne CAS, but operating with larger warning times.

Table B-6 (continued)

(d) ATC Function or Event: Traffic Structuring--Merging, Sequencing, and Spacing

1. Associated decisions (referenced to Level I).	Establish sequence. Plan spacing relations. Plan speed management. Select control actions and time to act.
2. Is function still performed?	Yes. (Concentrate on terminal metering sequencing and spacing. Concepts extendable to enroute flight situations.)
3. Are same decisions needed?	No (if computer process is functioning).
4. Are different or additional decisions needed?	Yes. Are computer-recommended control actions reasonable? Is computer-controlled processing operating effectively? Should individual computer-recommended actions be accepted or rejected? Is manual intervention in the process required? (partial override or complete reversion) Are automatic data inputs reasonable and proper? (supervisory and aircraft data)
5. Are new tasks added?	• Insertion of relevant operational data - System parameters (metering rate, spacing at the gate, flow patterns, runway direction) are supervisory inputs. - Aircraft data (performance characteristics, final approach speed) are stored or inserted by flight plan. Some information might be needed from controller. Insert via keyboard. • Approve or inhibit command transmission to aircraft (depend on implementation of supervisory review mode).
6. Are changes in information provided to controller?	Level II plus: Suggested control actions for each aircraft (heading, speed, altitude commands). Time of arrival at reference points. Indication of aircraft compliance with control instruction?
7. Is decision timing changed?	If computer-generated suggestions are accepted, computer paces the control process. Need to estimate time required for controller to review and act on computer-generated suggestions. Need to estimate command acquisition time (time between generation of command and acquisition by controller).

Table B-6 (continued)

(d) ATC Function or Event: Traffic Structuring--Merging, Sequencing, and Spacing (concluded)

8. Other factors to which decisions are sensitive.	Compatibility of the algorithm for metering sequencing and spacing with local control practices. Influence of local airspace restrictions. Control mode: heading, track, track + time Command display format (command integrated with target symbol display or located separately--tabular display or separate display). Method of G/A message delivery (voice or data link). Supervisory review mode (send message if OK, or inhibit message if not OK). Aircraft response accuracy and airborne navigational capability. Runway acceptance rate; operational spacing restrictions (i.e., wake turbulence). Final approach speed variations allowable. Rate at which computer recommendations are presented to controller for review. Time allowed to approve recommendations.
9. Qualitative assessment of automation effects.	Maximum operations rate is constrained by runway acceptance and operational factors. A skilled controller probably can control traffic as effectively as a computer-controlled process. Computer process assists average controller, upgrades his effectiveness, permits him to operate effectively in a shorter time, reduces variability between controllers. Automation might allow one controller to control more airspace (sequence and feed from more fixes). A skilled controller can recognize unsuitable system operation.

Table B-6 (continued)

(e) ATC Function or Event: Clearance Generation, Amendment, and Modification

1. Associated decisions (re 3renced to Level I).	Probe potential conflicts. Develop conflict-free clearance.
2. Is function still performed?	Yes. (Assume more highly structured routing and scheduling than in Level II environment, strategic elimination of high-density conflict points through route separation, closer surveillance and updating of flight data on aircraft in the system.)
3. Are same decisions needed?	Yes, with computer assistance.
4. Are different or additional decisions needed?	Yes. Is computer-generated clearance reasonable? Should it be accepted? If more than one alternative is suggested, are any acceptable? Which one is preferable? Is computer-clearance based on all essential information?
5. Are new tasks added?	Enter additional information needed for clearance generation. Enter flight plan changes through keyboard as required. Enter manual clearance overrides as required.
6. Are changes in information provided to controller?	Suggested clearances. Information on potential conflicts (who? where? when?). Indication to controller that action is needed.
7. Is decision timing changed?	• Conflict probe may allow potential conflicts to be displayed to controller earlier than he is aware of them now (when they appear on his scope). [Is this necessarily better? Are better alternatives available with earlier information? How will uncertainties affect conflict prediction? Can early information be used effectively without rigid control of schedule? Will early decisions impose unnecessary penalties?]* • Computer may alert controller when decision is required. Might allow action to be delayed until found to be necessary. • Need to estimate time to review a clearance, and to deliver clearance.
8. Other factors to which decisions are sensitive.	Level II considerations plus criterion for declaring conflict (minimum closest point of approach). Appropriate look-ahead time or clearance limit (compare with existing practice). Sector organization (impact of clearance on decision points downstream). (Assume separation responsibility is vested in ATC). (Assume some aircraft have 4D navigational capability). Mode of clearance delivery.

* Square brackets, [ ], indicate comments by authors.

Table B-6 (continued)

(e) ATC Function or Event: Clearance Generation, Amendment, and Modification (concluded)

9. Qualitative assessment of automation effects.	Strategic route structure design can eliminate crossing conflicts at high activity intersections (thereby eliminating need for a decision). Improved flight plan updating can identify potential conflicts not eliminated by strategic means. Improved airborne navigation provides potential means for managing crossing or merging time at intersections.

Table B-6 (continued)

(f) ATC Function or Event: Surveillance

1. Associated decisions (referenced to Level I).	Detect potential hazard. Transmit advisory. Transmit correction, if requested.
2. Is function still performed?	Yes.
3. Are same decisions needed?	No (if computer process is functioning).
4. Are different or additional decisions needed?	Are computer hazard alerts necessary? Is computer-suggested action acceptable? Has computer detected all hazards that bear advisories?
5. Are new tasks added?	Monitor hazard alert indications. Insert surveillance criteria (system parameter). Review and approve hazard advisories and corrective instructions.
6. Are changes in information provided to controller?	Hazard alert. Suggested control action (if needed).
7. Is decision timing changed?	Computer could generate an alert on a situation that controller might not feel is significant (system parameter selection). Estimate hazard alert acquisition time.
8. Other factors to which decisions are sensitive.	Surveillance tolerances. Acceptable alarm rate. Events appropriate for surveillance. Maneuver intentions. G/A message delivery mode. Surveillance data quality (precision, update rate).
9. Qualitative assessment of automation effects.	Need to assess benefits of computer-assisted surveillance service. Tradeoff between benefits derived from surveillance against added workload imposed on controller (surveillance tolerance is a parameter).

Table B-6 (concluded)

(g) ATC Function or Event: Workload Management

1. Associated decisions (referenced to Level I).	Establish priorities. Delegate responsibilities. Request flow restrictions. Request help.
2. Is function still performed?	Yes.
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	Is additional information required from computer to anticipate and manage workload?
5. Are new tasks added?	Interact with computer to obtain anticipated workload data and to explore alternatives for workload redistribution.
6. Are changes in information provided to controller?	Improved presentation of future workload (tabular arrival lists can be sorted by route and altitude). Information from central flow control.
7. Is decision timing changed?	Provide earlier anticipation of load buildup to smooth and redistribute peak load.
8. Other factors to which decisions are sensitive.	Distribution of arriving traffic Time Track and flight level Entry fixes.
9. Qualitative assessment of automation effects.	Workload management will remain primarily a human judgment assisted by improved organization of data by the computer and improved flow organization procedures.

Table B-7

IMPACT OF AUTOMATION ON ATC FUNCTIONS AND CONTROLLER DECISIONS (LEVEL IV SYSTEM)

(a) ATC Function or Event: Handoff or Control Transfer

1. Associated decisions (referenced to Level I).	Accept responsibility. Identify aircraft. Coordinate control restrictions and flight path intent. Transfer control.
2. Is function still performed?	Maybe (depends on the degree to which controller is responsible for the movements of individual aircraft).
3. Are same decisions needed?	No; if controller <u>is</u> responsible for individual aircraft, handoff becomes routine acknowledgment of track acquisition.
4. Are different or additional decisions needed?	• Are any aircraft arriving in the area of responsibility not properly associated with flight plans? • Is special handling required for any aircraft arriving in the area of responsibility?
5. Are new tasks added?	Monitor status of all aircraft acquired by the system (intent, separation, airborne system operation).
6. Are changes in information provided to controller?	• Aircraft status (flight plan correlation, airborne system function indication). • Handoff alert cues.
7. Is decision timing changed?	• Need to estimate time to detect abnormal aircraft status and probability of that event (flight plan deviation, navigation or communication failure). • If the controller is responsible for acquiring individual tracks, then time to detect is probably the same as Level III.
8. Other factors to which decisions are sensitive.	Controller responsibilities. Is controller responsible for acquiring or acknowledging acquisition of individual aircraft tracks? Is controller responsible for detecting intruders? Sector configuration: Size, route structure, entry points (consistency). Traffic features: Relative spacing along routes Flight path precision Distribution (routes, altitudes).
9. Qualitative assessment of automation effects.	Automated handoff function can change controller handoff activity to detection and handling of nonstandard situations.

Table B-7 (continued)

(b) ATC Function or Event: Pointout or Coordination

1. Associated decisions (referenced to Level I).	Establish or observe pointout. Coordinate flight path intent. Negotiate control restrictions.
2. Is function still performed?	Probably no (depends on airspace structure, traffic flow organization, and assignment of control responsibility).
3. Are same decisions needed?	No. (Coordination on use of shared airspace by traffic on organized tracks becomes planning function. Assume aircraft roquiring special handling--e.g., test, survey, tactical training, refueling. nonstandard routing--will be excluded from Level IV airspace.)
4. Aro different or additional decisions needed?	See conflict resolution and clearance generation.
5. Are new tasks added?	No.
6. Are changes in information provided to controller?	--
7. Is decision timing changed?	--
8. Other factors to which decisions are sensitive.	Airspace structure and flow organization: [Is Level IV Automation restricted to airspace containing only organized (published) paths?] Control responsibility: How is control responsibility assigned for aircraft on organized paths traversing common airspace (common final approach path, crossing intersections)?
9. Qualitative assessment of automation effects.	Procedural changes may delete use of pointout function in airspace where Level IV automation is employed.

Table B-7 (continued)

(c) ATC Function or Event: Conflict Detection and Resolution

1. Associated decisions (referenced to Level I).	Detect conflict. Select appropriate control action and time. Determine when situation is resolved.
2. Is function still performed?	Yes, but substantially modified. (Assume highly organized traffic flow in Level IV environment, generation of conflict-free clearances, automatic conflict alert and alleviation; assume conflicts arise from unplanned deviations.)
3. Are same decisions needed?	No (provided ground based clearance generation and conflict detection and resolution programs are functioning correctly).
4. Are different or additional decisions needed?	• Is controller intervention in the conflict detection and resolution process required? Modify control instructions Modify system or operational parameters Revert to manual control. • Is special handling required for any aircraft under jurisdiction? Is aircraft unable to comply with control instructions? Provide separation or protection to aircraft unable to comply.
5. Are new tasks added?	Detect computer-generated conflict alert. Override computer program as needed. Insert information into computer manually as needed. Interrogate computer to obtain needed information.
6. Are changes in information provided to controller?	Level III plus computer-generated alert for operator action.
7. Is decision timing changed?	• Significant decision times are: Time to detect computer-generated alert (seconds). Time to detect situations requiring operator attention. Time to resolve uncorrected conflict manually is <u>no less than</u> for Level I (but number of uncorrected conflicts should be much less). • Automated conflict resolution permits action selection to be delayed (but the limit would be the time the controller needs to cope with the situation manually).
8. Other factors to which decisions are sensitive.	Reliance on ATC system function (effectiveness, reliability, integrity). Controller responsibilities: Is responsibility for air-to-air separation delegated to or shared with pilots? Are aircraft equipped with air-derived separation assurance devices? Flow organization: Is flow organized so that controller can cope with aircraft unable to comply with control instructions?

Table B-7 (continued)

(c) ATC Function or Event: Conflict Detection and Resolution (concluded)

9. Qualitative assessment of automation effects.	• If ATC system effectiveness, reliability, and integrity are demonstrated to controllers' satisfaction, they will accept a higher level of operations than they could handle manually. • The amount of additional load that controllers would be willing to accept depends on the degree to which they are responsible for air-to-air separation. If controllers are totally responsible, the operations rate would be comparable to Level III. If pilots are made totally responsible for maintaining separation (through compliance with ATC clearances), operations rates may increase to levels consistent with surveillance capability or physical constraints.

Table B-7 (continued)

(J) ATC Function or Event: Traffic Structuring--Merging, Sequencing, and Spacing

1. Associated decisions (referenced to Level I).	Establish sequence. Plan spacing relations. Plan speed management. Select control actions and timing.
2. Is function still performed?	Yes. (Assume highly organized traffic flow, control of arrival time at designated control points, employment of computer-based algorithms to generate clearances and control instructions.)
3. Are same decisions needed?	No (provided computer process is functioning properly).
4. Are different or additional decisions needed?	• Is computer-controller process operating effectively? • Is special handling required for any aircraft? • Is manual intervention in the process required? Insertion of data Override instructions Reversion to noncomputer sequencing and spacing.
5. Are new tasks added?	Same as Level III, except that review and inhibition of control instructions to individual aircraft is accomplished only as needed.
6. Are changes in information provided to controller?	Same as Level III, except that control instructions (transmitted directly to aircraft without controller participation) may be displayed for review by controller.
7. Is decision timing changed?	Significant decision times are: • Time to detect deviation of individual aircraft from planned status. • Time to review sequencing and spacing effectiveness and to determine intervention action.
8. Other factors to which decisions are sensitive.	• Compatibility with local practice (paths, constraints). • Control modes: heading, track, time-of-arrival. • Aircraft navigational capability: 3D, 4D. • Airborne separation assurance capability: Knowledge of traffic situations Control of relative position. • Controller responsibilities Flight path or heading control Aircraft spacing control Sequence and spacing management. • Escape modes: i.e., reversion to less automated modes of control. • Reliance on ATC function. • TCA configuration: size, route structure, number of runways, merge points, feeder fixes.

Table B-7 (continued)

(d) ATC Function or Event: Traffic Structuring--Merging, Sequencing, and Spacing (concluded)

9. Qualitative assessment of automation effects.	Terminal metering and sequencing: • Level III considerations apply. • Maximum operations rate for a given runway is constrained by runway occupancy, wake turbulence, and noise limitations rather than by controller capability. • If the controller has confidence in the system reliability and effectiveness, if airborne users have suitable navigation and separation assurance capability, and if suitable escape and reversion procedures are available, an individual controller might assume responsibility for more airspace than under Level III control. • Level III operations provide direct translation to Level IV, when G/A message delivery is automatic, but with controller inhibit capability. • Ground based automated sequencing and spacing management should be matched with equivalent automation in airborne navigation (path and speed control) capability.

Table B-7 (continued)

(e) ATC Function or Event: Clearance Generation, Amendment, and Modification

1. Associated decisions (referenced to Level I).	Probe potential conflicts. Develop conflict-free clearance.
2. Is function still performed?	Yes (See Level III.)
3. Are same decisions needed?	No (if computer process is operating effectively).
4. Are different or additional decisions needed?	Should individual clearances be reviewed? Is manual intervention needed To override clearance generated by computer? To insert information or data? To modify system parameters?
5. Are new tasks added?	Same as Level III.
6. Are changes in information provided to controller?	Clearance data on arriving aircraft: Clearance limit (fix or altitude). Cleared track and flight level restrictions or modifications to resolve potential conflict. Information on potential conflicting traffic (who? where? when?). Computer indication that controller action is required.
7. Is decision timing changed?	Significant decision times are: • Time to detect computer-generated controller alert (short). • Time to review clearance data and to determine intervention action (variable, but low probability with suitable route structure and scheduling algorithms). [Need to analyze this in terms of specific sector, route, and schedule conditions.]
8. Other factors to which decisions are sensitive.	Airspace organization: size of jurisdiction under control, route structure, and complexity. Traffic features: distribution along tracks, and among tracks and flight levels; aircraft performance; aircraft navigation and separation assurance capability. System parameters: look-ahead time or distance, and separation criteria. Controller responsibility: degree to which responsibility for navigation and separation is centralized in ATC or distributed among pilots.
9. Qualitative assessment of automation effects.	• Level III considerations apply. • A computer can be used to identify those situations that require controller intervention (not amenable to straightforward computer algorithm). • A computer can be used in an interactive manner to aid the controller in decision-making (organize information and assess alternative actions). • Elimination of decision points by route structure and scheduling design may enable the controller to be cognizant over a larger block of airspace than in Levels I and II.

Table B-7 (continued)

(f) ATC Function or Event: Surveillance

1. Associated decisions (referenced to Level I).	Detect potentially hazardous deviation from plan. Transmit deviation advisory. Plan corrective action and transmit if requested.
2. Is function still performed?	Yes. (Surveillance is upgraded to conformance control function in Level IV system.)
3. Are same decisions needed?	No (if computer-controlled surveillance process is functioning).
4. Are different or additional decisions needed?	• Is surveillance process operating effectively? Are all significant deviations (consistent with surveillance criteria) detected? Are advisory messages sent to aircraft acceptable (frequency, urgency)? Are corrective instructions sent to aircraft acceptable (frequency, magnitude, urgency)? Are aircraft complying? • Is manual intervention needed To modify system parameters? To override advisories or instructions? To terminate surveillance?
5. Are new tasks added?	Monitor automatic surveillance process. Obtain surveillance data from computer as needed. Insert data to modify surveillance process. Transmit override instructions. Determine when intervention is needed.
6. Are changes in information provided to controller?	Surveillance data sent to aircraft (on request) Nature (advisory, correction) Content Duration Frequency. Violation of surveillance boundaries (indication of noncompliance). Computer-generated alert for manual intervention.
7. Is decision timing changed?	Significant decision times are: Time to detect computer-generated controller alert (noncompliance, impending boundary violation). Time to review and modify surveillance parameters (variable, but infrequent). Time to intervene--and select action (variable, but infrequent).
8. Other factors to which decisions are sensitive.	Same as Level III.

Table B-7 (continued)

(f) ATC Function or Event: Surveillance

9. Qualitative assessment of automation effects.	• Conformance control process can regulate attainable capacity in Level IV system (by dictating allowable spacing and separation standards, and schedule deviation tolerances). • Level IV surveillance is an integral part of air traffic management process, higher priority than Level I surveillance. • Automatic surveillance relieves the controller of workload burden (provided controller intervention is held at reasonable level). [A reasonable level might be construed as one or two interventions per hour.]

Table B-7 (concluded)

(g) ATC Function or Event: Workload Management

1. Associated decisions (referenced to Level I).	Establish priorities. Delegate responsibilities. Request flow restrictions. Request help.
2. Is function still performed?	Yes (could be managed on broader scale than sector: area, center, facility, or other).
3. Are same decisions needed?	Yes.
4. Are different or additional decisions needed?	Same as Level III.
5. Are new tasks added?	Same as Level III.
6. Are changes in information provided to controller?	Same as Level III.
7. Is decision timing changed?	Same as Level III.
8. Other factors to which decisions are sensitive.	Size of control jurisdiction. Look-ahead time. Routing and schedule structure.
9. Qualitative assessment of automation effects.	• The highly structured routing and scheduling anticipated for the Level IV environment should permit well planned workload distribution and management. • Workload management is essentially a local command (flow control function. • Automation may permit larger sectors, thereby broadening scope of workload management. • Workload management for interacting jurisdictions should be coordinated, rather than being treated independently.

REFERENCES

1. "Engineering Requirements--Computer Program for Metering and Spacing Assistance for ARTS III," ER-D-150-001, Federal Aviation Administration, Washington, D.C. (6 August 1969).

2. "Functional Description for Metering and Spacing Assistance," Federal Aviation Administration, Washington, D.C. (6 August 1969).

3. "Computer-Aided Metering and Spacing with ARTS III," Study Report FAA RD-70-82, Computer Systems Engineering, North Billerica, Massachusetts (December 1970).

4. "ARTS III Enhancement--Statement of Work," Federal Aviation Administration, Washington, D.C. (1 April 1971).

5. "An Associative Processor and Conflict Detection--System Description of the Field Test Model," Federal Aviation Administration, Washington, D.C. (no date, but believe it to be early 1971).

6. "An Associative Processor and Conflict Detection--Test Plan," Federal Aviation Administration, Washington, D.C. (July 1971).

7. "ARTS III System Description," SPO-MD-600, Federal Aviation Administration, Washington, D.C. (3 August 1970).

8. "Interface Control Document NAS Enroute Stage A-ARTS III," SPO-MD-601, Federal Aviation Administration, Washington, D.C. (25 June 1970, with changes dated 12 February 1971).

9. "ARTS III Joint Acceptance Inspection," SPO-MD-603, Federal Aviation Administration, Washington, D.C. (27 July 1971).

10. "NAS Enroute Stage A System Description," SPO-MD-109, Federal Aviation Administration, Washington, D.C. (30 May 1968).

11. "National Airspace System," Indoctrination Booklet, Federal Aviation Administration, Aeronautical Center, FAA Academy, Oklahoma City, Oklahoma (1 August 1967).

12. "Enroute Stage A, Flight Data Processing, Operational Equipment," Federal Aviation Administration, Aeronautical Center, FAA Academy, Oklahoma City, Oklahoma (January 1969).

13. "National Airspace System Enroute Stage A Model 1 Functional Package A Interactions with Air Traffic Control Positions," Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey (April 1968).

14. "National Airspace System Enroute Stage A Model 1 Functional Package B Interactions with Air Traffic Control Positions," Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey (April 1968).

15. "System Description for the Upgraded Third Generation Air Traffic Control System," Working Paper WP 7511, The MITRE Corporation (23 August 1971). (A revised version was issued in January 1972 as FAA-ED-01-1 entitled "Concepts, Design, and Description for the Upgraded Third Generation ATC System.")

16. R. A. Rucker, et al., "Controller Productivity Study," The MITRE Corporation (22 June 1971).

17. "Procedures for the Jacksonville ARTCC High Altitude Beacon Tracking System (NAS Model 1, Functional Package B)," FAA Order 7110.40, Federal Aviation Administration, Washington, D.C. (15 June 1971).

18. "Operational Procedures for Use with Functional Package B," FAA Order ZJX 7031.2A, Federal Aviation Administration, Jacksonville Air Route Traffic Control Center, Jacksonville, Florida (21 June 1971).

Appendix C

RELATIVE CAPACITY ESTIMATING PROCESS

Appendix C

RELATIVE CAPACITY ESTIMATING PROCESS

1. Background

As previously mentioned, the study effort for the second year of the project, A Methodology for Evaluating the Capacity of Air Traffic Control Systems, was focused on the analysis of the controller-centered capacity constraints. Most of the work entailed determination of the effects that the controller can have on the operationally attainable capacity of an automated ATC system. Since the various proposed automation levels are very costly to implement, a method of prediction or inference concerning the controller's impact on the capacity of those future systems based on present characteristics and information is indicated. We have performed this analysis by developing and using an analytical approach that estimates the changes in capacity that depend on controller-centered factors. This section describes the process that was used to estimate these changes. Since the controller impact on the ATC system is only one of the several constraints that have an impact on the capacity of the system,[1]* the capacity estimates obtained with this process are relative to the controller-centered conditions that exist. Appropriately then, the approach developed here is entitled the Relative Capacity Estimating Process, or RECEP.

2. Description

The project team limited its attention to three ATC decision classes or situations.[2] They are:

- Prediction and resolution of potential conflicts by R-controller.†

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* References are listed at the end of this appendix.

† Where some decision-making activities are split among several men working on a sector, "R-controller" (radar controller) denotes the team.

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- Implementation by R-controller of prescribed sequencing and metering requirements.
- Decisions required by traffic loads, facility outages, or other causes to invoke priorities of action or attention by R-controller.

An overall block diagram of the process used in the analysis is shown in Figure C-1. The process uses the traffic and sector characteristics in a scenario structure to obtain the numbers and frequencies of events (such as potential conflicts, overtakes, and the like) requiring a decision to intervene. These events are used in a decision structure, along with the configuration of the ATC operating system and the judgmental factors used by the controller, to estimate the time that would be required in decision-making related to these events. This information is then used, along with the usual sector capacity parameters, in a capacity evaluation process to yield relative capacity estimates for the different sets of input conditions. The specific procedures used in each step of the process are described in the following paragraphs.

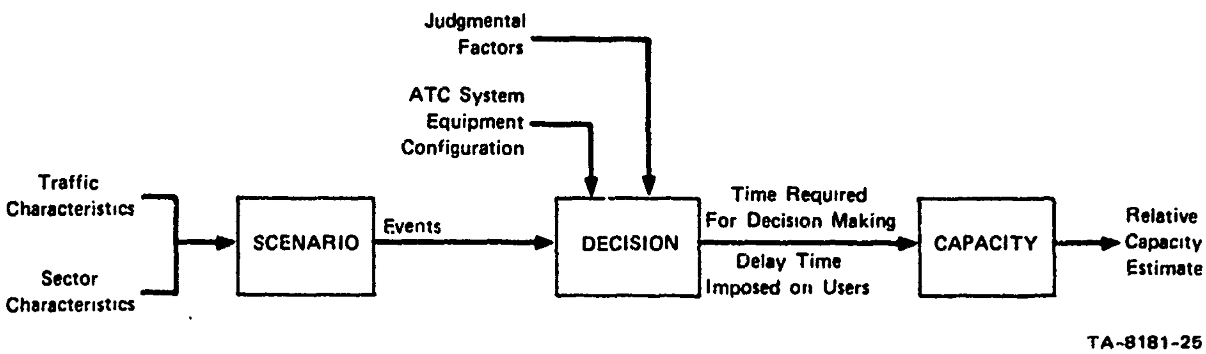

FIGURE C-1 RELATIVE CAPACITY ESTIMATING PROCESS

a. SCENARIO

A simple flow diagram of the SCENARIO portion of RECEP is shown in Figure C-2. A list of sector and traffic characteristic inputs needed is given below:

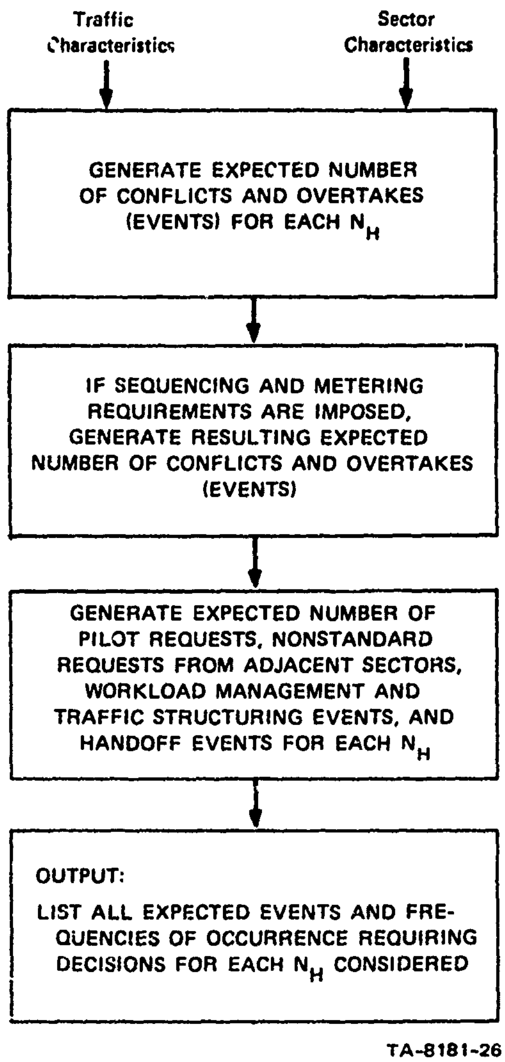

FIGURE C-2 SCENARIO FLOW DIAGRAM

- Input: traffic characteristics
  - The total number of aircraft per hour through the sector (N_H).
  - The flow of traffic on each airway route (aircraft per hour).
  - The percentage of the flow on each airway route that is at each altitude level associated with the route.
  - The percentage of the flow on each airway route that is nonmilitary traffic and the percentage that is military.

- The average speed and the speed distribution at each altitude level for each airway route.
- The climb and descent speeds used at each altitude level.
- The percentage of flow on each transitioning route.

- Input: sector characteristics
  - The airway routes and their lengths.
  - The airway routes that intersect, and the angles of intersection.
  - The sector boundaries.
  - The transitioning routes used in the sector.

The requirement for these particular parameters will become more evident as we describe the expressions required to generate the various types of expected events.

1) Generate the Expected Number of Conflicts and Overtakes

Recall that the first decision class, or situation, mentioned above pertained to prediction of potential conflict. Since this project was concerned with the radar environment, the ATC radar separation minima are the criteria to be maintained. These criteria are as follows:[3]

> If aircraft are separated by less than 1,000 feet in altitude (2,000 feet above FL290), then (1) aircraft less than 40 miles from the surveillance radar antenna must be separated by at least three miles and (2) aircraft 40 miles or more from the radar antenna must be separated by at least five miles.

These minima are often increased in practice where ATCRBS (air traffic control radar beacon system) is used to maintain the stated separations between beacon slashes. The two primary means by which these separation minima can be violated are by (1) intersecting of two aircraft flight paths or (2) one aircraft overtaking another. The possible combination of events resulting from these two violations are listed in Table C-1. Since there are differences among these events in the difficulty of resolving the potential conflicts, if possible the events should also be divided into type of aircraft involved, such as nonmilitary versus nonmilitary, military versus nonmilitary, and military versus military. However, during this effort, there were not sufficient data to make these distinctions meaningful.

Table C-1

EVENTS RESULTING IN VIOLATION OF RADAR SEPARATION MINIMA

Conflicts	Intersection of two aircraft flight paths at the same altitude.
	Intersection of a transitioning (climbing or descending) aircraft with a level aircraft at altitude.
	Intersection of two transitioning aircraft.
Overtakes	Aircraft at the same altitude.
	Aircraft transitioning on the same track.

SRI has developed a number of simple mathematical models for predicting the expected number of this type of event. Data acquired in our measurement phase of the project were compared with estimates generated by these models as verification. The development of the model used to predict the expected number of conflicts at an intersection of two air routes is described in detail in Refs. 4, 5, and 6; only the resulting expressions are presented here. Figure C-3 shows an illustration of the situation of two intersecting routes at the same altitude with different flow rates and velocities.

If the following assumptions are made: (1) a conflict event occurs any time an aircraft along route 1 is closer than X miles to an aircraft along route 2, (2) the arrival of aircraft at the sector entry point, along the air route, is randomly distributed, and (3) the variation in aircraft speed along the air route is negligible, then the relationship for the expected number of conflicts can be expressed as:[6]

$$E_{c_A} = \sum_i \frac{2 f_{i1} f_{i2} X \sqrt{V_{i1}^2 + V_{i2}^2 - 2V_{i1}V_{i2} \cos \alpha}}{V_{i1} V_{i2} \sin \alpha} \qquad (1)$$

where

E_{c_A} = expected number of conflicts per hour

f_{i1} = flow of aircraft at altitude i along route 1 (aircraft per hour)

f_{i2} = flow of aircraft at altitude i along route 2 (aircraft per hour)

X = separation minimum (miles)

V_{i1} = average speed of aircraft at altitude i along route 1 (miles per hour)

V_{i2} = average speed of aircraft at altitude i along route 2, (miles per hour)

α = angle of intersection between the routes

i = different altitude levels used along this air route.

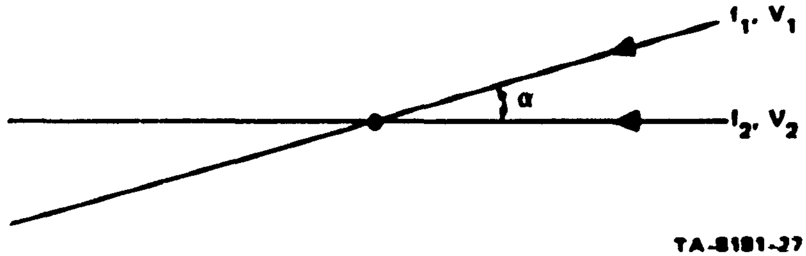

FIGURE C-3 TWO INTERSECTING ROUTES WITH FLOW RATES AND VELOCITIES OF f_1, V_1 AND f_2, V_2

The expected number of conflicts at an intersection of a transitioning aircraft track and a level aircraft route can be expressed as:

$$E_{c_B} = \sum_j \sum_k \frac{2 f_j f_k X \sqrt{V_j^2 + V_k^2 - 2V_j V_k \cos\left[\sin^{-1} \frac{V_t}{V_j}\right]}}{V_j V_k \left[\frac{V_t}{V_j}\right]} \tag{2}$$

where

E_{c_B} = expected number of conflicts per hour

f_j = flow of aircraft along the j^{th} transitioning track (aircraft per hour)

f_k = flow of aircraft along the route at the k^{th} altitude (aircraft per hour)

X = separation minimum (miles)

V_j = average speed of aircraft along the j^{th} transitioning track (miles per hour)

V_k = average speed of the aircraft along the route at the k^{th} altitude (miles per hour)

V_t = transitioning rate for the transitioning aircraft (miles per hour) (i.e., climb or descent rate for the transitioning aircraft)

j = each transitioning track used in the sector

k = each altitude level, used for air traffic that intersects j.

It can also be shown that the expected number of conflicts at an intersection of two transitioning aircraft routes can be expressed as.

$$E_{c_C} = \sum_{\ell}\sum_{m} \frac{2 f_\ell f_m X \sqrt{V_\ell^2 + V_m^2 - 2V_\ell V_m \cos\left[\sin^{-1}\frac{V_{t\ell}}{V_\ell} + \sin^{-1}\frac{V_{tm}}{V_m}\right]}}{V_\ell V_m \left[\frac{V_{t\ell}}{V_\ell} + \frac{V_{tm}}{V_m}\right]} \qquad (3)$$

where

E_{c_C} = expected number of conflicts per hour

f_ℓ = flow of aircraft along the ℓ^{th} transitioning route (aircraft per hour)

f_m = flow of aircraft along the m^{th} transitioning route (aircraft per hour)

X = separation minimum (miles)

V_ℓ = average speed of aircraft along the ℓ^{th} transitioning route (miles per hour)

V_m = average speed of aircraft along the m^{th} transitioning route (miles per hour)

$V_{t\ell}$ = transitioning rate for the aircraft along route ℓ (miles per hour)

ℓ = each transitioning route used in the sector

m = each transitioning route used in sector that intersects ℓ.

Equations (2) and (3) are used only if the situations under consideration pertain to transitioning aircraft and/or level aircraft that coincide along the same track. If the situation involves aircraft along different tracks, then the expression in Eq. (1) is also used to determine the expected number of conflicts at an intersection of transitioning aircraft and level aircraft (E_{c_B}) whose tracks do not coincide, as well as to determine the expected number of conflicts between two different transitioning tracks (E_{c_C}) that do not coincide. Hence, the expressions in Eqs. (1), (2), and (3) give estimates of the expected number of conflicts for each of the intersecting situations listed in Table C-1.

SRI has also developed some simple mathematical models for predicting the expected number of overtakes. These models are described in Refs. 7 and 8, and only the resulting expressions are presented here. If the following assumptions are made:

- An overtake event occurs anytime a faster moving aircraft comes within X miles (separation minima) of a slower moving aircraft, both at the same altitude and along the same air route, or both transitioning along the same route, during the peri , of time the aircraft are within the sector boundaries,
- The arrival of aircraft at the sector entry point, along the air route, are randomly distributed,
- The variations of aircraft speeds along the route are distributed in discrete speed classes,

then the relationship for the expected number of overtakes along an air route (including transitioning aircraft) can be expressed as:

$$E_o = \sum_{i=1}^{n-1} \frac{(\ell + 2X)\, f_i}{V_i} \sum_{k=i+1} \frac{f_k}{V_k} \left[\left(\frac{V_i + V_i'}{2}\right) - \left(\frac{V_k + V_k'}{2}\right)\right] \qquad (4)$$

where

E_o = expected number of overtakes per hour

n = number of discrete speed classes along the route

ℓ = length of air route (miles)

f_i = flow of aircraft travelling at the i^{th} speed (aircraft per hour)

V_i = beginning speed of aircraft in the i^{th} speed class (miles per hour)

f_k = flow of aircraft travelling at the k^{th} speed (aircraft per hour)

V_k = beginning speed of aircraft in the k^{th} speed class (miles per hour)

V_i' = ending speed of aircraft in the i^{th} speed class (miles per hour)

V_k' = ending speed of aircraft in the k^{th} speed class (miles per hour)

X = separation minimum (miles).

As stated above, this expression also includes expected overtakes for transitioning aircraft. Hence, Eq. (4) gives the expected number of overtakes for two overtake situations listed in Table C-1.

We plan to develop overtake models based on more sophisticated separation and speed assumptions; they will be compared for agreement with the models presented here.

Adding the expected conflict events and expected overtake events together yields a total of four possible expected conflict events that could occur. These four possible expected conflict events are then determined for each N_H.

2) Generate Expected Number of Conflicts and Overtakes Resulting from Imposed Sequencing and Metering Requirements

If the particular sector of interest has some specific sequencing and metering requirements placed on it, the expected number of conflicts and overtake events resulting from these requirements must be determined. These events can be calculated using the same expressions and procedures outlined in "1)" above, substituting separation imposed operationally for those specified by radar minima. For the air routes on which these restrictions are imposed, the values for the expected conflicts and overtake expressions calculated here will be used instead of the values obtained in "1)" above.

3) Generate Expected Number of Other Types of Events

The third class of events to be generated includes the events associated with pilot approval requests, requests from adjacent sectors (such as coordination or pointouts) and structuring and workload-planning events. These events are generated in the following manner. Events resulting from pilot approval requests are generated by assuming that they are linearly proportional to the number of aircraft handled by the controller. Therefore, the expression for the expected number of pilot approval request events is simply

$$E_{PR} = K_1 N_H \tag{5}$$

where

E_{PR} = expected number of pilot approval request events per hour

K_1 = a constant

N_H = number of aircraft per hour through the sector.

The value for K_1 was obtained from data collected during the ARTCC data collection stage as outlined and discussed in Appendix D. Pilot approval requests were recorded during this data collection stage along with the number of aircraft through the sector during the observation period. The average percentage of the sector traffic flow that makes pilot approval requests was then determined from all of the time periods that data were collected. This value was used for K_1 in RECEP.

Similarly, assuming that the expected number of events resulting from requests from adjacent sectors (such as pointouts, blocks, and the like) is proportional to the number of aircraft handled by the sector, then

$$E_{NS} = K_2 N_H \tag{6}$$

where

E_{NS} = expected number of contiguous sector requests, (events per hour)

K_2 = a constant

N_H = number of aircraft per hour through the sector.

The value for K_2 was also obtained from data collected as outlined in Appendix D. During the data collection stage, nonstandard requests from contiguous sectors, such as information pointouts, blocks, and so on, were recorded along with sector entry flow rates. The average percentage of nonstandard requests from adjacent sectors that was observed compared to the number of aircraft per hour through the sector for all of the observation periods was calculated, and this value was used as K_2 in RECEP

During our measurement program at Oakland and at Chicago ARTCCs, as well as during visits to other centers, we observed a great deal of coordination effort between sectors. These coordination efforts are usually associated with clarification and/or information exchange on certain aircraft that are of joint interest to two or more sectors. This could include information on an aircraft handoff, a pointout, or the like. This exchange is above and beyond the information that usually occurs with this type of effort. To account for these efforts, we assumed that the expected number of events resulting from sector coordination is again proportional to the number of aircraft through the sector during the same period of time. Hence:

$$E_{sc} = K_3 N_H \qquad (7)$$

where

E_{sc} = expected number of sector coordination events per hour

K_3 = a constant

N_H = number of aircraft per hour through the sector.

There are some decisions concerning handoff events that are judgment-based and hence treated in RECEP. During periods of heavy peak traffic, such things as when and where handoffs should be made to balance the traffic load are important aspects of a decision that must be considered. Since on the average there are two handoffs per aircraft through a sector, decisions associated with handoffs are acounted for in RECEP by

$$E_{HO} = 2N_H \qquad (8)$$

where

E_{HO} = expected number of sector handoff events per hour

N_H = number of aircraft per hour through the sector.

The final class of events to be treated is associated with the portion of the controller's work that is spent in trying to structure the traffic flow so that the workload is roughly leveled out over a period of time. The controller must take planning decisions on every aircraft that comes into the sector. Consequently, associated with each aircraft through the sector are certain basic traffic structuring events. If it is assumed that these events are proportional to the number of aircraft through the sector, then they can be expressed as

$$E_{TS} = K_4 N_H \qquad (9)$$

where

E_{TS} = the expected number of controller traffic structuring events per hour

K_4 = average number of traffic structuring events per aircraft

N_H = number of aircraft per hour through the sector.

4) Output

Table C-2 shows the list of events that require control[illegible] intervention and associated decision-making time for resolution. [illegible] events are the output of the SCENARIO portion of RECEP and are determ[illegible]d for each N_H considered.

b. DECISION

A simple flow diagram for the DECISION portion of RECEP (see box in Figure C-1) is shown in Figure C-4. The inputs required are:

- List of events for each N_H (shown in Table C-2).
- ATC system equipment configuration. (Must specify automation level to be used in the process. The four options are described in Appendix B.)
- Dominant judgmental factor
  - Perceived responsibilities
  - Perceived adequacy of system
  - Perceived system reliability

- Expected visibility of action
- Latitude of reasonable decision objectives.

The requirement for these parameters will become more evident as we describe the expressions developed to generate the time required to make various decisions.

1) Generate Decision-Making Time Required for Each Event

Appendix A presents the discussion and descriptions of the decision process proposed for use in RECEP. The process divided an ATC decision into three phases. They are: (1) deviation recognition, (2) situation assessment, and (3) action selection. Each of these phases consisted of several steps that were postulated as the (implied)

Table C-2

LIST OF EXPECTED EVENTS REQUIRING DECISIONS

E_{CA}	- Expected number of conflicts per hour between two intersecting routes.
E_{CB}	- Expected number of conflicts per hour at an intersection of a transitioning route and a level route.
E_{CC}	- Expected number of conflicts per hour at an intersection of two transitioning routes.
E_{O}	- Expected number of overtakes per hour.
E_{PR}	- Expected number of pilot approval requests per hour.
E_{NS}	- Expected number of nonstandard contiguous sector requests per hour.
E_{SC}	- Expected number of sector coordination events per hour.
E_{HO}	- Expected number of sector handoff events per hour.
E_{TS}	- Expected number of traffic structuring events per hour.

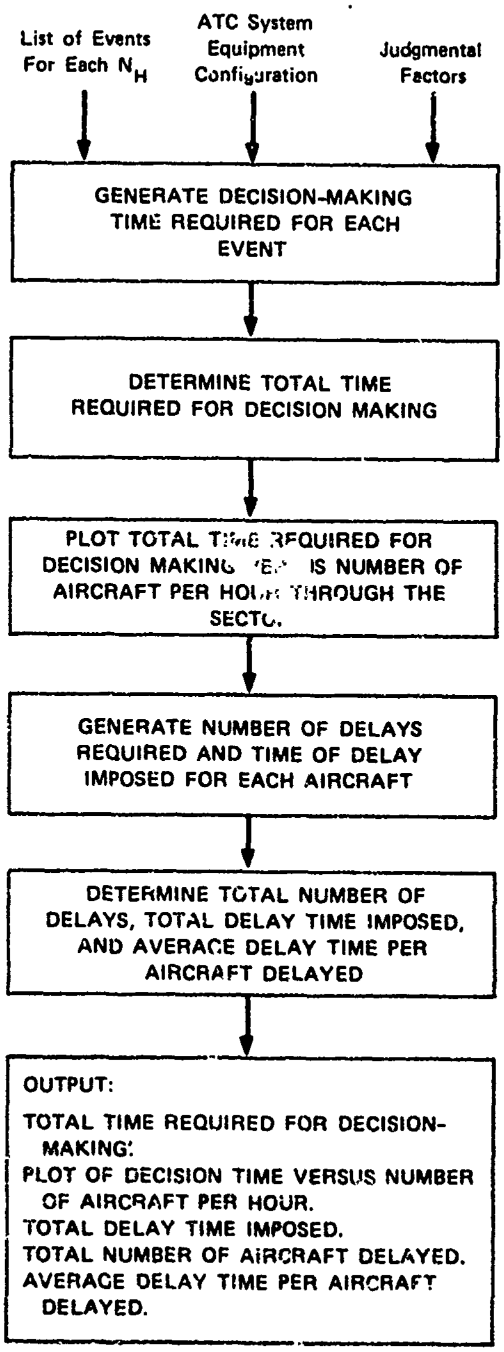

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FIGURE C-[illegible] DECISION FLOW DIAGRAM procedure used by the controller in making a decision. Ideally then, to determine the amount of time required in making a decision concerning one of the possible events one should know the amount of time required to perform each step of the three phases of a decision. However, since there are relatively little substantive data available in the field of ATC controller decision-making that is concerned with the controller's mental process, judgmental factors used, and time required for each step in the process to make a decision, and also since it is beyond the scope of this particular project to undertake a major effort to obtain this information, we will assume that the decision-making time for each event is a function of the judgmental factors and the ATC operating equipment configuration. Hence, for a given particular type of event, and a given judgmental factor or combination of judgmental factors along with a given automation level, we could specify the time required to make a decision if we knew the functional mathematical relationship. Since we do not know the functional relationship between these parameters, we assumed that given the parameters, we could measure the decision time required. Hence, theoretically, for each event we could generate a matrix similar to the one shown in Table C-3.

However, it would be an extremely large undertaking to try to obtain all of the elements of the matrix. Since there are 31 possible combinations* of the five postulated judgmental factors, four automation levels for each combination, and nine possible types of events, the total number of matrix elements to be measured and estimated is $31 \times 4 \times 9$, or 1,116. This number was reduced to a manageable size by first assuming that, although all five of the postulated jugmental factors are active, there is always a dominant one. Making this assumption reduces the elements in the matrix to a total of $5 \times 4 \times 9$, or 180. This is still a rather large number of elements; however, all of the elements are probably not unique. For instance, from our Oakland center measurements, we found one pattern of judgmental factors consistently active and used this single combination in our analysis.

Table C-4 shows an example of the type of matrix that was used for each of the nine types of expected events to obtain the decision-making time required.

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* There are 31 combinations of the five judgmental factors, if they are taken one at a time, two at a time, three at a time, four at a time, or all five at a time.

Table C-3

MATRIX RELATING JUDGMENTAL FACTORS AND AUTOMATION LEVEL TO DECISION-MAKING TIME

Factors	Automation Level			
	1	2	3	4
1	DT_{11}	DT_{12}	DT_{13}	DT_{14}
2	DT_{21}	.	.	.
3	.	DT_{32}	.	.
4	.	.	DT_{43}	.
5	.	.	.	DT_{54}

Table C-4

MATRIX RELATING DOMINANT JUDGMENTAL FACTORS AND AUTOMATION LEVEL TO DECISION-MAKING TIME

Factors	Automation Level			
	1	2	3	4
1	T_{11}	T_{12}	T_{13}	T_{14}
2	T_{21}	T_{22}	T_{23}	T_{24}
3	.	.	.	.
4	.	.	.	.
5	T_{51}	T_{52}	T_{53}	T_{54}

The information in Appendix B concerning the effects of decision-making postulated for each of the automation levels was used along with the Class B data (see Appendix D) and information obtained from the structured interviews with the controllers to determine the matrix element values for each type of event. The values used in the process are presented and discussed in Appendix E.

The total time required for decision-making during the time period of interest is obtained by summing up the decision time required for each event. Hence,

$$T_{DM} = \sum_{i} E_i \, T_i \qquad (10)$$

where

T_{DM} = total time required for decision-making per hour

E_i = expected number of i^{th} events per hour

T_i = decision time required for each of the i^{th} events.

This is determined for the events associated with each N_H.

2) Plot Total Decision Time Versus N_H

A plot of the total decision time versus the number of aircraft handled can be generated. If desired this plot can be a family of curves for different automation levels, as shown in Figure C-5.

3) Generate Number of Delays Required and Time Delay per Event

The number of aircraft delayed and the delay time imposed per aircraft will be obtained from a matrix for each type of event. The matrix will be as shown in Table C-5.

The elements of the matrix were to be obtained as estimates during the ARTCC data collection stage, as outlined in Appendix D, using the Class D data collected during the observation periods and information obtained concerning delays during the structured interview with the controllers. Average delay times imposed per aircraft

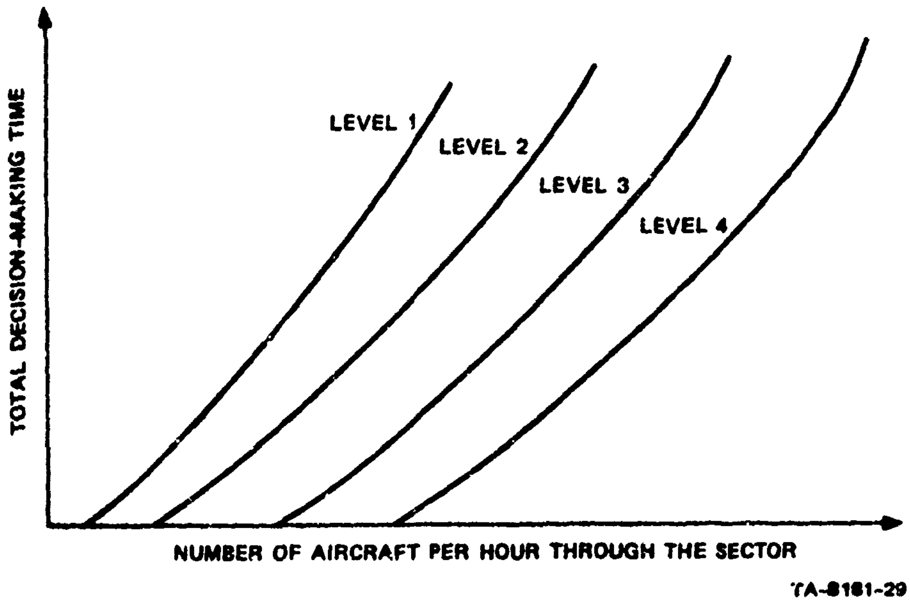

FIGURE C-5 DECISION-MAKING TIME AS A FUNCTION OF AIRCRAFT PER HOUR

Table C-5

MATRIX RELATING EVENT TYPE, NUMBER OF AIRCRAFT DELAYED, AND DELAY TIME

Event Type	Number of Aircraft Delayed	Delay Time Imposed per Aircraft Delayed
E_{OA}	N_{OA}	T_{OA}
E_{OB}	N_{OB}	T_{OB}
.	.	.
.	.	.
.	.	.
.	.	.
E_{TS}	N_{TS}	T_{TS}

along with the number of aircraft delayed were to be calculated from the Class B data. Information from the structured interviews was to be used to relate the delay times and the number of aircraft delayed to the various event types. (Due to time limitation the delay information data was not processed during the year of the study effort.)

4) Determine Other Delay Parameters

The total number of aircraft delayed, the total delay time imposed, and the average delay time imposed per aircraft delayed will be calculated here. The total delay time imposed per hour can be determined by summing up the delay time imposed for each event. Therefore, the expression for the total delay time is

$$T_L = \sum_i E_i N_i T_{Di} \qquad (11)$$

where

T_L = total delay time imposed per hour

E_i = expected number of i events

N_i = number of aircraft delayed for each of the i^{th} events

T_{Di} = delay time imposed per i^{th} event aircraft delayed.

These values will all be available from the matrix shown in Table C-5.

The total number of aircraft delayed can be determined from the following expression:

$$A_D = \sum_i E_i \cdot N_i \qquad (12)$$

where

A_D = total number of aircraft delayed

E_i = expected number of i events

N_i = number of aircraft delayed for each of the i^{th} events.

The average delay time imposed per aircraft delayed can be determined from

$$\overline{T}_A = T_L/A_D \tag{13}$$

where

$\overline{T}_A$ = average delay time imposed per aircraft delayed

T_L = total delay time imposed

A_D = total number of aircraft delayed.

5) Output

The output from the DECISION portion of RECEP consists of the total time required for decision-making, Eq. (10); the total delay time imposed, Eq. (11); the total number of aircraft delayed, Eq. (12); the average delay time imposed per aircraft delayed, Eq. (13); and the plot of decision time versus number of aircraft per hour passing through the sector.

c. CAPACITY

In Figure C-1 the last box represents the CAPACITY portion of RECEP. A simple flow diagram of this portion is shown in Figure C-6. The inputs required are:

- Sector traffic characteristics
  - Time period of observation (minutes)
  - Number of aircraft entering sector during observation period
  - Sector time history of each aircraft during observation period
- Total ime required for decision-making for each set of events associated with an N_H.

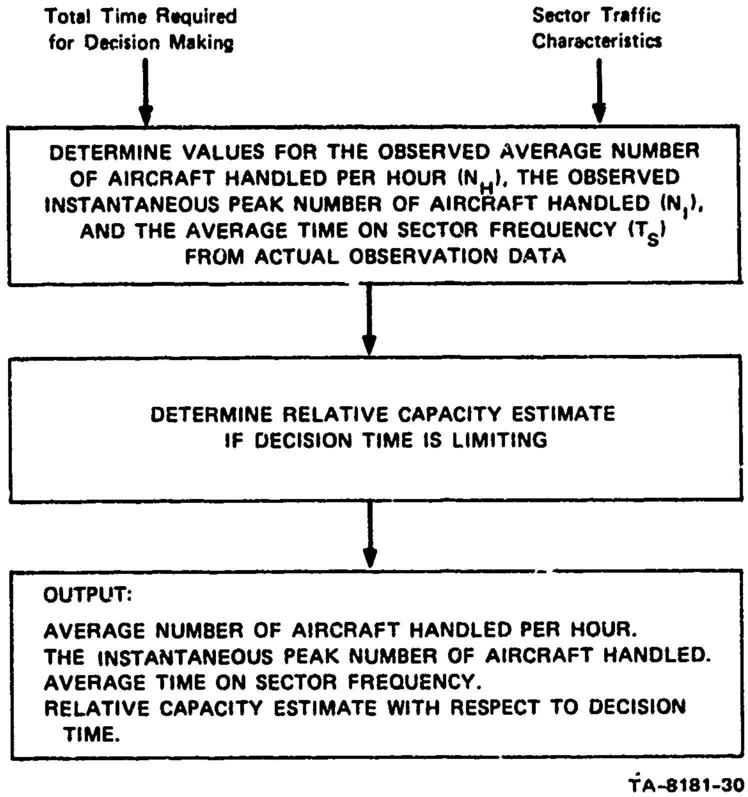

FIGURE C-6 CAPACITY FLOW DIAGRAM

1) Determine Sector Parameter Values from Observation Data

Using the data obtained during the time period spent observing traffic flow, sector parameter values--such as average number of aircraft handled per hour (N_H), instantaneous peak number of aircraft handled (N_I), and sector time on frequency (T_S)--can be determined. The values for the observed N_H can be obtained from:

$$N_H = \frac{(A_I + A_O)/2}{O_p/60} \qquad (14)$$

where

N_H = average number of aircraft handled per hour

A_I = total number of aircraft entering the sector during the observation period

A_O = total number of aircraft leaving the sector during the observation period

O_p = observation period (minutes).

A_I, A_O, and O_p can be tabulated from the data (called "Class B data") collected at the sector of interest during the data collection effort outlined in Appendix D.

Also, from the data collected during the observation period the highest instantaneous peak number of aircraft handled can be tabulated for the sector. The average time on sector frequency can be determined by making a frequency of occurrence chart of the number of minutes each aircraft that passes through the sector is on the sector's frequency (under sector control) during the observation period. Using this chart, the average time on sector frequency is

$$\overline{Ts} = \frac{1}{n} \sum_{i=1}^{m} T_i \, f_i \qquad (15)$$

where

$\overline{Ts}$ = average time on the sector frequency per aircraft

n = total number of aircraft observed

m = total number of different values observed for aircraft minutes on frequency

T_i = the i^{th} value of aircraft minutes on frequency

f_i = frequency of occurrence of T_i.

Also, the standard deviation associated with the average time on frequency per aircraft is

$$S_s = \sqrt{\frac{1}{n} \sum_{i=1}^{m} (T_i - \overline{Ts})^2 f_i} \qquad (16)$$

where

S_s = standard deviation of average time on sector frequency per aircraft

n = total number of aircraft observed

m = total number of different values observed for aircraft minutes on frequency

T_i = the i^{th} value of aircraft minutes on frequency

$\overline{Ts}$ = average time on sector frequency per aircraft

f_i = frequency of occurrence of T_i.

The average time on sector frequency per aircraft was chosen as the parameter rather than the more conventional average sector transit time because in our observations at the Oakland Center--before starting the data taking effort--we observed that aircraft came under the control of the controller (or sector frequency) 10 to 20 miles before entering the sector. Also, aircraft were asked to change frequency for control by the next contiguous sector while still 10 to 20 miles away from the next sector boundary.

2) Determine Relative Capacity Estimate

The relative capacity estimate with respect to the controller's decision-making time requirement is a difficult number to quantify. It can be inferred on a best estimate basis from observation, interview, and analysis. By observing the controller under different traffic loads, calculating the number of minutes spent in decision-making for those loads, asking the controller his own assessment of how busy he was, and asking the controller his own assessment of capacity, one can eventually iterate to a value of relative capacity with respect to decision time required. An analysis can be performed to determine how sensitive the results or prediction are to the best estimate of capacity relative to the controller's decision-making constraint.

3) Output

The output from the CAPACITY portion of RECEP consists of the average number of aircraft handled per hour calculated from the data taken during each observation period, the instantaneous peak number of aircraft handled, the average time on sector frequency per aircraft, and the best estimate of capacity relative to the controller's decision time requirement.

REFERENCES

1. R. S. Ratner, et al., "A Methodology for Evaluating the Capacity of Air Traffic Control Systems," First Annual Report, SRI Project 8181, Stanford Research Institute, Menlo Park, California, October 1970.

2. R. S. Ratner, "Capacity Limitations Associated with Controller Judgmental Factors," Initial Briefing for FAA Subprogram Review, SRI Project 8181, Stanford Research Institute, Menlo Park, California, 8 October 1971.

3. "Enroute Air Traffic Control," FAA, 7110.9, Department of Transportation, Washington, D.C., October 1967.

4. M. W. Siddiqee, "A Mathematical Model for Conflict Prediction," Technical Memorandum No. 3, SRI Project 1096, Stanford Research Institute, Menlo Park, California, May 1971.

5. _____________, "Conflict Prediction Model Based on Radar Separation Rules," Technical Memorandum No. 41, SRI Project 1096, Stanford Research Institute, Menlo Park, California, January 1972.

6. _____________, "An Extension of the Conflict Prediction Model," Technical Memorandum No. 8, SRI Project 1096, Stanford Research Institute, Menlo Park, California, January 1972.

7. _____________, "Air Route Capacity Models," File Note 21, SRI Project 1096, Stanford Research Institute, Menlo Park, California, September 1971.

8. R. S. Ratner, "Probabilistic Representation of Overtake Events," to be published.

Appendix D

DATA COLLECTION AND MEASUREMENT TECHNIQUE

Appendix D

DATA COLLECTION AND MEASUREMENT TECHNIQUE

1. Data Required

To calibrate and use RECEP to determine its feasibility, the information and data listed below had to be obtained from the center or TRACON where the data collection takes place. The data and information were categorized into three basic classes that were called A, B, and C, described in the listing below. Because the information in each class was acquired by different techniques, there are some items categorized in the different classes that are similar.

- Class A data--need to know
  - Objective

    Related to ATC organization (7110-manual).

    Related to facility management (operating manuals, letters of agreement, and so on).

    Related to controller.
  - R-controller tasks.
  - Changes in R-controller tasks as a function of the different automation features.
  - Lines of authority and responsibility. A descriptive model covering the personnel subsystem primarily concerned with factors contributing to the controllers' attitudes toward their jobs. This includes the facility training procedure.
  - Sector characteristics

    Boundaries

    Airway route structures

    Number of route intersections

    Route flow rates and directions

    Degree of adherence to route structure

    Number of peak load periods per day

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Time of day when peak loads occur

Duration of each peak load period.

- Class B data--need to measure as a function of time

  - Aircraft related

    Identification and type

    Planned route and altitude

    Sector entry handoff time

    Sector entry handoff location

    Call-in time

    Sector exit handoff time

    Sector exit handoff location

    Frequency change time and location

    Other.

  - Control instructions

    Speed change

    Altitude change

    Heading change

    Holding

    Other.

  - Controller requests

    Altitude indication

    Speed indication

    Heading

    Other.

  - Status report (from pilot)

    Altitude

    Speed

    Heading

    Other.

- Pilot requests

    Altitude change

    Course deviation

    Speed change

    Other.

- Advisories

    Traffic to IFR aircraft

    Traffic to VFR aircraft

    Weather

    Other.

- Intercontroller liaison

    Information pointout

    Air space block

    Clearance coordination

    Flow control coordination

    Coordination with contiguous sectors

    Request for assistance

    Other.

• Class C data

  - Need to know

    List of judgmental factors

    List of controller objectives.

  - Need to measure the time the following factors enter the controllers' decision process, along with the judgmental factors used:

    When significant deviation perceived

    Problem urgency priority

    Situation assessment

    Important situational measures considered

    Situational control objectives

Action alternatives considered

Other.

2. Field Data Collection Methodology

Field data were collected in two phases. All efforts undertaken in Phase I were concerned with verifying the feasibility of the RECEP approach. Because of its location and accessibility, the Oakland ARTCC was used for the data collection effort for Phase I.

Phase II was concerned with trying to extend and/or generalize the RECEP approach. As a part of this phase, measurements were taken at the Chicago ARTCC to determine if the approach could be generalized to include facilities that handle large numbers of aircraft. Also, the FAA awarded us an extension to this year's effort to undertake measurements in several terminal areas to determine if the approach can be extended to that type of facility. The terminal measurements are currently in progress. After these measurements have been taken and analyzed, a supplement to this final report, containing the findings and results of this work, will be issued.

The techniques and procedures used in the two phases are described below. Most of the information desired in Class A was obtained and compiled from FAA and local facility official documents, reports, and notes. Data are available at most of the centers from which one can ascertain the sector characteristics included in Class A. Other route flow information can also be obtained from the Class B data. The data desired in Class B were obtained by structured observations, at the center, and the Class C data were obtained by structured interviews and "what-if-games" with controllers from the center.

a. Selecting the Environment to be Observed

1) Facility

On the basis of convenience of access, and prior acquaintance with staff and operations, the Oakland ARTCC was chosen as the data collection site for Phase I. For Phase II, on the basis of recommendation from personnel in FAA Air Traffic Services (ATS), the Chicago ARTCC was chosen as being representative of a center that handles a large number of aircraft as well as having some complex airspace structure.

2) Sector

It was agreed that control operations would be sampled in airspace most likely to reflect system capacity in terms of responsiveness to user demand for the widest variety of services possible, within the operating context of the selected facility. Oakland Center personnel recommend High Altitude Sector 5 (now redesignated 42), on the grounds of high overall density, complexity of airway structure, mix of civil and military jet traffic, and prevalence of jet traffic transitioning to and from high altitudes.

On the basis of recommendations from ATS and Chicago Center personnel, the Bradford High Altitude, the Joliet High Altitude, and the Papi Arrival sectors were selected for observations during Phase II.

3) Time Period for Observing Control Activity

In consultation with Oakland Center personnel, and confirmed by our own preliminary observation, two daily periods of peak activity were identified in the chosen Oakland sector: 0900 to 1015 and 1100 to 1230, PST. The first was due principally to a concentration of departing air carrier flights from San Francisco and San Jose, while the second resulted from a concentration of arrivals. During the first period, there was also a concentration of military training missions outbound from bases in the vicinity of Sector 42. During the 20 working day data collection period, the first 15 days were confined to collecting data on the morning departure peak, while the last five were given exclusively to the midday arrival peak.

4) Controller Personnel

It had been initially stipulated that control operations would be observed under routine conditions; therefore, no special personnel requirements were levied on the controller staff manning Oakland Sector 42. Records were kept of the qualification status of controllers observed during data collection, but no controllers were selected for special assignment to duty during observation periods. The same procedure was followed at the Chicago Center.

b. Collecting the Data

1) Direct Observation of Control Actions

Two SRI staff members familiar with the structure of Oakland Sector 42 and trained in air traffic control procedures manually took time-annotated records of all communication transactions involving radar and handoff controllers at the sector working position. One SRI observer concentrated exclusively on the radar controller and the other on the handoff controller, by means of headsets plugged into appropriate jacks. A sample of some of the data recorded is shown in Figure D-1.

At the Chicago Center, since the radar controllers nearly always also performed the handoff functions, one SRI staff member was used at each of the three sectors to record the transactions.

2) Videotape Recording the Radar Display

While direct observation of control actions was occurring, a scan-converted radar display identical to that used by the control team was videotaped, accompanied with audio from the handoff controller's position. For this purpose a seven-inch maintenance radarscope was photographed with a Sony AV-3400 camera and videotape recorder, with audio fed from terminals in the interphone recording channel to the microphone input of the videotape system.

During the observation period at the Chicago Center, the video recording process used at the Oakland Center was used only on the Joliet sector. This sector was chosen because it was a high altitude transition sector, as was the Oakland 42 Sector. Since these two sectors were somewhat similar, some rudimentary comparison and analysis of the results could be performed.

3) Identifying Situation for Interview

At the conclusion of a data collection period, the SRI observers analyzed their notes and the videotape for that period and chose from one to three complete episodes of control transactions for possible interview. The criteria used by the SRI observers for selection of situations was that the situations (1) permitted both antecedent and consequent events to be identified and causal relationships to be inferred (leading to estimates of decision-making time), and (2) furnished insights into the significance of the judgmental factors postulated.

ID	TIME	EVENT	NOTES
ADOPT56	1936	∇	F290.5
UA486	1936	Δ	A310
		(I)	
UA123	1937	Δ	A380
		(I)	
DOBE88	1938	Δ	A270
		(I)	
DOBE88	1938	Δ	A330
		(A)	Expect lower in about 50 miles
UA123	1939	(A)	↓A280
UA926	1939	Δ	↑A240
		(I)	
UA943	1940	Δ	A390
		(I)	
UA943	1941	(A)	↓A240
UA926	1942	A	
		A̲	A280
DOBE89	1942	∇	F290.5
UA926	1942	H	
		H̲	080
UA123	1943	(A)	↓A240
UA926	1943	(A)	Report leaving A330
UA373	1944	Δ	A330
		(I)	
		(A)	↓A290
DOBE92	1944	Δ	↑A240 ← POSSIBLE SITUATION
		(I)	
		(A)	↑A280
DL814	1945	Δ	↑A240 ← POSSIBLE SITUATION
		(I)	
		(A)	↑A290
UA953	1945	Δ	A360
		(I)	
UA926		∇	F132.05
UA123		A	
		A̲	A280
		∇	F125.5
		∇	F132.05
DOBE8		∇	F319.1
UA747	1946	Δ	A360
		H̲	Direct MOD

ID	TIME	EVENT	NOTES
UA943	1946	(TA)	MIL Climbing to A280 (DOBE92)
DL814	1947	A	
		A̲	A 24.7
		(A)	↑A270 Expect higher East of J6
		(H)	086 to ILC
UA943	1947	(A)	Clear of traffic ↓A240
UA747	1948	(A)	↓A240
UA373	1948	A	
		A̲	Out of A370
DL814		A	
		A̲	At A270
DL814		(A)	Clear of traffic ↑A330, A MIL at A280
DOBE92		A	
		A̲	Out of A275
UA747	1949	A̲	Out of A330
TW31	1949	Δ	A380
		(I)	
UA271		Δ	A380
UA943	1949	∇	F125.5
TW31	1950	(A)	↓A240
UA373		(A)	↓A240
		∇	F125.5
DL814	1950	A	
		A̲	Out of A290
		(TA)	
DOBE92		A	
		A̲	Level A280
DL814	1951	∇	F132.05
DOBE92		(TA)	
		∇	280.3
UA271	1952	(A)	↓A240
UA271	1952	(H)	Cleared to OAK
AA140	1953	Δ	A240
		(I)	
		(A)	↑A370

∇ = Controller instruction to pilot to change frequency

Δ = Pilot initial call in on sector frequency

(I) = Controller instruction to pilot to identify

(A) = Controller giving altitude instruction to pilot

A̲ = Pilot giving the altitude status report

H = Controller requesting the pilot to report the heading of the aircraft

H̲ = Pilot reporting the heading of the aircraft

(TA) = Controller giving traffic advisories to pilot

A = Controller requesting the pilot to report the aircraft altitude

(H) = Controller giving a heading instruction to the pilot

ILC = Wilson Creek fix

MOD = Modesto fix

FIGURE D-1 SAMPLE OF SOME OF THE DATA RECORDED DURING THE OBSERVATION PERIOD 16 MARCH 1972

4) Interviewing Controllers

Both the radar and the handoff controllers (except in Chicago where the radar controller also performed handoff) who had been observed during a particular period were made available for a 45-minute interview, which started from one and one-half to two hours after the observation period ended. Each of the situations previously selected (as described above) was reconstructed by referring both to the observers' notes and to the appropriate passages of the videotape. The following questions were asked of the radar controller:

(1) Regarding this particular traffic situation, when did you first decide to take control action?

(2) Why did you choose to take the specific action you did?

(3) What result did you expect from this particular control action?

(4) What other actions could you have taken under the circumstances? How would they have turned out?

(5) With respect to the action you did take, did it turn out as expected? (That is, was it a good choice?) Explain.

(6) What would have happened if you had lost air-ground radio during this situation?

(7) What would have happened if you had lost radar during this situation?

(8) What are the most significant problems of controlling aircraft in this sector?

With consent of the controllers, all interviews were tape-recorded. These recordings were subsequently reduced to written transcriptions, which were analyzed to yield data revealing the decision making processes operating in each critical incident.

5) Logging Flight Strip Data

By prearrangement, flight data strips for all aircraft operating in the sector during the observation periods were made available to SRI observers. These strips furnished data reflecting user demand on the sector, such as true airspeed, altitudes, aircraft type and flight identifier, times over navigational reference points, and the like.

Appendix E

DATA REDUCTION AND RECEP PARAMETER DETERMINATION

Appendix E

DATA REDUCTION AND RECEP PARAMETER DETERMINATION

As has been previously mentioned, data were collected and measurements taken at a high altitude transition sector in the Oakland ARTCC to determine the feasibility and the adequacy of the RECEP approach. This portion of the project was considered to be Phase I. During Phase II, data and measurements were taken at three sectors in the Chicago ARTCC to try to extend and/or generalize the RECEP approach.

The sectors where observations and measurements were taken were:

- Oakland ARTCC Sector 42 (formerly High 5)
- Chicago ARTCC Bradford High Altitude Sector
- Chicago ARTCC Joliet High Altitude Sector
- Chicago ARTCC Papi Arrival Sector (low altitude).

1. Oakland ARTCC Sector 42 (H5)

a. Brief Sector Description

Figure E-1 shows a drawing of the major air routes with the primary altitudes used on each air route for the Oakland Sector 42. As can be seen, the major jet airways used in the sector are:

- J84 for outbound eastward
- The vicinity of J80 for inbound to the bay area
- J5 for crossing traffic from Reno to Los Angeles and vice versa
- J65 between Sacramento and Fresno.

Two major military air routes are indicated by the two dashed lines. The traffic on J84 enters the sector climbing to 24,000 feet and usually continues climbing until reaching one of the three cruising altitudes of 29,000, 33,000, or 37,000. Since this traffic is usually below the traffic on J65 and the MIL1 military route, there are usually no potential

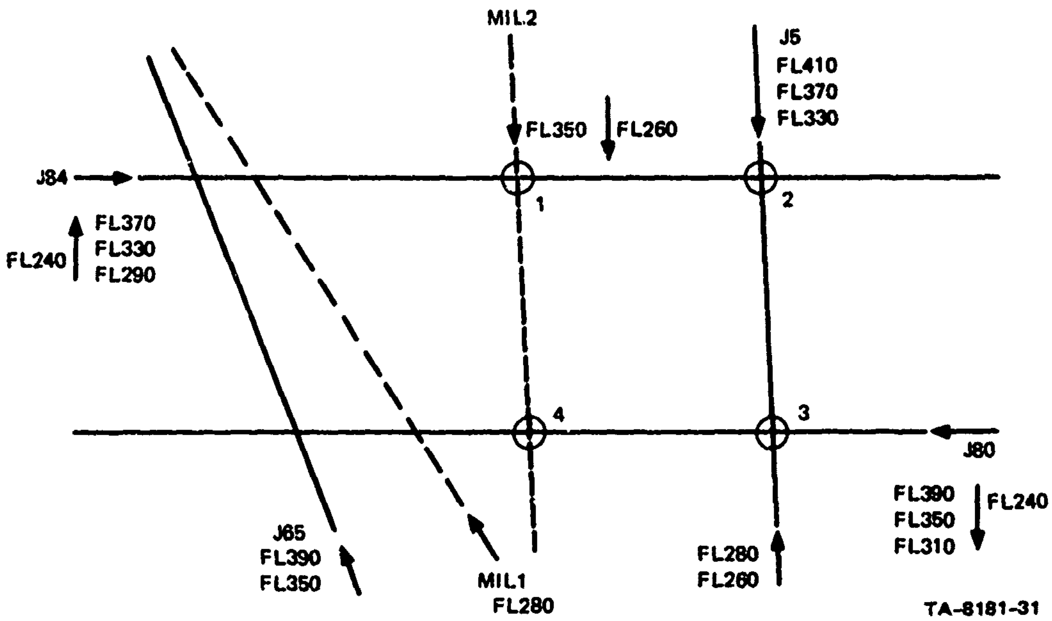


FIGURE E-1 OAKLAND ARTCC H5 SECTOR MAP: PRIMARY ALTITUDES AND POTENTIAL CONFLICT POINTS

intersection conflicts between these routes. However, potential conflicts exist between the traffic on J84 and (1) the military traffic on the route designated as MIL2 and (2) the traffic on J5 that is at 33,000 and 37,000 feet. These potential conflict points are indicated by Circles 1 and 2 in Figure E-1. All the traffic in the vicinity of J80 going to the Bay Area airports (San Francisco, Oakland, San Jose) must descend to 24,000 feet and be put in trail for final sequencing and spacing. As indicated by Circles 3 and 4, the J80 traffic has potential conflict points with both J5 traffic and MIL2 traffic.

b. Traffic and Sector Parameter Determination

Table E-1 gives the breakdown of aircraft type observed during our data collection effort. Although the controllers indicated that there was some difference in control action that must be taken when handling the high performance general aviation type as compared to the air carriers, we did not have a large enough sample size to detect this difference. Consequently, for this analysis the breakdown of aircraft type was made between military and nonmilitary aircraft, with the air carrier and high performance general aviation types making up the nonmilitary class.

Table E-1

OAKLAND H5 SECTOR AIRCRAFT TYPE SUMMARY

	Totals	Percentage
Number of observation periods	19	n.a.
Observation time (hours)	24.72	n.a.
Number of military aircraft	160	22.2%
Number of air carriers	535	75.2
Number of high performance general aviation aircraft	18	2.6
Number of nonmilitary aircraft	553	77.8

n.a. = not applicable.

From the data we find that about 40 percent of the military aircraft was on the airways and the remaining 60 percent was about evenly divided between the two major military routes, MIL1 and MIL2. Table E-2 shows the distribution of the nonmilitary aircraft on the different sector routes for the morning peak, the noon peak, and for a composite of the two. Since RECEP has not yet been programmed for a computer, all of the calculations were performed manually. Since this is a rather time consuming process, the complete process could not be performed for all three breakdowns. So, in all cases where there was a choice, the composite breakdown was used for this analysis.

Tables E-3 through E-6 show the altitude distribution of aircraft on J84, J80, J5, and J65, respectively. The asterisk indicates the altitudes for each route that were used in the RECEP analysis.

Table E-2

DISTRIBUTION OF NONMILITARY AIRCRAFT ON SECTOR ROUTES

Route	Morning Peak		Noon Peak		Composite	
	Total	Percentage	Total	Percentage	Total	Percentage
J84	202	56%	65	34%	267	43%
J5	74	20	15	8	89	16
J80	70	19	105	55	175	32
J65	18	5	5	3	23	4
Total	364	100%	190	100%	554	100%

Table E-3

ALTITUDE DISTRIBUTION OF AIRCRAFT ON J84

Altitude	Morning Peak		Noon Peak		Composite	
	Total	Percentage	Total	Percentage	Total	Percentage
270	1	1%	3	5%	4	1%
290*	25	12	1	1	26	10
330*	55	27	22	34	77	29
370*	119	59	39	60	158	59
410	2	1	0	0	2	1
Total	202	100%	65	100%	267	100%

* These altitudes were used in the RECEP analysis.

Table E-4

ALTITUDE DISTRIBUTION OF AIRCRAFT ON J80

Altitude	Morning Peak		Noon Peak		Composite	
	Total	Percentage	Total	Percentage	Total	Percentage
280	0	0%	4	4%	4	2%
310*	28	40	20	19	48	27
350*	30	43	43	41	73	42
390*	9	13	37	35	46	26
410	2	3	1	1	3	2
430	1	1	0	0	1	1
Total	70	100%	105	100%	175	100%

* These altitudes were used in the RECEP analysis.

Table E-5

ALTITUDE DISTRIBUTION OF AIRCRAFT ON J5

Altitude	Morning Peak		Noon Peak		Composite	
	Total	Percentage	Total	Percentage	Total	Percentage
240	1	1%	0	0%	1	1%
250	1	1	0	0	1	1
260*	12	16	1	7	13	15
270	0	0	3	20	3	3
280*	6	8	4	27	10	11
290	3	4	2	13	5	6
310	5	7	0	0	5	6
330*	9	12	2	13	11	12
370*	21	28	3	20	24	27
410*	16	22	0	0	16	18
Total	74	99%	15	100%	89	100%

* These altitudes were used in the RECEP analysis.

Table E-6

ALTITUDE DISTRIBUTION OF AIRCRAFT ON J65

Altitude	Morning Peak		Noon Peak		Composite	
	Total	Percentage	Total	Percentage	Total	Percentage
280	1	5%	1	20%	2	9%
290	1	5	0	0	1	4
330	1	5	0	0	1	4
350*	3	17	3	60	6	26
390*	10	56	1	20	11	48
410	2	11	0	0	2	9
Total	18	99%	5	100%	23	100%

* These altitudes were used in the RECEP analysis.

Tables E-7 through E-9 show the distribution of TAS (true air speed) on J84, J80, and J5 respectively. For J65 the most frequently used TAS was 460 knots, and for MIL1 and MIL2 it was 450 knots. Since the number of aircraft observed on those routes was too small to get a good distribution, the values for the most frequently used TAS were used in the analysis.

c. Determination of Parameters for E_{PR}, E_{NS}, E_{SC}, and E_{TS}

To determine the value of the constants required in the expressions given in Appendix C for E_{PR}, the expected number of pilot requests; E_{NS}, the expected number of nonstandard contiguous sector requests; E_{SC}, the expected number of sector coordinations; and E_{TS}, the expected number of controller traffic structuring and workload management events, a summary was made of all of those types of events along with the total number of aircraft observed during the total data collection effort. These values are shown in Table E-10. (For this particular sector, E_{NS} is used synonymously with a pointout event.) Taking

Table E-7

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J84

Altitude	Speed (knots)	Percentage	Average Speed (knots)
290	470	15%	
	490	85	485
330	465	15	
	475	25	
	485	60	480
370	460	40	
	475	50	
	485	10	470

Table E-8

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J80

Altitude	Speed (knots)	Percentage	Average Speed (knots)
310	465	15%	
	475	60	
	485	25	475
350	465	20	
	475	45	
	485	35	475
390	455	30	
	465	15	
	475	55	470

Table E-9

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J5

Altitude	Speed (knots)	Percentage	Average Speed (knots)
260	470	100%	470
230	410	25	
	440	25	
	449	25	
	490	25	450
330	475	100	475
370	457	70	
	490	30	465
410	457	80	
	475	20	460

the average of each of these components yields the constants for each of the above mentioned expressions. Hence:

K_1 [see Eq. (5) in Appendix C] = 0.1

K_2 [see Eq. (6) in Appendix C] = 0.3

K_3 [see Eq. (7) in Appendix C] = 0.4

K_4 [see Eq. (9) in Appendix C] = 6

Table E-10

EVENT DATA SUMMARY

	Total Number of Events
Observation periods	19
Traffic structuring events	4,228
Pilot requests	90
Sector coordinations	252
Pointouts	201
Aircraft handled	713

d. Decision-Making Times for Each Event Type

Recall that it was previously stated that the concern here was to determine the decision-making time required for each type of event, when the controller was operating at or near capacity. The following factors were attendant to this data collection effort:

- There were no controllable variables.
- There were insufficient data to get a complete distribution of the decision-making time required for each type of event.
- The average number of aircraft per hour through the sector varied between 20 and 30 during the data collection effort.

It was decided that using the minimum observed decision time required for each type of event would provide the best estimate of this parameter for the situation when the controller was operating at or near capacity for some sustained period of time.

Table E-11 shows the breakdown of the number and type of potential crossing and overtake situations that were selected for controller interviews (as described in Appendix D). The minimum decision-making time required for each of the types of events was obtained in the following manner. The interview was usually started by replaying on the monitor the actual traffic situation when the controller issued an instruction that signified the end of a decision (i.e., a speed restriction,

Table E-11

NUMBER OF POTENTIAL TRAFFIC SITUATION TYPES SELECTED FOR CONTROLLER INTERVIEWS

Type	Number
Overtaking	
Level	4
Climbing	4
Descending (including sequencing)	1
Total overtakes	9
Crossing	
Level/level	3
Level/climbing	13
Level/descending	3
Climbing/climbing	2
Descending/descending	1
Descending/climbing	2
Total crossings	24
Total, all types	33

an intermediate altitude clearance, a vector to parallel traffic, and so on) as described in Appendix D. Since the time that this control instruction was issued was already recorded, the time associated with the end of the decision-making process was known. During the course of the interview the video playback was used along with questioning of the controller to determine when he first became aware that this situation would require some decision on his part. This, along with the recorded notes, yielded the time that the decision-making process started; hence, the decision-making time was the elapsed time between this point and the issuance of the control instruction. Although this seems to be a simple way of measuring the time period, in reality there are some difficulties.

For example, at the Oakland Center, some of the time the controller became aware of a potential situation as soon as a handoff was made to him of an aircraft entering his sector. Although the controller might have decided what he was going to do, he could not issue the control instruction that signified the end of the decision until the aircraft of interest called in on the sector frequency. Sometimes this could mean an elapsed time of three to four minutes, even though the actual decision time was somewhat less. However, in these interviews, when this type of decision was observed, the controller was asked when he had actually made the decision and what process he went through that related to his decision while he was waiting for the aircraft to come on the sector's frequency. Other than by these questions, continuing "follow-up" surveillance was not investigated per se--further decisions that may have been required were treated separately.

Using the approach outlined above, the minimum required decision-making time for a potential overtake or crossing event was found to be one minute. From the interview with the controller, there was some indication that there were instances when some of the times could be less than this; however, this was the resolution of our time recordings and it was used in the analysis.

The decision time required for other types of events was determined by using a stopwatch with several of the videotapes showing the events to determine the minimum times.

Table E-12 shows the minimum decision times observed and used in RECEP. These times are for the Level I system that is described in Appendix C, along with the operating judgmental factors described in Appendices A and B. The decision times determined in the following paragraphs for Levels II, III, and IV are obtained by assuming that the same judgmental factors will be operating.

The Level II system as described in Appendix C is not too different--in terms of the decisions required of the controller--from Level I. The human controller still has full responsibility for making and implementing ATC decisions. Assistance in the organization and presentation of information is provided by the computer. The important information with regard to decision-making provided by the computer is the alphanumeric tag with the associated altitude information and the availability of aircraft speed information. From our observation of controllers in action, from extensive controller interviews, and from the tables given in Appendix C (that describe in detail how the assumed system functions and how operational policies will affect controller

Table E-12

EVENTS AND MINIMUM DECISION TIMES: LEVEL I

Events	Level I
	Minimum Decision Time
Potential conflict	1 minute per event
Intersection	
Level/level	
Transitioning/level	
Transitioning/ transitioning	
Handoff	6 seconds per handoff
Pointout	12 seconds per pointout
Coordination	6 seconds per coordination
Request	
Information	
Pilot request	5 seconds per request
Traffic structuring and workload management	5 seconds per event

decisions) we were able to determine how these factors will affect the decision times associated with the Level I system. Briefly the effect will be as follows.

For a potential overtake or crossing conflict under the present (Level I) system, because of the lack of up-to-date altitude and/or speed information on the aircraft involved, the controller often must wait during the decision-making period for a scan of the display strobe for information update before completing his decision-making. Hence, with the availability of the up-to-date aircraft altitude information and with the immediate accessibility to accurate speed information, the decision time will be reduced by at least one strobe scan. Since there are six scans per minute, the reduction for this type of event was assumed to be a minimum of ten seconds.

Also, on the average at least one of the traffic structuring and workload management events was an altitude request from the controller. With the availability of the accurate altitude information with the alphanumeric tag, the average number of this type of event per aircraft can be reduced from six to five. Table E-13 shows the events and decision times used for the Level II system.

Table E-13

EVENTS AND MINIMUM DECISION TIMES: LEVEL II

Events	Level II	
	Number of Events	Minimum Decision Time
Potential conflict	*	50 seconds per event
Handoff	*	Same as Level I
Pointout	*	Same as Level I
Coordination	*	Same as Level I
Pilot request	*	Same as Level I
Traffic structure and workload management	5 per aircraft	Same as Level I

* The same as would be calculated for Level I.

Although the Level III system as described in Appendix C will be significantly more automated than the previous two systems, the controller will still be in control and will be pacing the flow of the traffic. Changes in the controller's decision time and function will result mostly from the conflict alert indication and the computer-assisted spacing, metering, and sequencing. These will affect the decision times in the following manner.

From our observation of the controllers in action, and from the interviews, it was determined that due to the lack of precise information on aircraft, the inaccuracy of unaided human prediction capability, and so on, the major portion of the decision time for a potential crossing or overtake conflict was taken up by the controller trying to assess if the potential conflict would really occur if no action was taken. In terms of the decision model presented in Appendix A, these steps coincide with the Deviation Recognition and Situation Assessment phases of the decision process. (As soon as these two phases of the decision process were completed, the "action selection" part was accomplished very quickly by the controllers. These factors are discussed in more detail in Volume I.) Hence, with the assistance of the computer in conflict alert indication, most of the time spent on the decision process for these types of events will no longer be required of the controller. Most of the controller's time will then be spent in reviewing the computer-generated recommended actions to determine if they coincide with what he thinks. Since this phase (action selection) of the decision process takes a short time, and since there are not a great many different alternative solutions for each potential conflict situation, we use a value of ten seconds for this decision time.

Since a lot of the traffic structuring and workload management function of the controller will be performed by the computer, most of his time will be spent reviewing recommended actions. We assumed that these decisions will require only half the time that is required in Level I.

For the other types of events, let us assume that there are two Level III systems, IIIa and IIIb. The difference between these two systems is as follows:

> Level IIIa is as described in Appendix C, except that it is assumed that the traffic in some areas is still so unstructured that intersector voice communications are still required between controllers for coordination. Hence, pointouts, coordination, and handoffs will be handled basically as in Level I and Level II.
>
> Level IIIb is a system where the traffic is sufficiently structured that no voice coordination is required between controllers. Hence, the complete automated handoff will be in effect, and the only time required will be the amount of time associated with the controller's acknowledgment of a handoff and other required duties for this function.

Tables E-14 and E-15 show the events and decision times related to the Level IIIa and Level IIIb systems respectively. The decision times for these systems as described here were used in the analysis as outlined in Volume I.

Table E-14

EVENTS AND MINIMUM DECISION TIMES: LEVEL IIIa

Events	Level IIIa	
	Number of Events	Minimum Decision Time
Potential conflicts	*	10 seconds per event
Handoffs	*	Same as Level I
Pointout	*	Same as Level I
Coordination	*	Same as Level I
Pilot request	*	Same as Level I
Traffic structure and workload management	5 per aircraft	Same as Level I

* The same as would be calculated for Level I.

Table E-15

EVENTS AND MINIMUM DECISION TIMES: LEVEL IIIb

Events	Level IIIb	
	Number of Events	Minimum Decision Time
Potential conflicts	*	10 seconds per event
Handoffs	*	3 seconds per handoff
Traffic structure and workload management	5 per aircraft	Same as Level I

* The same as would be calculated for Level I.

2. Chicago ARTCC Bradford High Altitude Sector

a. Brief Sector Description

Figure E-2 shows a drawing of the major air routes, and the primary altitudes used on each, for the Chicago Bradford High Altitude sector. As can be seen, the major jet airways used in the sector are:

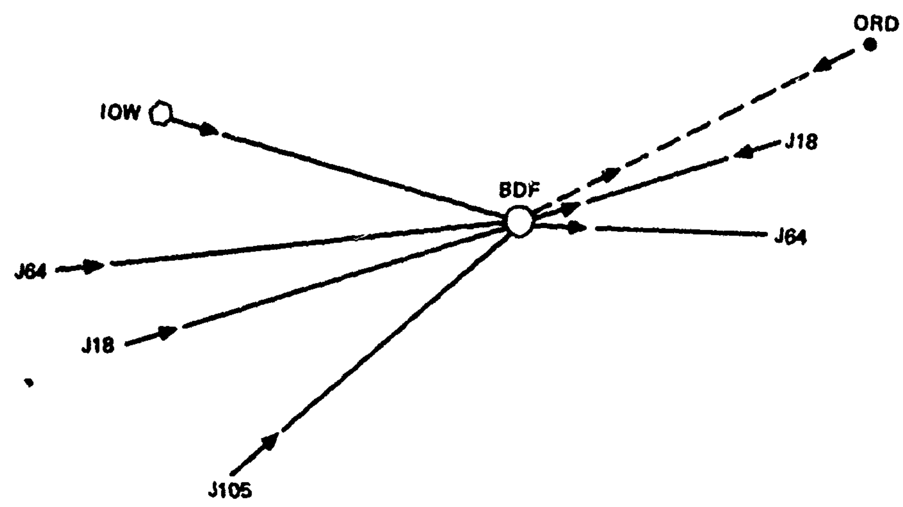
- J64 for eastbound overs and arrivals into O'Hare
- J18 for eastbound and westbound overs and arrivals into O'Hare
- J105 for arrivals into O'Hare
- IOW-BDF for eastbound overs
- ORD-BDF for departures from O'Hare for J18.

The primary altitudes used on each of these routes are indicated in Figure E-2. As can be seen, this sector has only one major potential conflict point. This point is located at BDF, which is the point where all of the primary routes used in the sector intersect. This potential conflict point is indicated by the circle in the figure. There are potential level intersection conflicts between the traffic on J64 and J18, J64 and IOW-BDF, J18 (westbound) and the traffic merging from O'Hare, and J18 and IOW-BDF. There are potential intersection conflicts between traffic descending on J64 and traffic level on J64, traffic descending on J18 and traffic level on J18, traffic climbing from O'Hare and traffic level on J18 (westbound). There are potential conflicts between traffic descending on J64 and J18, J64 and J105, and J18 and J105. Also there are the potential overtake conflicts on nearly all the routes.

b. Traffic and Sector Parameter Determination

Table E .6 shows the breakdown of the types of aircraft observed during the data collection effort. Since we have not quantitatively detected a difference in the control procedure used for air carriers as compared to that used for high performance general aviation, and since there was such a small amount of military traffic (5 percent) in the analysis of this sector, all aircraft were treated as if they were air carriers.

The distribution of the traffic on the different routes used in the sector is given in Table E-17.



ROUTE	ALTITUDES EASTBOUND		ALTITUDES WESTBOUND	
J64	FL410 FL370 FL330			
J64-BDF (ORD)	FL370 FL330 ↓	FL240		
J18	FL410 FL370 FL330 FL290			FL350 FL310 FL280
J18-BDF (ORD)	FL370 FL330 ↓ FL290	FL240		
J105	FL370 FL330 ↓ FL290	FL240		
IOW-BDF	FL410 FL370 FL330			
ORD-BDF			FL240 ↑	FL350 FL310 FL280

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FIGURE E-2 CHICAGO ARTCC BRADFORD HIGH ALTITUDE SECTOR MAP: PRIMARY ROUTES, ALTITUDES, AND POTENTIAL CONFLICT POINT

Table E-16

CHICAGO BRADFORD SECTOR AIRCRAFT TYPE SUMMARY

	Totals	Percentage
Number of observation periods	5	n.a.*
Observation time (hours)	7.6	n.a.*
Number of aircraft	237	100%
Number of air carriers	210	89
Number of high performance general aviation aircraft	14	6
Number of military aircraft	13	5

* n.a. = not applicable.

Tables E-18 and E-19 show the distributions of altitudes on the major routes used in the sector for eastbound and westbound traffic respectively.

The distributions of the true air speed of the aircraft on the major routes for eastbound and westbound flows are shown in Tables E-20 and E-21.

c. Determination of Parameters for E_{PR}, E_{NS}, E_{SC}, and E_{TS}

A summary was made of the total number of pilot requests and the traffic structuring events to determine the values of the constants required in the expressions for E_{PR}, the expected number of pilot

Table E-17

DISTRIBUTION OF AIRCRAFT ON SECTOR ROUTES

	Entering Aircraft					Exiting Aircraft		
	Point of Entry	Way Point	Percentage of Total Entries	Descending to or Climbing from ORD (percentage of total entries)	Overs (percentage of total entries)	Way Point	Point of Exit	Percentage of Total Exits
Eastbound	J64	BDF	36%	13%	23%	BDF	ORD	34%
	J18	BDF	23	13	10	BDF	J18	24
	J105	BDF	7	7	0	BDF	J64	13
	IOW	BDF	5	1	4	BDF	Other	2
	Other	BDF	2		2	Other	Other	3
	Other	Other	3		3			
Subtotal			76%	34%	42%			76%
Westbound	ORD	BDF	13%	13%	0%	BDF	J18	15%
	J18	BDF	1		4	BDF	J64	3
	EVV	BDF	2		2	BDF	DBQ	3
	J64	BDF	1		1	CAP	IOW	2
	Other	BDF	1		1	Other	Other	1
	CAP	IOW	2		2			
	Other	Other	1		1			
Subtotal			24%	13%	11%			24%
Total			100%					100%

Table E-18

DISTRIBUTION OF ALTITUDES ON MAJOR TRAFFIC ROUTES: EASTBOUND

(a) Number of Aircraft as a Percentage of Total Entering Each Route

Route	Flight Level	Descend (to ORD)		Overs	
		Entry	Exit	Entry	Exit
In J64 through BDF	240	--%	36%	--%	--%
	290	--	--	--	--
	330	11	--	7	10
	370	25	--	35	30
	410	--	--	22	24
Total		36%	36%	64%	64%
In J18 through BDF	240	--%	57%	--%	--%
	290	14	--	8	8
	330	20	--	6	6
	370	23	--	23	23
	410	--	--	6	6
Total		57%	57%	43%	43%
In J105 through BDF	240	--%	100%	--%	--%
	290	7	--	--	--
	330	50	--	--	--
	370	43	--	--	--
	410	--	--	--	--
Total		100%	100%		
From IOW through BDF	240	--%	20%	--%	--%
	290	20	--	--	--
	330	--	--	10	10
	370	--	--	50	50
	410	--	--	20	20
Total		20%	20%	80%	80%

Table E-18

DISTRIBUTION OF ALTITUDES ON MAJOR TRAFFIC ROUTES: EASTBOUND

(a) Number of Aircraft as a Percentage of Total Entering Each Route

Route	Flight Level	Descend (to ORD)		Overs	
		Entry	Exit	Entry	Exit
In J64 through BDF	240	--%	36%	--%	--%
	290	--	--	--	--
	330	11	--	7	10
	370	25	--	35	30
	410	--	--	22	24
Total		36%	36%	64%	64%
In J18 through BDF	240	--%	57%	--%	--%
	290	14	--	8	8
	330	20	--	6	6
	370	23	--	23	23
	410	--	--	6	6
Total		57%	57%	43%	43%
In J105 through BDF	240	--%	100%	--%	--%
	290	7	--	--	--
	330	50	--	--	--
	370	43	--	--	--
	410	--	--	--	--
Total		100%	100%		
From IOW through BDF	240	--%	20%	--%	--%
	290	20	--	--	--
	330	--	--	10	10
	370	--	--	50	50
	410	--	--	20	20
Total		20%	20%	80%	80%

Table E-18 (Concluded)

(b) Number of Aircraft as a Percentage of Total Exiting Each Route

Route	Flight Level	Descend (to ORD)		Overs	
		Entry	Exit	Entry	Exit
Through BDF out J64	240	--%	--%	--%	--%
	290	--	--	15	15
	330	--	--	11	11
	370	--	--	48	44
	410	--	--	26	30
Total				100%	100%
Through BDF out J18	240	--%	--%	--%	--%
	290	--	--	--	--
	330	--	--	16	20
	370	--	--	52	48
	410	--	--	32	32
Total				100%	100%
Through BDF out ORD	200	--%	100%	--%	--%
	290	14	--	--	--
	330	30	--	--	--
	370	50	--	--	--
	410	--	--	--	--
Total		100%	100%		

Table E-19

DISTRIBUTION OF ALTITUDES ON MAJOR TRAFFIC ROUTES: WESTBOUND

(a) Number of Aircraft as a Percentage of Total Entering Each Route

Route	Flight Level	Climb (from ORD)		Overs	
		Entry	Exit	Entry	Exit
From ORD through BDF	240	54%	--%	--%	--%
	260	12	--	--	--
	280	21	8	--	--
	310	13	59	--	--
	350	--	33	--	--
	390	--	--	--	--
Total		100%	100%		
In J18 through BDF	240	--%	--%	--%	--%
	260	--	--	--	--
	280	--	--	--	--
	310	--	--	12	12
	350	--	--	88	88
	390	--	--	--	--
Total				100%	100%

Table E-19 (concluded)

(b) Number of Aircraft as a Percentage of Total Exiting Each Route

Route	Flight Level	Climb (from ORD)		Overs	
		Entry	Exit	Entry	Exit
Through BDF out J18	240	47%	--%	--%	--%
	260	10	--	--	--
	280	18	7	--	--
	310	11	50	--	3
	350	--	29	14	11
	390	--	--	--	--
Total		86%	86%	14%	14%

requests, and E_{TS}, the expected number of controller traffic structuring and workload management events. This summary is given in Table E-22. Only a small portion of the pointouts and sector coordination was performed via the interphone system. Most of these types of events were performed informally and verbally between controllers and coordinators. We were not prepared to conveniently record the verbal exchange. Consequently we did not get an accurate record of these types of events; such a record would have aided in determining the values of the constants for E_{NS} and E_{SC}.

d. Decision-Making Times for Each Event Type

Formal controller interviews to determine decision-making times were performed only on situations that were video recorded at the Joliet sector during this data collection effort. Since we were at the Chicago Center for only five days of observation, and could only get at most five situations for controller interview, it was decided that we should perform the interviews on one sector only. The Joliet sector was selected because it was the one most similar to the Oakland Sector 42. In addition to the formal interviews, we talked informally, when convenient, with the various controllers that had been monitored to find out if

Table E-20

DISTRIBUTIONS OF TRUE AIR SPEED PER FLIGHT LEVEL ON VARIOUS ROUTES: EASTBOUND

(a) Eastbound Entry

Route	Entry Flight Level	Average Speed (knots)	True Air Speed (knots)										
			450	455	460	465	470	475	480	485	490	495	500
EB overs, enter into J64	330	470	%	%	29%	%	14%	43%	%	14%	%	%	%
	370	475			17		21	12	17	29	4		
	410	470	6	6	38		19	13	6		6	6	
EB descent (to ORD), enter into J64	330	475			12	12		12	64				
	370	470		12			44	13	19		6	6	
EB overs, enter into J18	290	490									100		
	330	475			33		31				33		
	370	475				11	34	22		11	11	20	11
	410	465			50		50						
EB descent (to ORD), enter into J18	290	495							17		33		50
	330	480						10	80	10			
	370	470			18	18	9	28	18		9		
EB descent (to ORD), enter into J105	290	480							100				
	330	480					14	14	72				
	370	480						25	75				
EB overs, enter from IOW	330	475						100					
	370	480					25	25	25		25		
	410	470			67						33		
EB descent (to ORD), enter from IOW	290	470					100						

(b) Eastbound Exit*

Route	Entry Flight Level	Average Speed (knots)	True Air Speed (knots)										
			450	455	460	465	470	475	480	485	490	495	500
EB descent, exit to ORD, enter from J64, J18, J105, and IOW	290	485	%	%	%	11%	11%	%	22%	%	22%	%	34%
	330	480			4	4	4	12	72	4			
	370	475		6	6	6	27	19	27		6	3	

* For eastbound exits on J18 and J64, see Joliet sector entries, Paragraph 3.

Table E-21

DISTRIBUTION OF TRUE AIR SPEED PER FLIGHT LEVEL ON VARIOUS ROUTES: WESTBOUND

(a) Westbound Entry*

Route	Entry Flight Level	Average Speed (knots)	True Air Speed (knots)								
			455	460	465	470	475	480	485	490	495
WB overs, enter into J18	310	480	%	%	%	%	%	100%	%	%	%
	350	475		16		16		68			

* For westbound entries from ORD, see westbound exits out J18.

(b) Westbound Exit

Route	Exit Flight Level	Average Speed (knots)	True Air Speed (knots)								
			455	460	465	470	475	480	485	490	495
WB climb from ORD, exit out J18	280	490	%	%	%	%	%	%	%	100%	%
	310	480	7				8	46	31	8	
	350	475		11	11		45	22			11
WB overs, exit out J18	350	480						100			

Table E-22

EVENT DATA SUMMARY

Total Number of:			
Observation Periods	Traffic Structuring Events	Pilot Requests	Aircraft Handled
5	1,625	85*	237

* This number is somewhat higher than usual because one of the major VORs went out during one of the observation periods resulting in more pilot requests.

their methods of control were markedly different from what had been observed and described to us at the Oakland Center. We neither found nor observed any major differences. Therefore, the decision-making time for each event determined at Oakland seems to be valid at Chicago.

3. Chicago ARTCC Joliet High Altitude Sector

a. Brief Sector Description

Figure E-3 shows a drawing of the major air routes, with the primary altitudes used on each, for the Chicago Joliet High Altitude Sector. As can be seen, the major jet airways used in the sectors are:

- J64 for eastbounds
- J60 for eastbounds
- J18 for eastbounds
- J101 for overs and arrivals to O'Hare and Milwaukee
- ORD-RBS for departures from O'Hare
- J99 for departures from O'Hare.

The primary altitudes used on each of these routes are shown in the figure. As can be seen, this sector has only one major potential conflict point. This point is located at the JOT (Joliet) fix, which is the point where J60, J18, and J101 intersect; it is indicated by the circle labeled 1 in the figure. The only potential intersection conflict at this point is between the traffic at 41,000, 37,000, and 33,000 feet on J60 and J18. There are potential overtake conflicts on nearly all of the routes.

b. Traffic and Sector Parameter Determination

The summary of the types of aircraft observed during the data collection effort is shown in Table E-23. Table E-24 shows the distribution of the traffic on the different routes used in this sector. The distribution of altitudes on these routes is shown in Table E-25. Tables E-26 through E-33 show the distribution of true air speed of the aircraft on the routes.

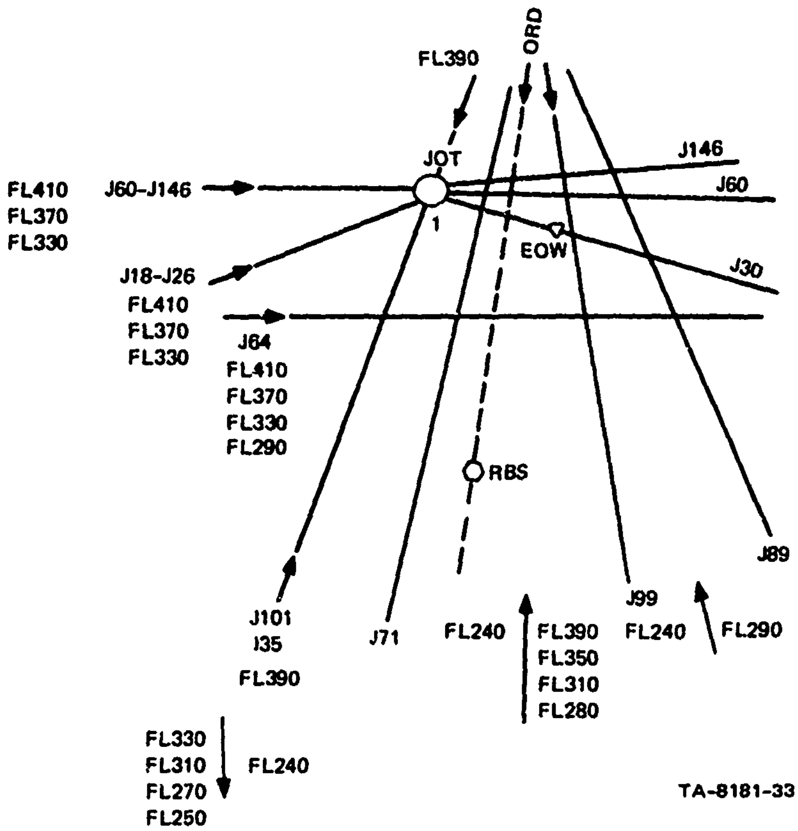

FIGURE E-3 CHICAGO ARTCC JOLIET HIGH ALTITUDE SECTOR MAP: PRIMARY ROUTES, ALTITUDES, AND POTENTIAL CONFLICT POINT

c. Determination of Parameters for E_{PR}, E_{NS}, E_{SC}, and E_{TS}

The same procedures, handicaps, and conclusions that were previously presented for the Chicago Bradford Sector apply here for these parameters. Table E-34 gives a summary of the events observed for this sector.

d. Decision-Making Time for Each Type of Event

The same procedures and guidelines used for obtaining the decision-making times at the Oakland ARTCC were also applied here. Table E-35 shows a breakdown of the number and type of situations that

Table E-23

CHICAGO JOLIET SECTOR AIRCRAFT TYPE SUMMARY

	Totals	Percentage
Number of observation periods	5	n.a.*
Observation time (hours)	6.02	n.a.*
Number of aircraft	199	100%
Number of air carriers	162	81
Number of high performance general aviation aircraft	22	11
Number of military aircraft	15	8

* n.a. = not applicable.

were selected for controller interviews. The interviews were augmented by informal discussions with most of the controllers observed to determine if the information obtained in the formal procedures seemed to indicate the routine control approach. These informal discussions not only strongly supported the information obtained in the formal interview but also revealed that the basic control approach did not differ much from that used in the Oakland ARTCC.

The minimum decision-making times were obtained in the same manner as in the Oakland effort and were found to be close enough that no modifications to those values were required for RECEP.

Table E-24

DISTRIBUTION OF AIRCRAFT ON SECTOR ROUTES

Route	Number of Aircraft	Percentage of Total
J18-JOT	44	33%
J146-JOT	24	18
JOT-146	39	29
JOT-J60	29	22
J64	20	15
J101	15	11
RBS	12	9
J99	15	11
Other	5	4
Total	135	100%

A discussion of some of the information obtained from these interviews along with a comparison with information from the Oakland interviews is presented in Volume I.

4. Chicago ARTCC Papi Arrival Sector

a. Brief Sector Description

Figure E-4 shows a drawing of the major air routes, with the primary altitudes used on each, for the Chicago Papi Arrival Sector. As can be seen, the major jet airway used in the sector is V84/J94 for inbounds from the east into O'Hare.

The aircraft enter the sector at altitudes between 20,000 and 30,000 feet and are handed off to approach control at 10,000 feet. Since there are no major intersecting routes, there are no potential conflict points. Due to the sequencing and spacing for final approach, about the

Table E-25

ALTITUDE DISTRIBUTION OF AIRCRAFT

Altitude	Route: J18-JOT No. of Aircraft	J18-JOT Percentage	J146-JOT No. of Aircraft	J146-JOT Percentage	JOT-J146 No. of Aircraft	JOT-J146 Percentage	JOT-J60 No. of Aircraft	JOT-J60 Percentage	J64 No. of Aircraft	J64 Percentage	J101 No. of Aircraft	J101 Percentage	RBS No. of Aircraft	RBS Percentage	J99 No. of Aircraft	J99 Percentage
250		%		%		%		%		%	5	33%		%		%
270											5	33				
280													4	33		
290									4	20					15	100
310											1	7	3	25		
330	4	9	2	8	1	5	5	17	2	10	2	13				
350			1	4			1	4					3	25		
370	25	57	12	50	22	56	15	52	5	25						
390			1	4			1	3			2	13	2	17		
410	15	31	8	34	16	41	7	24	9	45	—	—	—	—	—	—
Total	44	100%	24	100%	39	100%	29	100%	20	100%	15	100%	12	100%	15	100%

Table E-26

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J18-JOT

Altitude	Speed (knots)	Percentage of Traffic	Average Speed (knots)
410	485	20%	
	475	15	
	465	65	
			470
370	485	40	
	475	40	
	465	20	
			477
330	475	70	
	465	30	
			472

Table E-27

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J146-JOT

Altitude	Speed (knots)	Percentage of Traffic	Average Speed (knots)
410	465	55%	
	455	45	
			461
390	465	100	
370	470	70	
	460	30	467
350	450	100	
330	475	100	

Table E-28

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON JOT-J146

Altitude	Speed (knots)	Percentage of Traffic	Average Speed (knots)
410	485	25%	
	465	40	
	455	35	
			466
370	485	50	
	470	50	
			477
330	475	100	

Table E-29

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON JOT-J60

Altitude	Speed (knots)	Percentage of Traffic	Average Speed (knots)
410	475	25%	
	465	75	
			467
390	465	100	
370	470	80	
	460	20	
			468
350	450	100	
330	475	100	

Table E-30

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J64

Altitude	Speed (knots)	Percentage of Traffic
410	460	100%
370	470	100
330	480	100
290	490	100

Table E-31

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J101

Altitude	Speed (knots)	Percentage of Traffic
390	480	100%
330	480	100
310	480	100
270	475	100
250	470	100

Table E-32

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON RBS

Altitude	Speed (knots)	Percentage of Traffic
390	470	100%
350	485	100
310	470	100
280	470	100

Table E-33

DISTRIBUTION OF TRUE AIR SPEED OF AIRCRAFT ON J99

Altitude	Speed (knots)	Percentage of Traffic	Average Speed (knots)
290	475	35%	
	465	30	
	455	35	465

Table E-34

EVENT DATA SUMMARY

	Total Number of Events
Observation periods	5
Traffic structuring events	902
Pilot requests	43
Aircraft handled	199

only type of conflict in this sector is the potential overtakes during descent.

b. Traffic and Sector Parameter Determination

Table E-36 is a summary of the types of aircraft observed during the data collection effort. The distribution of the traffic on the different routes used in this sector is shown in Table E-37. As previously stated, the dominant route is V84/J94, which primarily services civil jets arriving from the east and northeast. The north-south crossing traffic does not enter the traffic picture from a control

Table E-35

NUMBER OF PCTENTIAL TRAFFIC SITUATION TYPES
SELECTED FOR CONTROLLER INTERVIEWS

Type	Number
Overtaking--level	1
Crossing	
Level/climbing	1
Climbing/climbing	1
Descending/descending	1
Total crossings	3
Total, all types	4

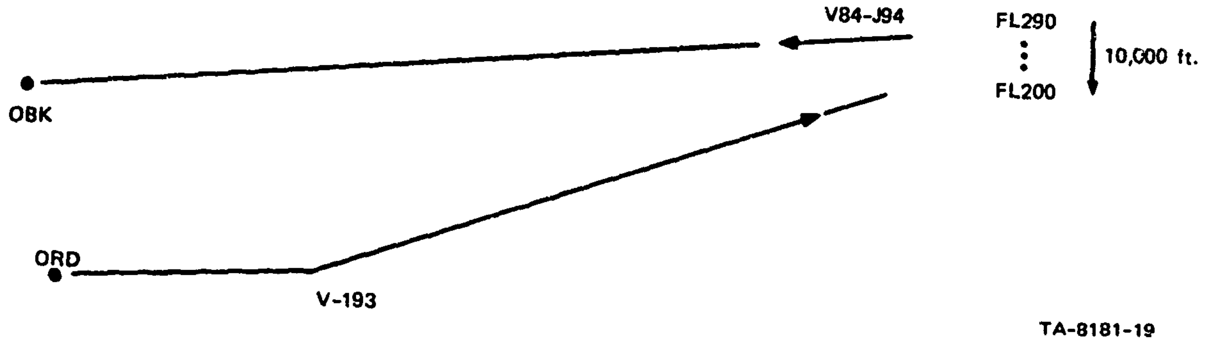

FIGURE E-4 CHICAGO ARTCC PAPI ARRIVAL SECTOR MAP: PRIMARY ROUTES AND ALTITUDES

Table E-36

CHICAGO PAPI SECTOR AIRCRAFT TYPE SUMMARY

	Totals	Percentage
Number of observation periods	8	n.a.*
Observation time (hours)	8.3	n.a.*
Number of aircraft	179	100%
Number of air carriers	153	86
Number of general aviation aircraft	25	14
Number of military aircraft	1	0

* n.a. = not applicable.

Table E-37

DISTRIBUTION OF AIRCRAFT ON SECTOR ROUTES

Route	Number of Aircraft	Percentage of Total
V84-J9	167	91%
V215	2	1
North-south crossing	9	5
Outbound	5	3
Total	183	100%

standpoint, since it flies at various altitudes above 8,000 feet. This is above the arrival stream going to O'Hare.

The distribution of entry altitudes used in V84/J94 is shown in Table E-38. Most of the aircraft, although cleared to 7,000 feet, left the sector at 10,000 feet.

The aircraft enter Papi indicating 300 to 350 knots at an altitude of 20,000 to 30,000 feet. They generally try to reduce speed to 250 knots (indicated) for handoff to approach control at 10,000 feet. When traffic is heavy, or if a slow aircraft is in the stream, further speed reductions to 160 or 180 knots may be used.

c. Decision-Making Times for Each Type of Event

The process that was described for the Chicago Bradford sector was also used here.

Table E-38

DISTRIBUTION OF ENTRY ALTITUDES ON V84/J94

Altitude	Number of Aircraft	Percentage of Total
Above 300	5	3%
300	4	3
290	4	3
280	8	6
270	9	6
260	10	7
250	12	8
240	14	10
230	9	6
220	11	8
210	3	2
200	13	9
190	2	1
180	2	1
170	1	1
160	6	4
150	3	2
140	8	6
130	1	1
120	2	1
110	0	0
100	6	4
90	1	1
80	5	3
70	3	2
Total	142	100%

Appendix F

ANALOGOUS SYSTEMS

Appendix F

ANALOGOUS SYSTEMS

Large scale operational control systems that have undergone varying degrees of automation were examined in an attempt to identify one or more such systems that are analogous to the ATC system. A study of a reasonably analogous system might provide additional insights into the underlying factors that affect ATC operations as well as information concerning the limitations of automation. Although automated control systems that are partially analogous to the ATC system were identified, the degree of analogy was not sufficient to warrant further study.

Automated control systems were examined against criteria based on the task situations and operational characteristics that pertain to the ATC system. The task situations criteria were used as a preliminary sorting device to identify potentially analogous systems. The operational characteristics criteria were used to pinpoint specific system conditions required of an analogous system.

The task situations criteria were identified in part by Schrenk[1]* and are oriented to the overall decision-making process inherent in the ATC system. The task situations criteria are:

- That fairly well defined objectives exist.
- That significant action alternatives are available.
- That relatively high stakes are involved.
- That incomplete information is available for decision-making.
- That there is limited time for decision.
- That complex decisions regarding the selection of actions are required.

The operational characteristics criteria used are those that distinguish the job of the ATC controller from other (nonanalogous) jobs

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* References are listed at the end of this appendix.

involving operational system control and management. These criteria describe specific qualities of the ATC controller's operational activities and are designed to identify those analogous systems whose mode of operation may provide some insight into the factors affecting ATC operation.

The operational characteristics criteria are predicated on the assumption that a central decision maker (controller) operates the control system. The criteria are:

- That the controller's explicit responsibility for the control system's objectives (i.e., human life and safety) is implicitly predicated on the fact that his career and emotional well-being are directly involved in the consequences of any mistake he may make, but his physical safety is not.
- That the controller carries out his responsibilities by exercising control in the system only indirectly; that is, through a complex system of people and machines, without direct and proximate influence over the objects of this control (e.g., individual aircraft).
- That the controller's responsibility includes the implementation of control decisions; that is, the controller's active command over a situation requiring a decision does not end when control instructions are issued, but is maintained at least until the appropriate actions are performed.

Numerous operational automated control systems were examined and none were found to be significantly analogous to the ATC system in terms of the specified criteria. Automated systems found to partially satisfy the task situations criteria include those used for manufacturing process control[2,3] and electric power distribution.[4] Those control systems are typically provided with conclusive information regarding the state of the objects under control from which a course of control action is readily identifiable; hence, the task situations associated with information availability and decision complexity are not analogous to those of the ATC system. Furthermore, those control systems exercise direct influence over the objects under control, and therefore do not satisfy one of the operational characteristics criteria. For example, the automation of one blooming and slabbing process in the steel industry[2] entails the automatic tracking of material flows and the collection of related data. From this information the automated control system calculates the optimum processing schedule and mechanically implements it.

Military tactical command and control systems[5] satisfy the task situations criteria, but are not analogous to the ATC system in terms of the operational characteristics criterion pertaining to decision implementation responsibility. For example, in the Naval Tactical Data System[5] a central decision maker is not responsible for the implementation of his decisions. A controller assigns a weapon (e.g., aircraft or missile) to a particular mission (e.g., destroy a specified target), but does not guide or directly monitor the weapon. Since this controller essentially functions as a dispatcher, the scope of his responsibilities is not broad enough to be considered analogous to that of the ATC controller.

Automation has been applied to medical diagnostic systems (e.g., automatic clinical analysis laboratories[6]), manufacturing process diagnostic systems (e.g., automatic machine failure indicators[7]), and vehicle detection and monitoring systems (e.g., automatic police car[8] and bus[9] location and identity systems). The automation of these systems is constrained to a data collection function. Since the automation involved is not oriented to decision-making task situations and is not directly related to the pertinent operational characteristics of a decision-making system, these automated systems are not analogous to the ATC system.

REFERENCES

1. L. P. Schrenk, "Aiding the Decision Maker--A Decision Process Model," Ergonomics, Volume 12, No. 4, pp. 543-557 (1969).

2. S. Hachiya, et al., "All-Round Computer Control System of a Blooming and Slabbing Process," Iron and Steel Engineer, pp. 71-80 (December 1971).

3. D. Brivio, "On-Line Production Control in an Integrated Steel Mill," Control Engineering, pp. 79-81 (October 1971).

4. S. J. Bailey, "Control Practice in the Electric Power Industry," Control Engineering, pp. 41-53 (September 1971).

5. F. Leary, "Tactical Command and Control," Space/Aeronautics, pp. 94-109 (April 1966).

6. "A Study of Automated Clinical Laboratory Systems," Berkeley Scientific Laboratories, Inc., DHEW Publication No. (HSM) 72-3004 (August 1971).

7. R. L. Douglas, "Aims and Techniques of Computer-Aided Automatic Assembly," Automation, pp. 34-36 (October 1971).

8. V. Bender, "More Mini Power for Management," Business Automation, pp. 30-32 (January 1972).

9. "Automated Bus System," The American City, pp. 130-134 (September 1970).

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