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VALIDATION OF AIR TRAFFIC CONTROLLER WORKLOAD MODELS

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16. Abstract

During the past several years, computer models have been developed for off-site estimation of controller's workload. The inputs to these models are audio and digital data normally recorded at an Air Route Traffic Control Center (ARTCC). This report summarizes the results of a study to validate the models at the Chicago ARTCC. For validation purposes, two additional estimates of workload were used.

One estimate consisted of journeyman controllers observing peer controllers during actual operations and assigning workload ratings. A second estimate of workload was obtained from a survey of controllers based on past experiences working the sectors. During this time, audio and digital data were collected and then processed off-line for inputs to the controller workload models. The models were then used to estimate controller workload. A high degree of correlation was found between the models' estimated workloads and controllers' estimates of workload. Based on this validation study, it is concluded that the models can be used to provide an index of controller workload and as a prediction of controller workload as a function of traffic.

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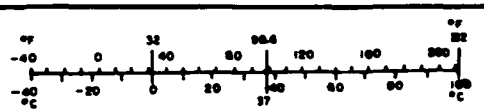
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The validation tests and analysis described in this report were performed by the System Technology Division, Transportation Systems Center (TSC), U.S. Department of Transportation. The work was sponsored by the ATC Systems Division, Systems Research and Development Service, Federal Aviation Administration (FAA). Over the past several years, the FAA in conjunction with SRI-International has developed computerized processes for estimating and measuring ATC controller workload. They are the Relative Capacity Estimating Process (RECEP) and the Air Traffic Flow (ATF) model. This work represents the final phase in the development of RECEP and ATF and was performed for the purpose of validation of the processes prior to their utilization in FAA studies.

Acknowledgement is given to the FAA Project Managers, William Petruzel and George Scott, who not only directed the project, but also provided liaison with the various FAA facilities involved and participated in the conduct of field tests. We also wish to acknowledge the support given by Peter Kovalick and James Moreland of the FAA Air Traffic Service in arranging the field tests with the Chicago Center.

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The Chicago Center, and particularly Deputy Chief Michael Ciancanelli, provided invaluable support in the conduct of field tests. Center facilities, records, and staff support were offered generously. Five journeymen controllers, Al Broholm, Terry Anderson, Ron Gillette, Bernie Miller, and John Vogel, served as workpace raters for an entire week and gave expert advice in describing the functions of an air traffic controller.

John Sigvydas of the Boston Center provided assistance in the availability and operation of voice recording equipment while John McDade, Development Program Branch of the National Aviation Facilities Experimental Center (NAFEC), was instrumental in editing digital Systems Analysis Recording (SAR) tapes during the data reduction phase of the project.

Kentron International Limited provided the software support for the project. This included development of computer programs for processing SAR data and modification to the controller workload models. The key personnel were Dr. John W. Royal and Herbert W. Landon.

CONTENTS

Section		Page
1.	INTRODUCTION	1
1.1	Background	1
1.2	Objectives	2
1.3	Organization of Report	3
2.	DESCRIPTION OF RELATIVE CAPACITY ESTIMATING PROCESS (RECEP) AND AIR TRAFFIC FLOW (ATF) MODELS	5
2.1	RECEP Description	5
2.1.1	Routine Workload	5
2.1.2	Surveillance Workload	14
2.1.3	Conflict Prevention Workload	15
2.2	ATF Description	20
2.3	Summary of Changes to RECEP/ATF	22
2.3.1	Definition of Routine Workload Activities	23
2.3.2	Activity Performance Times	24
2.3.3	Surveillance Workload	25
2.3.4	Sector Capacity/Workload Limit	27
2.3.5	Sample Interval Duration	28
2.3.6	Measurement of Aircraft Flow	29
3.	VALIDATION FIELD TEST AND DATA REDUCTION	31
3.1	Chicago Center Operational Aspects	31
3.2	Conduct of Tests	34
3.3	RECEP/ATF Data Reduction Methodology	38
3.4	Summary of RECEP Data	41
3.5	Summary of ATF Data	51
3.6	Example of the Determination of Potential Conflict Workload Coefficients	55
4.	VALIDATION ANALYSIS OF WORKLOAD DATA	69
4.1	Introduction	69
4.2	Summary Statistics for Sampled Sector Activities	71
4.3	Workpace Ratings in Relation to Expected Traffic Levels	78
4.4	Correlations Between Workload and Traffic Variables	81
4.4.1	Rated Workload as a Function of Traffic	82

CONTENTS (CONT.)

Section		Page
	4.4.2 Computed Workload as a Function of Traffic	84
	4.4.3 Linear Workload-Traffic Functions	86
4.5	Workload as a Function of Sector Control Difficulty	90
	4.5.1 Measures of Relative Sector Difficulty	92
	4.5.2 A Comparison Among Workload Estimators Relative to Control Difficulty	95
4.6	Correlation Between Concurrent Measures of Rated and Computed Workload	99
4.7	Workload at Capacity	101
4.8	Converging Lines of Evidence Reviewed	109
5.	CONCLUSIONS	110
5.1	Validation of Workload Estimates made by Controllers	110
5.2	Validation of RECEP as a Workload Index	110
5.3	Validation of RECEP as a Workload Predictor	111
5.4	Calibration of RECEP at Capacity Workload Conditions	112
APPENDIX -	CONTROLLER SURVEY TO DETERMINE SECTOR WORKLOAD LEVELS	A-1

LIST OF ILLUSTRATIONS

Figure		Page
3-1.	COMPONENTS OF ROUTINE WORKLOAD	50
3-2.	WORKLOAD VERSUS PERCENT OF TIME	56
3-3.	TRAFFIC HANDED OFF TO BDF 1800-1900 GMT, 2-28-78	58
3-4.	GROUND TRACKS OF TRAFFIC HANDED OFF TO BDF 1800-1900 GMT, 2-28-78	59
3-5.	GROUND TRACKS OF AIRCRAFT ENTERING BDF 1800-1815 GMT, 2-28-78	61
3-6.	GROUND TRACKS OF AIRCRAFT ENTERING BDF 1815-1830	62
3-7.	GROUND TRACK OF AIRCRAFT ENTERING BDF 1830-1845	63
3-8.	GROUND TRACK OF AIRCRAFT ENTERING BDF 1845-1900	64
4-1.	MEAN COMPUTED WORKLOAD AS A FUNCTION OF MEAN WORKPACE	75
4-2.	WORKPACE IN RELATION TO DEVIATIONS FROM EXPECTED AVERAGE TRAFFIC	80
4-3.	COMPUTED TOTAL WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL IN RATED SECTORS	88
4-4.	COMPUTED TOTAL WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL IN UNRATED SECTORS	89
4-5.	JUDGMENTS OF SECTOR CONTROL DIFFICULTY	93
4-6.	WORKLOAD ESTIMATORS RELATIVE TO RATED SECTOR DIFFICULTY	97
4-7.	WORKLOAD ESTIMATORS RELATIVE TO SECTOR DIFFICULTY CITATIONS	98
4-8.	COVARIATION OF TOTAL COMPUTED WORKLOAD AND RATED WORKLOAD IN SECTOR VAINS	102
4-9.	COVARIATION OF TOTAL COMPUTED WORKLOAD AND RATED WORKLOAD IN SECTOR MLI	103

LIST OF TABLES

Table		Page
2-1.	AIR/GROUND MESSAGE TYPES AND PERFORMANCE TIMES....	10
2-2.	KEYBOARD MESSAGE TYPES AND PERFORMANCE TIMES.....	12
2-3.	FLIGHT STRIP ACTIVITIES, PERFORMANCE TIMES, AND FREQUENCY COUNT SOURCES.....	13
3-1.	WORKPACE DEFINITIONS.....	36
3-2.	RECEP/ATF PARAMETERS DERIVED FROM SAR.....	40
3-3.	WORKLOAD-AIRCRAFT-WORKPACE SUMMARY.....	42
3-4.	SECTOR FLIGHT TIMES	52
3-5.	ATF WORKLOAD EQUATION COEFFICIENTS.....	54
3-6.	AIRCRAFT ENTERING BDF 1800-1900 GMT, February 28, 1978.....	60
3-7.	CONFLICT WORKLOAD COEFFICIENTS.....	68
4-1.	STATISTICS FOR VARIABLES IN RATED SECTORS.....	72
4-2.	STATISTICS FOR VARIABLES IN UNRATED SECTORS.....	73
4-3.	CORRELATIONS BETWEEN MEASURES OF TOTAL WORKLOAD AND MEASURES OF AIRCRAFT TRAFFIC.....	83
4-4.	WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL FUNCTIONS DERIVED FROM OBSERVERS' WORKPACE RATINGS.....	87
4-5.	WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL FUNCTIONS DERIVED FROM QUESTIONNAIRE JUDGMENTS....	91
4-6.	NUMBER OF CONTROLLERS CITING DIFFICULTY FACTORS IN CHICAGO SECTORS.....	94
4-7.	COMPUTED WORKLOAD PREDICTED FROM RATED WORKLOAD...	100
4-8.	COMPUTED WORKLOAD FOR SELECTED WORKPACE VALUES DERIVED FROM QUESTIONNAIRE RESPONSES.....	105
4-9.	COMPUTED WORKLOAD FOR SELECTED WORKPACE VALUES DERIVED FROM WORKPACE RATINGS.....	106

1. INTRODUCTION

1.1 BACKGROUND

Over the past several years the FAA, sponsoring work by SRI-International and utilizing TSC technical direction, has developed fast-time computer models of controller work activities at Air Route Traffic Control Centers (ARTCC). The models are designed to provide quantitative estimates of controller workload under various system configurations. Thus, the models can provide estimates of improved controller productivity attributable to newly-developed equipment sets such as the Electronic Tabular Display Subsystem (ETABS) or to revised traffic control procedures. The models also can be used to verify productivity benefits after new configurations have been implemented.

Two computer models have been developed. The Relative Capacity Estimating Process (RECEP) provides a static measurement of controller workload as a function of traffic flow rate through individual sectors. The Air Traffic Flow (ATF) model dynamically simulates traffic flow along routes through a multi-sector area and provides a continuous measure of controller workload as well as aircraft delays, if any.

Emphasis has been placed on the development of methods for the off-line collection and computer processing of work activity and other data required as inputs to the models. This allows field measurement to be taken with minimum effort on Center operations. It also provides means for processing large amounts of data rapidly, greatly enhancing the utility for the models.

RECEP and ATF models have been created for the Atlanta and Miami Centers based on limited amounts of data collected and processed manually. A preliminary comparison has been made between standard NAS Stage A and ETABS operations at Miami.

1.2 OBJECTIVES

The FAA has directed that a formal validation process be conducted of the models. Therefore an experiment was designed to simultaneously measure controller workload by the RECEP/ATF process and by other workload-measuring techniques. The measurements were made at the Chicago ARTCC under operational conditions in 11 sectors. Results were then analyzed. The level of agreement between RECEP/ATF and the other measures of workload indicates the validity of the RECEP/ATF models. The purpose of this report is to describe the

operational tests which were conducted, the subsequent analysis which was performed, and to establish the validity of the RECEP and ATF models.

1.3 ORGANIZATION OF REPORT

Section 2 contains a summary description of the RECEP and ATF models. The models have been described repeatedly in previous documents (Refs. 1, 2). Therefore, this section is not intended as an exhaustive description. Emphasis is placed more on methodology while highlighting areas where changes in the process have been made as a result of the work described herein.

Section 3 contains a description of the operational tests performed at the Chicago ARTCC in which simultaneous measures of workload were obtained. The section also describes the data reduction methodologies for the RECEP and ATF models and summarizes the results obtained using the models.

Section 4 contains analyses that compare RECEP workload with other measures of workload. In addition, the mathematical relationship of components of workload, as defined by RECEP, to traffic flow and other measures of workload is established. Finally, measures which re-

late to sector capacity are evaluated.

Section 5 is a summary of the conclusions which result from the validation experiment.

One appendix is included. This appendix contains a description of a controller survey which was conducted to provide various subjective estimates of workload for comparison with RECEP workload.

2. DESCRIPTION OF RELATIVE CAPACITY ESTIMATING PROCESS (RECEP) AND AIR TRAFFIC FLOW (ATF) MODELS

2.1 RECEP DESCRIPTION

RECEP is a procedure for estimating the workload of a controller or team of controllers at an Air Route Traffic Control Center. The procedure is applied on a sector-by-sector basis and can be used to estimate the workload of an individual control position such as the radar (R) or the manual (D) or combinations of control positions within a sector. RECEP is intended to measure the primary physical and mental activities which a controller performs, and results in a quantitative estimate of man-minutes of work performed during a specific time interval. RECEP divides controller workload into three basic categories: routine, surveillance, and conflict prevention workload. Total workload is the sum of the three. The work activities within each category and the measurement and computation methods are discussed in the following sections.

2.1.1 Routine Workload

Routine workload consists of the activities associated with air/ground and interphone voice communications, keyboard operations, and flight strip processing. The RECEP procedure involves

measurement of the frequency with which each activity is performed within a specified time interval. This frequency is multiplied by the average time a controller takes to perform the activity. Total routine workload for the time interval is the sum of the frequency-time products for all activities. The frequency of occurrence of an activity will vary from one time interval to another and must be measured for each interval. Average performance time for each activity is considered to be invariant from sector to sector and need not be measured repeatedly.

Measuring activity frequencies over many intervals for several sectors involves a large quantity of data. Previously it was necessary to obtain frequency counts by observing controller activities and manually tabulating counts in real-time. However, TSC has developed techniques by which all required data can be obtained from SAR and voice communication tapes which record continuously at all Centers. This not only eliminates the need to have many observers in the operations area, but also allows selection of sample intervals after traffic levels and other operational conditions have been evaluated.

For air/ground and interphone communications, the individual activities correspond to the type of message being transmitted or received by the controller. Each type of message is unique and has a specific average performance time. The RECEP definition of message types is adapted from a method for categorizing and coding voice messages which has been developed at NAFEC. This work is summarized in Ref. 3. The NAFEC coding system identifies 25 major types of air/ground messages, with a more detailed breakdown within each type. The more detailed breakdown was adopted for RECEP, in that messages were categorized not only by general functional type, but also with regard to whether the message conveyed information (e.g., clearances, advisories, and instructions), asked a question, restated previously communicated information, or acknowledged the receipt of information. These distinctions were made both for air/ground and interphone commmunications (NAFEC recently began applying the air/ground codes to interphone messages, although no published results are available at present). Another distinction made just for air/ground communications is whether the message was transmitted by the R controller (controller

speaking) or by a pilot (controller listening). For interphone communications, it was not possible to reliably discriminate whether a message was spoken by the controller in the studied sector or in another sector. In general, the frequency counts derived for RECEP are only for communications that involved the exchange of information. Because information exchange requires some amount of mental work, the frequency counts provide an index of workload. Brief acknowledgements, such as "Roger," and "Wilco," and salutary messages, such as "Have a good day," were thus excluded.

Average performance times for each air/ground message type have been obtained from a large volume of communications data collected at the New York Common IFR Room by Princeton University under FAA sponsorship and contained in Ref. 4. These values are in reasonable agreement with air/ground message durations measured at the Los Angeles Center by SRI-International (Ref. 2) on a smaller volume of data. A large data bank for interphone performance times does not exist. For RECEP, a nominal value of five seconds is used for all interphone message types. This value is in close agreement with the message durations measured by SRI-International at Los

Angeles and with the mean message duration obtained through an analysis of 24 hours of interphone communications from the Chicago Center tests described herein.

Table 2-1 is a listing of the 25 message types including average performance times both for the controller transmitting and receiving.

Keyboard operations are performed by the controller for the purpose of computer data entry. As in the case of voice communications, individual activities are defined which correspond to the type of message being entered into the computer. Keyboard entries for all control positions are recorded on the SAR tapes. TSC has developed procedures to extract this data from SAR and to code and tabulate message frequencies by type. A total of 19 unique message types are identified plus an "all other" category. Performance times for each message type are taken from the stopwatch measurements done by SRI-International at the Los Angeles Center. Although there is not an exact one-to-one correspondence between message types as defined by SRI-International and by TSC in the current RECEP model, there is enough similarity to assure a high degree of validity

TABLE 2-1. AIR/GROUND MESSAGE TYPES AND PERFORMANCE TIMES

MESSAGE TYPE	PERFORMANCE TIME (SECONDS)	
	TRANSMITTING	RECEIVING
A/C Vectoring/Heading	2.9	2.4
A/C Holding	4.6	2.4
Altitude Control	3.0	2.9
Speed Control	2.9	2.3
Clearance w/o Holding	3.1	2.7
Clearance with Holding	4.2	4.8
Clearance Delivery - Air Files	4.6	4.8
Clearance Delivery - Flight Plans	4.6	4.8
Call-Up	1.6	2.1
Beacon (Nondiscrete) Control	2.9	2.0
Handoff/Frequency Change	3.7	2.2
Beacon (Discrete) Code	3.3	2.3
Mode C Altitude Report	2.9	2.0
A/C Position Report	3.0	2.6
A/C Altitude Report	2.0	2.6
Heading and Speed Report	2.3	2.5
Aircraft Identification	2.3	1.8
Facility Report	3.4	3.0
A/C Traffic Advisory	4.9	2.4
A/C Status	2.6	1.9
General Weather	4.4	2.3
Airport/Facility Status	4.3	2.3
Specific Weather/Flight Conditions	2.7	3.7
Altimeter Setting	3.6	2.0
Approach/Departure Information	3.9	2.4

in the values assigned. Table 2-2 lists the 20 message types and associated performance times.

Flight strip activities comprise the remaining portion of routine workload. The activities consist primarily of marking the flight strips to record the occurrence of a specific control event. One exception to this is the preparation of a new flight strip, usually by the D controller, in response to an aircraft requesting IFR status after becoming airborne (pop-up aircraft). Thirteen activities have been identified, each having a specific performance time. Again, the performance times are taken from the SRI-International measurements from the Los Angeles Center. Obtaining frequency counts for flight strip activities is the only case in estimating workload where the data cannot be extracted directly from SAR or voice tapes. However, flight strip markings are made in response to specific control events that are recorded either by particular voice messages, keyboard operations, or SAR traffic counts. Therefore, flight strip frequency counts are obtained by inference from these other sources. Table 2-3 lists the 13 flight strip activities, the performance time associated with each, and the

TABLE 2-2. KEYBOARD MESSAGE TYPES AND PERFORMANCE TIMES

MESSAGE	PERFORMANCE TIME (SECONDS)
Handoff Acceptance	2.0
Handoff Initiation - Manual	3.0
Flt Data Altitude Insert	3.0
Flt Data Altitude Amendment	3.0
Flt Data Code Update	3.0
Flt Data Route Amendment	10.0
Printout-Data Block Suppression	3.0
Pointout Initiation	3.0
Data Block/Leader Offset	2.0
Data Block Forcing Removal	3.0
Altitude Limits Change	2.0
Flight Plan/Track Removal	2.0
Flight Plan Readout	3.0
Track/Route Display	3.0
Flt Data Update	3.0
Wind/Weather Request	3.0
Flt Strip Request	3.0
Miscellaneous Amendments	3.0
Track Initiation	3.0
Other Messages	3.0

TABLE 2-3. FLIGHT STRIP ACTIVITIES, PERFORMANCE TIMES, AND FREQUENCY COUNT SOURCES

ACTIVITY	PERFORMANCE TIME (SECONDS)	FREQUENCY COUNT SOURCE
Prep New Flt Strip	10	Offline Estimate*
Handoff Initiation/Freq Change Instruction	2	Controller Air/Ground
Handoff Acceptance/ Pilot Call-in	2	SAR Traffic Count
Flt Data Altitude Insert	2	Keyboard
Flt Data Code Amend	2	Keyboard
Vector/Heading Control	2	Controller Air/Ground
Altitude Control	2	Controller Air/Ground
Speed Control	2	Controller Air/Ground
Clearance/Air Filed	2	Controller Air/Ground
Clearance/Grd Filed	2	Interphone
Altitude Report	2	Pilot Air/Ground
Heading/Speed Report	2	Pilot Air/Ground
Altimeter Set Instruction	1	Controller Air/Ground

*The frequency of new flight strip preparations is based on average values obtained by direct observation of controller activities at the Los Angeles Center. It is assumed that the D-Controller performs this task.

source from which the frequency count is inferred.

2.1.2 Surveillance Workload

Surveillance workload is the process of scanning the PVD to retain a mental picture of the traffic situation. SRI-International, in tests at the Los Angeles Center, conducted controller interviews using video tape playbacks of actual traffic situations to determine the amount of time spent on this task. On an average, the controller is likely to look at an aircraft's data display once every minute with a dwell time of between 1.0 and 1.5 seconds per aircraft. Therefore, a workload value of 1.25 seconds per aircraft-minute is used. This value is applied to the total time an aircraft full data block symbol appears on the PVD, and to all aircraft being observed--not just aircraft under the sector jurisdiction--on the assumption that a controller displays aircraft symbols only if they are of concern. SAR data provides an exact count of the number of minutes each symbol is displayed during a specific time interval.

2.1.3 Conflict Prevention Workload

Conflict prevention workload represents the time spent in detecting potential conflicts (violation of minimum separation), assessing the situation, and taking corrective action. In general, two types of potential conflicts can occur: crossing conflicts where the projected flight paths of two aircraft intersect with less than minimum altitude separation, and overtaking conflicts where aircraft are on the same flight path at different speeds.

General equations for estimating the expected number of conflicts per specific time period have been derived by Siddiqee (Ref. 5) and Dunlay (Ref. 6). The equation used in this study for the expected numbers of crossing conflicts per unit time period at the intersection of two flight paths is:

$$C = \frac{2\, f_1\, f_2 \times \sqrt{V_1^2\ V_2^2 - 2\, V_1\, V_2 \cos \alpha}}{V_1\, V_2 \sin \alpha} \quad (1)$$

where

C is the expected number of conflicts per unit time period;

f_1 and f_2 are the flow of aircraft along

flight paths 1 and 2 respectively (aircraft per time period);

V_1 and V_2 are the average ground speeds of aircraft along flight paths 1 and 2 respectively (nautical miles per time period);

α is the angle of intersection between the two flight paths;

X is the separation minimum (nautical miles).

The equation used to determine the expected number of overtakes along a flight path is:

$$O = \sum_{i=1}^{n-1} \frac{(\ell + x) f_i}{V_i} \sum_{k=i+1}^{n} \frac{f_k}{V_k} (V_i - V_k) \quad (2)$$

where

Ø is the expected number of overtakes per unit time period;

n is the number of discrete speed classes along the route;

f_i and f_k are the flow of aircraft at the ith and kth speed classes respectively (nautical

miles per time period);

V_i and V_k are the average ground speeds of the ith and kth speed classes respectively (nautical miles per time period);

X is the separation minimum (nautical miles).

The crossing conflict equation was derived on the assumption that the flight paths were both level. In practice, the flight path angles of transitional aircraft in an enroute sector are small. Therefore, the above conflict equation can be used for transitional as well as level flight paths.

Potential conflicts exist when two or more flight paths merge into one. It can be shown that the crossing conflict equation is an excellent approximation for the expected number of conflicts due to the merging of flight paths.

The above approximations are in agreement with previous work. In Appendix D of Ref. 1, S.R.I. states that the level-level crossing equation should be used for the above two cases.

Another type of potential conflict is the altitude intersection of two flight paths along the same ground track. A form of the crossing conflict equation could be applied to this case (Ref. 1). However, since the angle between the two flight paths is small, the overtake equation will be used. This is in agreement with S.R.I. Atlanta case study (Ref. 7).

The last type of potential conflict analyzed was the case of two aircraft heading toward each other. In this case, the expected number of potential conflicts was considered 1.0.

Utilizing the above equations and assumptions, the method of computing conflict prevention workload for a specific time interval is discussed in the following paragraphs.

For each sector, many samples of traffic flow are obtained from SAR data. A fifteen-minute sample interval is used because this value approximates the average sector flight time. Therefore, the number of aircraft entering the sector can be directly equated to flow rate. The flight path of each aircraft is reconstructed from SAR data and the paths are analyzed for potential conflict points. The probability of aircraft actually being in

conflict is then computed based on previously delineated criteria. A workload value to resolve conflicts is obtained by multiplying the number of probable conflicts by an average time to resolve conflicts. A value of 60 seconds and 40 seconds is used for crossing conflicts and overtaking conflicts, respectively (Ref. 1). Thus for each sample, a data point is obtained which relates conflict workload to the number of aircraft. Based on many sample data points, a function defining workload versus aircraft is obtained. This function typically takes the form of a quadratic:

$$W_s = CN_s^2 \qquad (3)$$

where W_s = conflict prevention workload expressed in man-minutes per sample interval

C = a constant in units of man-minutes per sample interval per (aircraft)^2

N_s = number of aircraft

The slope of the quadratic function (C) derived

from sampled data is then used to compute workload for any specified time interval:

$$W_c = \frac{P_I}{P_C} \quad CN^2 \qquad (4)$$

where W_c = conflict prevention workload expressed in man-minutes per time interval

P_I = duration of time interval in minutes

P_S = duration of sample interval in minutes

N = mean number of aircraft under control

An example of conflict prevention workload calculations is contained in Section 3.6.

2.2 ATF DESCRIPTION

ATF is a computerized fast-time simulation of aircraft flow along defined routes within a multisector area of an ARTCC. ATF can be used to simulate traffic flow within an individual sector or an entire Center. Typically, an area of from 10 to 12 contiguous sectors

is simulated. An empirical traffic sample, in the order of six to eight hours, is used to define a route structure and traffic flow along each route for the entire area. Routes are divided into arcs which correspond to the segment of the route traversing an individual sector. Aircraft are sequenced along a route from sector to sector based on average arc transit times. Sequencing is performed minute by minute.

Workload is computed for each sector minute by minute using the following relationship (Ref. 1):

$$W_L = K_1 N + K_2 N^2 \tag{5}$$

where W_L = workload in man-seconds per computation interval

K_1 = coefficient in man-seconds per computation interval per aircraft

K_2 = coefficient in man-seconds per computation interval per $(\text{aircraft})^2$

N = number of aircraft in sector

Coefficients are determined by measuring total RECEP workload over many sample intervals and, by curve-fitting, deriving a second order function of workload versus aircraft. The form of the function

assumes that routine and surveillance workload vary linearly with aircraft, that conflict workload varies as the square of aircraft, and that there is zero workload with zero traffic.

A workload limit is assigned to each sector. ATF has look-ahead capability to sense when saturation is about to occur. Under this condition, aircraft are delayed from entering the sector until the saturation is relieved. Traffic can be artifically increased in order to investigate saturation conditions within the area.

Output measures of the ATF model are workload for each sector and aircraft flow rate and delays either by route or sector. Output measures can be summed or averaged for specific time intervals.

The primary uses of the ATF model are in measuring system delay characteristics under alternate system configurations and in evaluating sector workload over long periods of time and varying traffic conditions.

2.3 SUMMARY OF CHANGES TO RECEP/ATF

Over the past several years, SRI-International, under FAA sponsorship, has developed the RECEP/ATF process and applied it in several FAA studies. Numerous descriptive reports have been generated and have

received wide circulation. In conducting the Chicago ARTCC validation tests described herein, TSC has made refinements to the process. This section contains a brief review of those refinements for the purpose of calling attention to those areas where previous concepts, perhaps firmly established, do not apply.

2.3.1 Definition of Routine Workload Activities

In the past, the subdivision of routine workload into individual activities was done on a functional basis. There was no requirement that the activities correspond to a previously defined coding system. TSC, however, in developing automated SAR data extraction programs and in adopting the NAFEC voice coding system was forced to deviate slightly from previous definitions of activities. The sum total of all activities still accounts for total routine workload, however. In addition, previous RECEP models have included as a component of routine workload the time spent in direct face-to-face conversations between controllers. TSC has eliminated direct voice as a workload component on the basis that these conversations are for the purpose of verification and coordination and do not add fundamentally to the workload.

2.3.2 Activity Performance Times

Activity performance times were previously defined by SRI-International in terms of the minimum time required to perform an activity. In the present RECEP model, average times based on a large sample of data are used for voice communications activities, but minimum times obtained from SRI-International reports are used for the other routine activities, namely, keyboard entry actions and flight strip operations. It is suspected that average activity durations more accurately reflect differences between control activities than minimum durations do. In the large sample of voice communications data (Ref. 4), the minimum durations of many different message types are approximately equal, all on the order of one second; however, the average durations for those different message types differ. It is noteworthy that the average durations of voice messages in those large samples are on the same order of magnitude as the minimum times that are reported or evident (through subdivision of voice communications transactions into their component messages) in the work by SRI-International. The agreement is probably due to the fact that SRI's minima were drawn

from relatively small samples of data. Increasing the sample size would have increased the opportunity for observing the very short (low probability) minimum durations that are actually seen in large samples. The minimum times reported by SRI-International for the other routine activities, keyboard entries and strip operations, might also prove to be approximately equal to the average durations in large samples of activity data, which are now unavailable. Accordingly, the working hypothesis is that all the performance times used for the present version of RECEP--both the large sample averages for voice communications, and the small sample minima for other activities--are average durations.

2.3.3 Surveillance Workload

In previous versions of RECEP, the R controller's surveillance workload was based on the average number of minutes that all aircraft were under the jurisdiction of a sector. This average sector flight time was used to estimate the average surveillance workload. This approach has two difficulties. First, R controllers often monitor aircraft that are not under their jurisdiction. The airspace is a

continuous volume, and controllers are alert to traffic near the borders of the airspace over which they have jurisdiction. Secondly, surveillance workload varies from one time interval to another. This variability should be measured when comparing RECEP workload to workpace ratings taken every five minutes. Since the ratings vary over time, the measure of RECEP workload should be capable of analogous variations. Whether the two measures of workload vary in time together to an appreciable degree is one of the questions that bears on the validity of RECEP workload measures.

Therefore, in the present version of RECEP, the R controller's surveillance workload is based on the average number of aircraft full data blocks that are displayed at the same time on the sector's Plan View Display. These data blocks represent aircraft that are under the sector's jurisdiction, pointed out to the sector by controllers in another sector, or selected for display (i.e., "forced") by the controllers in the sector. The number of aircraft simultaneously displayed is sampled once every five minutes, and the average number is calculated for three successive five-minute intervals to give the 15-minute value. This

sampling procedure is analogous to the one used for workpace ratings, that is, a rating once every five minutes, and 15-minute averages based on three successive ratings.

2.3.4 Sector Capacity/Workload Limit

Past RECEP models included the concept that each sector is limited in traffic capacity, expressed in aircraft per hour, which corresponds to an upper limit in the workload a controller can perform. Values of workload limit were found to be 48 man-minutes per hour for a Radar Controller and 66 man-minutes per hour for a combined Radar/Manual Controller team in several sectors evaluated at the Los Angeles Center. Several aspects of this concept are now being questioned as a result of the work performed at the Chicago Center. First, controllers apparently do not think of traffic capacity or workload in hourly terms. Aircraft simultaneously under control is more meaningful and would serve as a better definition of capacity conditions. Secondly, during the Chicago tests, several sectors were operating at capacity conditions (as defined by "very heavy" workpace ratings) for periods of five minutes or more. The RECEP workload values for these

periods, however, varied from sector to sector. It is therefore questionable that one workload value such as 48 man-minutes per hour can be used to define a limit for all sectors. Finally, the absolute values of 48 and 66 man-minutes per hour appear to be low. During the tests at the Chicago Center described herein, there were numerous incidents of workload as computed by RECEP exceeding 15 man-minutes during a 15-minute time interval. Admittedly, the tests were conducted at the busiest Center in the country and only busy hours were selected. The fact is, however, that RECEP measures the time spent on activities which may be performed simultaneously, thus making it possible to exceed 100% of the total time available. Expressing workload in units of man-minutes is more a measure of the busyness of a controller rather than an absolute measure of working time versus idle time.

2.3.5 Sample Interval Duration

In the past, RECEP workload values and ATF coefficients were computed from data combined over one-hour observation intervals. A shorter sample provides more accurate workload data for several reasons. First, more frequent sampling

gives a truer indication of workload variation over time. This is the reason why workpace ratings are ordinarily made once every 5 or 10 minutes during FAA studies. Second, in the case of conflict prevention workload, sampling on an hourly basis in order to compute conflict probability results in an erroneously high value. The overestimation occurs because aircraft are treated as if they are in the sector at the same time, when the aircraft are actually separated in time by as much as three sector flight times, and therefore cannot interact with each other. A sample interval of 15 minutes has been selected for the present work because it approximates the average sector flight time over all sectors, has a greater capability than 60 minutes for reflecting workload variations, and is still consistent with practical constraints on data reduction and analysis.

2.3.6 Measurement of Aircraft Flow

In determining the constant coefficients in the ATF equation for computing workload, total RECEP workload is measured for many sample intervals and, by curve-fitting, a function of workload versus aircraft is derived. In the past,

traffic flow rate (TFR) has been used as the measure of the number of aircraft in the sample. TFR is defined either as aircraft entering plus aircraft exiting divided by two or, simply, as aircraft entering during the time interval. However, in the ATF model, workload is determined by multiplying the coefficients by the number of aircraft in the sector during each computation interval. TFR is not the same quantity as aircraft in the sector and an erroneous workload value results. The mean number of aircraft under control (AUC) during each sample interval is a more accurate measure of the number of aircraft in the sector and is analogous to the aircraft flow parameter used in the ATF model. The current RECEP model uses AUC as the measure of aircraft flow.

3. VALIDATION FIELD TEST AND DATA REDUCTION

RECEP and ATF have their greatest value for evaluating controller workload at high traffic levels. It is for high traffic levels that improvements to the ATC system have been designed, in order to reduce the workload of controllers per aircraft, and so permit controllers to safely handle more aircraft. Because the study to validate the RECEP/ATF models should be conducted in sectors where reasonably high traffic levels could be expected often, the Chicago Center was selected. Daily traffic counts for the Center for the year 1977 were reviewed and from this a test period from 2/28/78 to 3/3/78 was selected where higher than average traffic could be expected. By choosing the busiest hours within this period, it was felt that a reasonable number of very high traffic samples would be obtained. The Center was most cooperative in scheduling the tests and supplying the necessary staff support and facilities.

3.1 CHICAGO CENTER OPERATIONAL ASPECTS

In deriving RECEP and ATF models of controller workload, certain aspects of the operational environment are of interest. These are discussed below.

The Chicago Center has approximately 40 active sectors which operate individually during the day and evening shifts. Some are combined during the mid-shift. The sectors are divided into seven areas of specialization. Controllers are qualified to work any sector within an area. The layout of the sectors is centered around O'Hare Airport. There are alternately four arrival and four departure sectors aligned on the major points of the compass. Most O'Hare traffic is fed directly from or to eight high altitude sectors which are also aligned radially. There are approximately 20 outlying low altitude sectors and three superhigh sectors which primarily handle enroute traffic.

In planning an ATF model of a portion of the Chicago Center, it was desirable to select contiguous sectors arranged to contain continuous flows of traffic. Eleven sectors west of O'Hare were chosen. These include the West Departure sector and Farmm and Vains, the northwest and southwest arrival sectors, respectively. Also included are the four western high altitude sectors, Dubuque, Iowa, Bradford and Joliet; one superhigh sector, McCook, which overlays Iowa, Bradford and much of Joliet; and three underlying low altitude sectors, Rockford, Moline and Peoria. These 11 sectors account for 30% of the Center traffic and contain all of the O'Hare arrivals and departures to the west. The areas involved are West Terminal, West

High Altitude, and West Low Altitude.

Traffic at the Chicago Center is quite heavy from 7 AM to 7 PM. Peak loads occur throughout the day. Pronounced peaks regularly occur at about 9 AM, 1 PM, 3 PM, and 5 PM. In order to consolidate the hours of data-taking and other activities, the period from noon to 5 PM was designated as the test period. Within that period, individual hours were selected for data reduction and analysis after traffic levels and other considerations had been evaluated.

The controller team composition within sectors normally includes a Radar (R) Controller and Manual (D) Controller. In addition, coordinators are assigned to coordinate traffic flow between several sectors. As an example, one coordinator may work between an arrival sector and the several sectors which feed it. Assistant (A) Controllers prepare and distribute flight strips to the appropriate sectors. One A-Controller normally services an entire area. Handoff (H) Controllers are sometimes assigned to a sector team under extremely busy conditions. The function of the H-Controller is to assist the team in coordination, keyboard entries, and interphone.

At the time of the validation tests, the 9020 computer software version in effect was NAS Stage A3d2.4. Controller workload models derived during these tests

would be valid for most software versions being used in the field. However, if the system configuration were changed significantly, the models would require amendment.

3.2 CONDUCT OF TESTS

The primary objective of the validation tests was to obtain a comparison of controller workload as measured by RECEP with other measures of workload for the purpose of validating the RECEP process. Two other measures were used: workpace ratings and a subjective rating of workload obtained by a survey of controllers. The general approach followed was to gather RECEP and workpace data over a four-day period while monitoring test conditions and then selecting specific time intervals on which to base the comparison. All measures of workload were for the R-Controller position which has the heaviest workload and is the most critical in defining sector capacity.

As stated previously all data required for RECEP and ATF modelling are gathered continuously offline on SAR and voice tapes. However, for the purpose of the validation tests, it was desirable that all test intervals selected reflect a uniform set of test conditions. Therefore, two observers were present in the operations area during all test periods to monitor

test conditions at the 11 sectors. Control team composition was of primary interest. If the R-Controller was assisted by an H-Controller, these periods were rejected because in reducing taped data it was not possible to distinguish between the R and H work contributions. In addition, if the R-Controller was also working the D position, this was noted because additional data channels would then be searched in computing workload. Periods which involved unusual traffic conditions such as holding patterns or rerouting of traffic due to changes in active runways at O'Hare were noted and rejected as test intervals. Test intervals were also based on uniform weather conditions as far as possible.

Workpace rating is a technique used by the FAA to estimate workload level. A peer journeyman controller observes the work activities of a controller on duty and subjectively rates the work level on a seven-point scale ranging from "very light" to "very heavy." Ratings are made at five-minute intervals and can be continued for a period of one hour or more. Table 3-1 contains a list of various ratings and a definition of each. From the 11 sectors being modeled, five of the busiest were chosen for workpace ratings. They are Vains, Farmm, Moline, Peoria, and Bradford. Volunteers served as workpace raters for sectors in which they were qualifed, with two raters alternating between

TABLE 3-1. WORKPACE DEFINITIONS

- Very Light Workload (VL). A "VL" rating should be assigned when the Workpace level is so low that relatively little attention has to be paid to the position of operation. Minimal exertion is required.

- Light Workload (L). An "L" rating should be assigned when the Workpace is such that more than minimal exertion is required, but the complexity of situations is such to only engage the controller's complete attention periodically. There are no complex control situations.

- Average Workload (A). An "A" should be assigned when the situation complexity requires almost full-time attention of the controller. The workload is evenly distributed and places no unusual demand upon the controller. This pace could be maintained up to an 8-hour period with normal relief.

  - Gradient. A- should be assigned when significantly less than full attentiveness is required at the position; the demands placed upon the controller are slightly less than one could expect at average. Infrequent periods of inactivity occur.

  + Gradient. A+ should be assigned when the demands are slightly greater than A. Rare periods of inactivity, full attentiveness to the position is required. A controller could be expected to work at this pace up to six hours with normal relief.

- Heavy Workload (H). An "H" rating should be assigned when the complexity and exertion required to cope with the situation necessitate rapid decisions; there is constant operational activity. Demands placed upon the controller exceed those of a normal pace. A controller could be expected to securely deal with this level of work for up to 3 hours.

- Very Heavy (VH). A "VH" should be assigned when there is continuous, laborious activity; superior exertion is required and the rapidity of response and thinking processes are critical. There are delays in acknowledging demands placed upon the position. A controller would be "pushed" to maintain this pace for 1 hour.

Vains and Farmm and two between Peoria and Moline. A single rater made all observations for Bradford. Ratings were made for three one-hour periods on each of the four days. The ratings were converted to a numerical scale from 1 to 7 and ratings for three successive five-minute periods were summed and averaged to obtain a mean value of workpace for each 15-minute period. From this total set of workpace data, 24 15-minute periods per sector were later selected as test intervals for comparison with RECEP. The selection was based on high workpace ratings and on satisfying uniform test conditions. It should be noted that one day was spent prior to the beginning of testing familiarizing the raters with the workpace technique and in trial runs.

During the four-day test period, off-line interviews were conducted with volunteer controllers using questionnaires designed to estimate workload levels in the 11 sectors. Controllers were asked to rate only those sectors in their area of specialization. Five controllers in each of the three areas participated. Three questionnaire forms were used. The first provided a listing of relative sector difficulty within an area based on a seven-point scale ranging from "easiest to control" to "most difficult to control" during typical busy periods. The second form provided an estimate of the maximum sector traffic capacity.

The questionnaire originally asked for an hourly maximum capacity estimate. However, controllers are better able to estimate maximum simultaneous aircraft. Therefore, the latter is the estimate obtained from the interviews. The third questionnaire form provided a seven-point workpace estimate versus the number of simultaneous aircraft under control, again ranging from "very light" to "very heavy". The ratings obtained from these interviews were used in the RECEP validation analysis discussed in Section 4. The Appendix contains a description of the interview process and examples of the questionnaire forms.

3.3 RECEP/ATF DATA REDUCTION METHODOLOGY

SAR tapes run continuously collecting digital data on Center operations for all sectors. Because of the high volume of traffic at Chicago, each tape contains only 15 minutes of data. SAR tapes for the test period, noon to 5 PM, for each of four days were shipped to Code ARD-141, NAFEC, where a DART editing and cataloging operation was performed to provide edit tapes of a DART LOG data base. The edit tapes were then shipped to TSC. TSC has developed FORTRAN computer programs which extract specific information from the edit tapes required for RECEP and ATF modelling. The programs are run on an IBM-360 machine which is compatible in language and symbology with the

9020 computers used in the field and at NAFEC. Table 3-2 contains a listing of the RECEP/ATF parameters which are derived from the SAR data. Where applicable, the parameters are segregated by sector and by test interval. The programs also provide hourly summations of appropriate parameters.

Voice tapes also run continuously recording air/ground and interphone communications for all control positions within all sectors. Each tape contains 16 hours of communication. Voice tapes for the four days of testing were taken to the Boston Center where playback tapes were made for the test intervals selected for each of the 11 test sectors. A typewritten transcription was made from the playback tapes. Each message was then coded in accordance with the list contained in Table 2-1 and frequency counts of message types were tabulated for each test interval.

Voice messages for the Radar position in the Farmm sector were not obtained due to a malfunction in the recorder at the Center. As a result, routine workload could not be estimated based on direct measurements. This problem was circumvented by computing the average routine workload per aircraft in the Vains sector and applying it to the traffic in Farmm. Vains and Farmm are very similar in function, operations, and traffic characteristics.

TABLE 3-2. RECEP/ATF PARAMETERS DERIVED FROM SAR

1.	Position and speed history of all aircraft.
2.	Jurisdictional control history of all aircraft.
3.	Jurisdiction Times of all aircraft within each sector.
4.	Average sector jurisdiction Times (sector flight time).
5.	Time under surveillance of all aircraft within each sector.
6.	Average sector surveillance Times.
7.	Number of aircraft under control within each sector.
8.	Number of aircraft under surveillance within each sector.
9.	Average route and arc transit Times.
10.	Number of aircraft on each route and arc.
11.	Coded keyboard activity frequency counts by control position.

3.4 SUMMARY OF RECEP DATA

Following the conclusion of the validation tests, RECEP workload was calculated for specific time intervals, each of 15 minutes duration. Twenty-four intervals were selected for each of the five workpace-rated sectors and eight intervals were selected for the remaining six sectors. For the workpace-rated sectors, the selection was based on the highest workpace ratings while satisfying uniform test conditions. For the other sectors, the selection was based on the highest number of aircraft in the sector during the first two days of testing. Two of the intervals selected for the Rockford Sector were later rejected when it was discovered that all O'Hare arrivals traversing Dubuque and Farmm were being displayed on the Rockford Plan View Display. This was not a normal operating mode and had the effect of greatly inflating the Rockford surveillance workload. The reason for it is unknown so the two intervals were rejected.

Table 3-3 summarizes the RECEP workload values obtained for each of the time intervals selected. The table includes values for routine, surveillance and conflict workload as well as total workload. The units of workload are in man-minutes per interval. In addition, the table contains the mean value for the number of aircraft under control during each interval, and the

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY

SECTOR	DATE/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALED 1-7)
BDF	2/28	1830	8.72	5.31	3.46	17.67	12.07	3.00
		1845	11.29	5.00	3.20	19.49	11.36	5.00
		1900	7.89	2.81	1.02	11.72	6.39	3.67
		1915	1.70	1.56	0.32	3.58	3.55	2.00
	2/28	2115	8.03	5.31	3.64	16.99	12.07	6.33
		2130	6.40	4.38	2.47	13.24	9.94	4.67
		2145	4.02	3.44	1.52	8.98	7.81	3.00
		2200	4.40	3.44	1.52	9.36	7.81	2.67
	3/1	1815	7.34	5.00	3.20	15.54	11.36	4.00
		1830	4.84	5.00	3.20	13.04	11.36	3.33
		1845	6.67	6.67	4.10	16.39	12.78	5.00
		1900	6.37	6.37	1.80	11.92	8.52	4.67
	3/1	2100	2.52	2.81	1.00	6.33	6.39	2.00
		2115	4.44	2.19	0.62	7.25	4.97	2.00
		2130	5.50	2.81	1.00	9.32	6.39	2.33
		2145	9.76	4.69	2.80	17.25	10.65	4.00
	3/2	1815	5.83	3.75	1.80	11.38	8.52	2.00
		1830	5.12	3.75	1.80	10.67	8.52	2.00
		1845	4.07	4.06	2.10	10.24	9.23	2.00
		1900	5.45	4.06	2.10	11.61	9.23	2.33
	3/3	1815	5.53	3.44	1.50	10.47	7.81	2.00
		1830	9.58	5.31	3.60	18.49	12.07	3.67
		1845	11.24	5.31	3.60	20.15	12.07	5.33
		1900	10.10	4.06	2.10	16.26	9.23	4.00

*Interval Start Time (GMT)

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY (Cont.)

SECTOR	DATA/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALED 1-7)
MLI	2/28	2000	6.25	3.44	3.00	12.68	11.00	3.67
		2015	3.75	2.19	1.23	7.17	7.00	2.33
		2030	1.95	1.88	0.90	4.72	6.00	2.33
		2045	3.41	3.13	2.50	9.03	10.00	4.67
	2/28	2130	4.49	2.81	2.00	9.30	9.00	2.00
		2145	5.82	3.44	3.00	12.26	11.00	4.33
		2200	3.34	2.81	2.00	8.15	9.00	2.00
		2215	6.57	2.81	2.00	11.39	9.00	2.67
	3/1	2000	1.25	1.25	0.40	2.90	4.00	2.33
		2015	3.36	2.19	1.23	6.77	7.00	3.00
		2030	2.09	1.88	0.90	4.87	6.00	2.00
		2045	2.62	2.19	1.23	6.04	7.00	2.00
	3/1	2130	4.52	2.19	1.23	7.94	7.00	2.33
		2145	4.19	2.19	1.23	9.61	7.00	2.00
		2200	4.47	2.81	2.00	9.28	9.00	2.00
		2215	4.31	2.81	2.00	9.12	9.00	2.00
	3/3	1830	4.47	3.13	2.50	10.09	10.00	4.00
		1845	3.26	2.19	1.23	6.68	7.00	3.33
		1900	2.50	1.88	0.90	5.28	6.00	3.33
		1915	2.04	1.56	0.60	4.20	5.00	2.67
	3/3	2130	3.64	2.50	1.60	7.74	8.00	3.67
		2145	5.50	3.44	3.00	11.94	11.00	3.67
		2200	3.52	2.50	1.60	7.62	8.00	2.67
		2215	3.26	2.19	1.23	6.68	7.00	3.33

*Interval Start Time (GMT)

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY (Cont.)

SECTOR	DATE/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALE 1-7)
VAINS	2/28	1830	4.33	3.75	0.75	8.83	6.36	4.67
		1845	7.15	4.69	1.17	13.00	7.95	5.67
		1900	10.23	6.25	2.10	18.58	10.60	6.67
		1915	10.98	5.63	1.70	18.30	9.54	7.00
	2/28	2000	8.66	4.69	1.17	14.52	7.95	4.67
		2015	9.68	4.38	1.00	15.06	7.42	4.67
		2030	7.49	5.00	1.30	13.79	8.48	4.67
		2045	8.16	5.31	1.50	14.98	9.01	5.67
	3/1	1830	5.43	3.75	0.75	9.93	6.36	3.67
		1845	7.87	5.00	1.30	14.17	8.48	5.67
		1900	11.51	5.63	1.71	18.85	9.54	6.33
		1915	7.30	4.69	1.17	13.16	7.95	5.33
	3/1	1830	5.29	3.75	0.75	9.79	6.36	3.33
		1845	7.08	5.00	1.30	13.38	8.48	5.67
		1900	10.41	5.63	1.70	13.38	9.54	6.00
		1915	6.78	4.38	1.00	12.15	7.42	4.67
	3/2	2130	11.12	5.63	1.70	18.45	9.54	6.00
		2145	6.63	4.38	1.00	12.01	7.42	4.67
		2200	4.99	4.38	1.00	10.36	7.42	4.33
		2215	4.91	4.38	1.00	10.28	7.42	5.00
	3/3	2000	8.82	3.44	0.63	12.88	5.83	4.67
		2015	3.33	3.13	0.52	6.97	5.30	2.33
		2030	9.02	5.00	1.30	15.32	8.48	5.33
		2045	9.56	5.94	1.88	17.38	10.07	6.00

*Interval Start Time (GMT)

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY (Cont.)

SECTOR	DATE/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALED 1-7)
FARMM	2/28	1830	7.84	4.69	1.20	13.73	8.10	4.33
		1845	12.00	7.19	2.85	22.04	12.42	6.33
		1900	8.36	5.00	1.38	14.74	8.64	5.67
		1915	4.18	2.50	0.35	7.03	4.32	2.33
	2/28	2130	9.93	5.94	1.95	17.82	10.26	5.33
		2145	8.36	5.00	1.38	14.74	8.64	4.33
		2200	7.32	4.38	1.06	12.76	7.56	3.67
		2215	8.36	5.00	1.38	14.74	8.64	3.67
	3/1	1830	3.66	2.19	0.26	6.11	3.78	4.00
		1845	7.84	4.69	1.20	13.73	8.10	5.67
		1900	8.36	5.00	1.38	14.74	8.64	5.67
		1915	5.75	3.44	0.65	9.84	5.94	3.67
	3/1	2130	7.32	4.32	1.06	12.76	7.56	6.00
		2145	5.75	3.44	0.65	9.84	5.94	3.67
		2200	8.89	5.31	1.56	15.76	9.18	5.33
		2215	7.32	4.38	1.06	12.76	7.56	2.33
	3/2	1830	3.66	2.19	0.26	6.11	3.78	2.00
		1845	9.93	5.94	1.95	17.82	10.26	6.00
		1900	8.89	5.31	1.56	15.76	9.18	5.67
		1915	4.18	2.50	0.35	7.03	4.32	2.67
	3/2	2130	9.41	5.63	1.75	16.79	9.72	5.33
		2145	8.89	5.31	1.56	15.76	9.18	6.00
		2200	7.32	4.38	1.06	12.76	7.56	4.67
		2215	6.27	3.75	0.78	10.80	6.48	4.33

*Interval Start Time (GMT)

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY (Cont.)

SECTOR	DATE/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALE: 1-7)
PIA	2/28	1830	6.78	3.13	2.00	11.91	9.20	5.33
		1845	6.46	2.50	1.30	10.26	7.36	5.33
		1900	5.86	3.44	2.46	11.76	10.12	5.00
		1915	1.84	2.19	1.00	5.03	6.44	3.00
	2/28	2130	10.07	5.31	5.87	21.25	15.64	6.67
		2145	7.02	3.44	2.46	12.91	10.12	4.67
		2200	6.94	3.75	2.93	13.62	11.04	5.00
		2215	6.43	3.13	2.00	11.55	9.20	4.33
	3/2	1815	5.64	1.56	0.50	7.70	4.60	3.00
		1830	3.63	1.88	0.73	6.24	5.52	2.33
		1845	3.70	2.81	1.65	8.16	8.28	4.33
		1900	5.94	3.44	2.46	11.84	10.12	4.33
	3/2	2130	6.23	2.81	1.65	10.70	8.28	5.00
		2145	5.50	2.50	1.30	9.30	7.36	3.67
		2200	7.25	2.81	1.65	11.71	8.28	4.67
		2215	4.52	3.13	2.00	9.65	9.20	5.00
	3/3	1830	3.57	2.50	1.30	7.37	7.36	2.67
		1845	7.24	4.06	3.40	14.70	11.96	4.33
		1900	6.17	4.06	3.40	13.63	11.96	4.67
		1915	10.59	3.44	2.46	16.49	10.12	6.00
	3/3	2000	3.62	1.56	0.50	5.68	4.60	4.00
		2015	2.42	1.56	0.50	4.48	4.60	2.67
		2030	2.76	2.81	1.65	7.22	8.28	4.33
		2045	7.18	4.06	3.40	14.64	11.96	5.67

*Interval Start Time (GMT)

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY (Cont.)

SECTOR	DATE/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALED 1-7)
JOT	2/28	2115	5.75	3.44	0.06	9.25	5.5	N/A
		2130	4.81	3.44	0.06	8.31	5.5	
		2145	4.23	3.75	0.08	8.06	6.0	
		2200	6.88	3.13	0.05	10.05	5.0	
	3/1	1815	7.77	5.31	0.15	13.23	8.5	
		1830	7.82	6.25	0.21	14.28	10.0	
		1845	7.26	5.31	0.15	12.73	8.5	
		1900	6.50	5.00	0.13	11.63	8.0	
DBQ	2/28	1815	6.50	5.31	0.95	12.76	10.71	N/A
		1830	9.26	5.94	1.20	16.40	11.97	
		1845	6.79	3.75	0.47	11.01	7.56	
		1900	2.41	1.25	0.05	3.71	2.52	
	3/1	1815	1.76	2.19	0.16	4.11	4.41	
		1830	4.39	3.75	0.47	8.61	7.56	
		1845	7.55	4.69	0.74	12.98	9.45	
		1900	3.96	2.81	0.27	7.04	5.67	
IOW	2/28	2145	2.73	2.50	0.23	5.46	6.00	N/A
		2200	2.63	3.44	0.44	6.51	8.25	
		2215	4.09	4.38	0.71	9.18	10.50	
		2230	3.23	4.06	0.61	7.90	9.75	
	3/1	1815	4.84	5.94	1.30	12.08	14.25	
		1830	7.23	5.63	1.17	14.02	13.50	
		1845	3.65	3.44	0.44	7.53	8.25	
		1900	1.38	1.56	0.10	3.04	3.75	

*Interval Start Time (GMT)

TABLE 3.3 WORKLOAD-AIRCRAFT-WORKPACE SUMMARY (Cont.)

SECTOR	DATE/ TIME*		ROUTINE WORKLOAD (M-MIN)	SURV. WORKLOAD (M-MIN)	CONFLICT WORKLOAD (M-MIN)	TOTAL WORKLOAD (M-MIN)	CONTROLLED AIRCRAFT (MEAN)	WORKPACE (SCALE: 1-7)
WDPT	2/28	1900	3.91	2.81	0.33	7.05	5.04	N/A
		1915	6.84	5.00	1.04	12.88	8.96	
		1930	8.49	5.31	1.18	14.98	9.52	
		1945	7.79	5.63	1.32	14.73	10.08	
	2/28	2130	4.09	3.44	0.49	8.02	6.16	
		2145	3.76	2.50	0.26	6.52	4.48	
		2200	5.25	4.38	0.80	10.43	7.84	
		2215	6.43	5.31	1.18	12.92	9.52	
RFD	2/28	1815	2.31	2.50	1.04	5.85	6.96	N/A
	**	1830	2.64	6.56	2.56	11.77	18.27	
	**	1845	2.83	7.19	3.58	13.59	20.01	
		1900	4.75	3.13	1.72	9.60	8.70	
	2/28	2130	5.40	3.75	3.05	12.20	10.44	
		2145	4.92	3.75	3.05	11.72	10.44	
		2200	2.31	1.88	0.76	4.95	5.22	
		2215	4.12	2.81	1.72	8.65	7.83	
MCK	2/28	2115	3.11	2.81	1.14	7.07	7.38	N/A
		2130	2.95	3.75	2.03	8.73	9.84	
		2145	5.06	4.06	2.39	11.51	10.66	
		2200	3.18	2.50	0.90	6.58	6.56	
	3/1	1815	3.43	3.13	1.40	7.96	8.20	
		1830	5.39	5.00	3.60	13.99	13.12	
		1845	1.71	3.13	1.40	6.24	8.20	
		1900	1.40	1.56	0.35	3.31	4.10	

*Interval Start Time (GMT)

**Interval rejected due to aberrant conditions

workpace rating, where applicable. Workpace ratings are on a numerical scale from 1 to 7 where 7 represents "very heavy" workpace. The average value of workload over the 166 test intervals is 11.1 man-minutes. Routine, surveillance and conflict workload account for 51%, 35%, and 14% of the total, respectively.

Routine workload was analyzed by dividing it into the five components: air/ground controller speaking, air/ground controller listening, interphone, FDP operations, and flight strip activities. Workload values for each component were obtained for all test intervals. From these data a maximum, minimum, and mean value were obtained for each component. A uniform pattern emerged for all sectors. Figure 3-1 illustrates the results for the Vains Sector, which are typical of all sectors. Air/ground controller speaking was always the highest value, accounting for over 30% of the total routine workload.

SAR data for all four days of testing were analyzed to determine the average length of time aircraft were under the surveillance of each sector and also under the jurisdiction, or control, of each sector. The average jurisdiction interval is equivalent to sector flight time. Sector flight time is of interest when converting RECEP flow rate to hourly flow rate and also in selecting the duration of RECEP test intervals and,

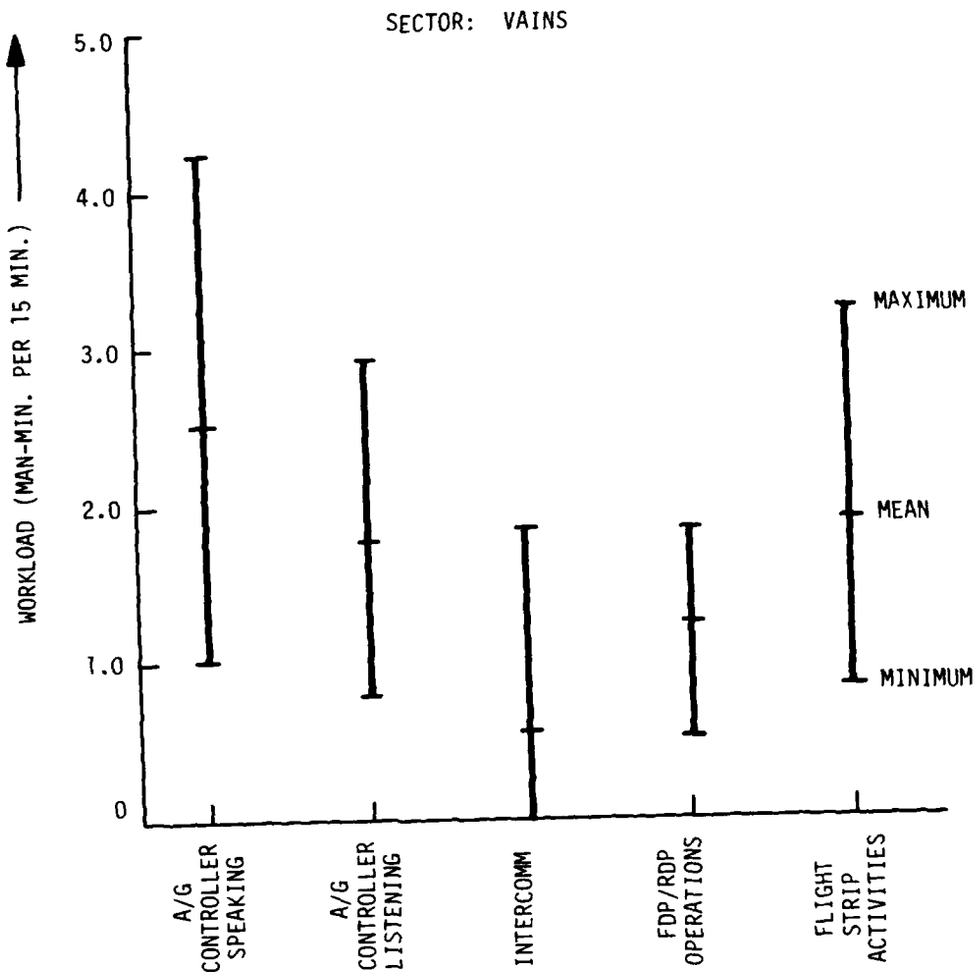


FIGURE 3-1. COMPONENTS OF ROUTINE WORKLOAD

in the case of conflict prevention, in selecting traffic samples. Table 3-4 lists both the surveillance and jurisdiction intervals for all sectors for each of the four days of testing as well as an average value for all days. The table lists in parentheses the number of aircraft on which each value was based. The surveillance interval was obtained by measuring the duration of time that all aircraft symbols with full data blocks were displayed on the Plan View Display regardless of jurisdictional control. Thus, pointout aircraft symbols are included. The jurisdiction interval was obtained by measuring the duration of time between FDP hand-in and hand-out events. This necessarily involves a smaller sample of aircraft since some handoffs do not involve computer flight data processing. This is particularly true for low altitude sectors. As can be seen from the table, the sector flight times vary from 7.0 to 20.3 minutes with an average value of 13.35 minutes.

3.5 SUMMARY OF ATF DATA

An empirical traffic sample from noon to 5 PM on the first day of testing was chosen for the construction of an ATF model of the eleven sector area. Over 700 aircraft traversed the area during this five-hour period. The time and flight path histories of all aircraft were extracted from SAR data and a route

TABLE 3-4. SECTOR FLIGHT TIMES[1]

	SURVEILLANCE INTERVAL[2]					JURISDICTION INTERVAL[3]				
SECTOR	2/28	3/1	3/2	3/3	ALL DAYS	2/28	3/1	3/2	3/3	ALL DAYS
MCK	24(114)	26(100)	-	24(78)	24.7	20(91)	21(77)	-	20(61)	20.3
IOW	26(90)	25(113)	24(102)	26(110)	25.2	19(59)	19(72)	18(73)	20(83)	19.0
DBQ	20(135)	20(110)	19(121)	20(113)	19.8	12(103)	11(91)	13(101)	14(91)	12.5
BDF	17(134)	17(144)	18(135)	20(142)	18.0	13(106)	11(102)	13(100)	14(98)	12.7
JOT	15(143)	16(168)	15(152)	16(158)	15.5	7(121)	8(137)	8(127)	8(137)	7.8
FARMM	20(154)	19(119)	19(144)	19(122)	19.3	11(101)	10(87)	10(98)	11(89)	10.5
RFD	19(132)	18(81)	-	18(106)	18.4	16(42)	16(31)	-	16(34)	16.0
VAINS	20(172)	18(152)	19(167)	20(167)	19.3	10(135)	10(105)	10(127)	11(116)	10.2
WDPT	13(167)	13(161)	11(38)	12(171)	12.5	8(121)	6(105)	6(33)	7(116)	7.0
PIA	18(130)	14(106)	18(90)	17(122)	16.8	19(33)	13(28)	13(25)	16(45)	15.5
MLI	14(124)	14(92)	13(99)	13(108)	13.5	16(30)	14(20)	16(18)	15(23)	15.3

NOTES:
1. TABLE LISTS FLIGHT TIMES IN MINUTES, NUMBER OF AIRCRAFT IN PARENTHESES.
2. INTERVAL OF FULL DATA BLOCK ON PLAN VIEW DISPLAY.
3. INTERVAL BETWEEN HANDOFFS, TO AND FROM SECTOR.

structure was determined from the flight paths. A total of 83 routes were defined. Each route was divided into arcs which correspond to the segment of the route traversing individual sectors. Arc transit times were computed based on the average time duration of all aircraft on each arc. Arc transit times varied from 3 to 28 minutes. Aircraft were assigned to the appropriate route. The entry times of aircraft entering routes were extracted from SAR data in groups of 15-minute intervals. The ATF computer program randomly distributes the actual entry time within each interval.

The coefficients for the ATF workload equation were determined by performing a least squares regression analysis on the values obtained for total RECEP workload versus number of aircraft under control from each of the RECEP test intervals. A second order function with a zero constant term was assumed in performing the regression. Table 3-5 lists the coefficients obtained for each of the eleven sectors as well as the generalized ATF workload equation with the units of each term. RECEP workload values are measured in man-minutes per 15 minutes whereas the ATF model computes workload in man-seconds per minute. Therefore, a factor of 60/15 is applied in computing the coefficients.

TABLE 3-5. ATF WORKLOAD EQUATION COEFFICIENTS

SECTOR	K_1	K_2
JOT	5.73	0
BDF	4.60	0.10
DBQ	4.52	0.068
IOW	3.08	0.044
MLI	2.73	0.15
WDPT	4.96	0.088
VAINS	4.74	0.25
RFD	2.58	0.195
FARMM	6.2	0.074
PIA	4.17	0.073
MCK	2.82	0.1

$$W_L = K_1 N + K_2 N^2$$

WHERE: W_L = WORKLOAD IN MAN-SECONDS PER MINUTE

K_1 = COEFFICIENT IN MAN-SECONDS PER MINUTE PER AIRCRAFT

K_2 = COEFFICIENT IN MAN-SECONDS PER MINUTE PER (AIRCRAFT)^2

N = NUMBER OF AIRCRAFT

Figure 3-2 illustrates one usage of the ATF model in evaluating long-term workload. The five-hour traffic sample was run into the program. The first 30 minutes were considered to be an initialization period as aircraft entered routes and flowed from one sector to another, leaving 270 minutes for meaningful measures. Workload was printed out minute-by-minute and the percent of time that workload was above a given level was determined for each sector. The shape of the function shown in the figure is typical for all sectors. A comparison of sectors provides an indication of relative sector workload over long periods of time. The figure also indicates the workload level which corresponds to an average workpace rating. This was determined from the controller survey data which equated the number of aircraft in the sector with various workpace ratings. The number of aircraft was then converted to a RECEP workload value by means of the RECEP function for workload versus aircraft.

3.6 EXAMPLE OF THE DETERMINATION OF POTENTIAL CONFLICT WORKLOAD COEFFICIENTS

The Bradford (BDF) high altitude sector has been selected to demonstrate the methodology used in estimating potential conflict workload coefficients.

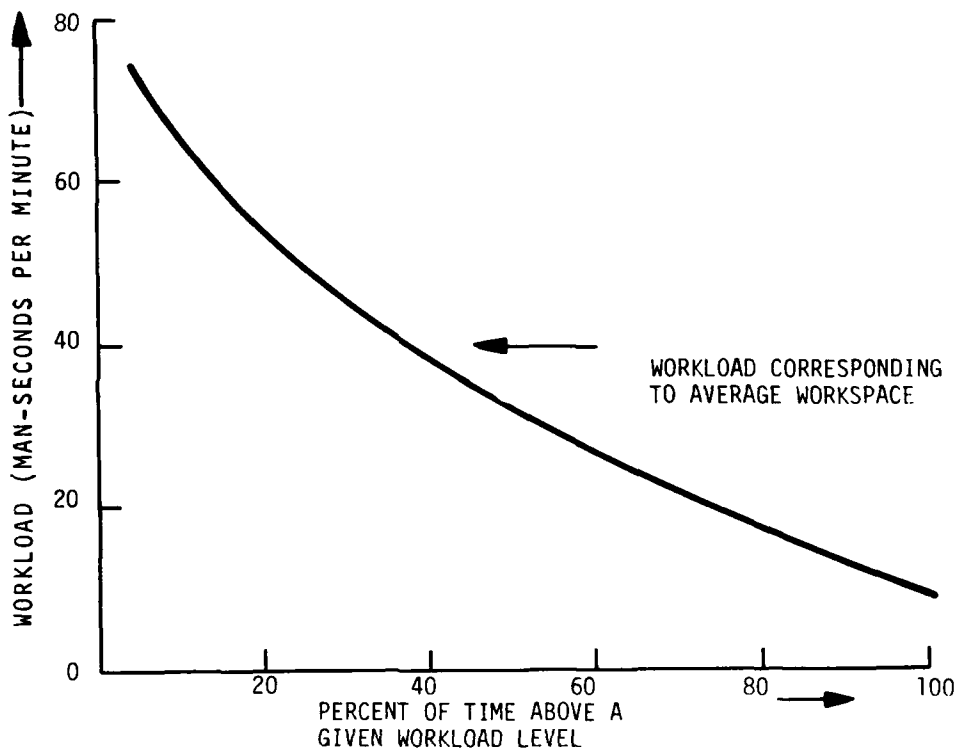


FIGURE 3-2. WORKLOAD VERSUS PERCENT OF TIME

A major part of BDF traffic consists of southwest arrivals to O'Hare (ORD). There is also a southwest departure route from ORD. The remaining traffic is essentially overflights. Figure 3-3 shows the flight plan ground tracks for one hour of aircraft entering BDF. Figure 3-4 shows the actual SAR ground tracks for the same aircraft.

Table 3-6 lists all the flights entering BDF along with ground speed and altitude information. Figures 3-5 through 3-8 are plots of the SAR ground tracks for the four 15-minute periods. The conflict and overtake equations of Section 2.1.3 were used to calculate the expected number of conflicts using Table 3-6 and the appropriate figure, the expected number of conflicts can now be calculated.

<u>1800 - 1815</u>

Expected No. of Overtakes

2 and 3 O = 0.154

Expected No. of Crossings

4 with 2 and 3 C = 0.261

<u>1815 - 1830</u>

Expected No. of Overtakes

6, 7, and 8 O = 0.050

Expected No. of Crossings

9 with 10 and 12 C = 0.495

<u>1830 - 1845</u>

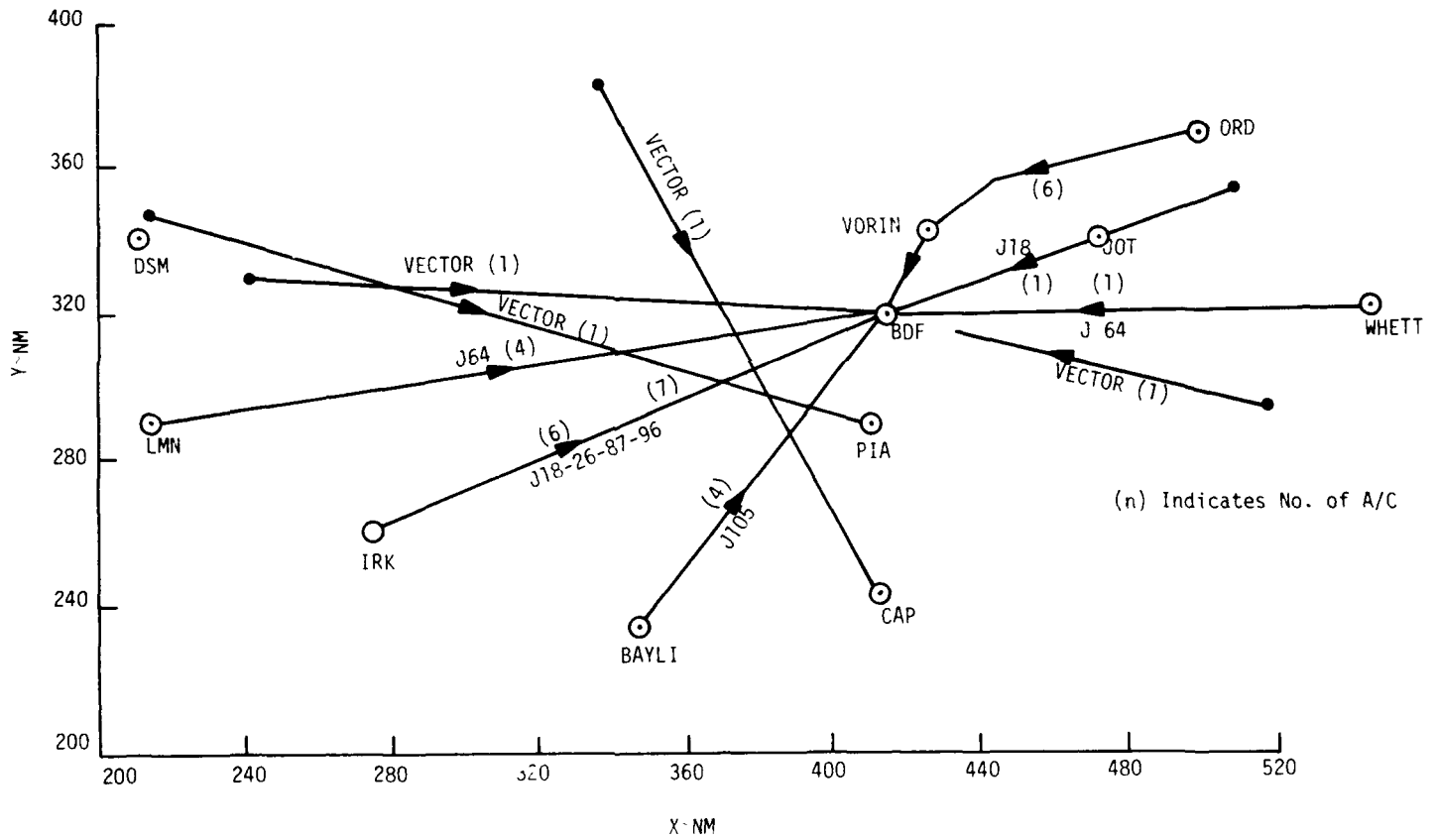


FIGURE 3-3. TRAFFIC HANDED OFF TO BDF 1800-1900 GMT, 2-28-78

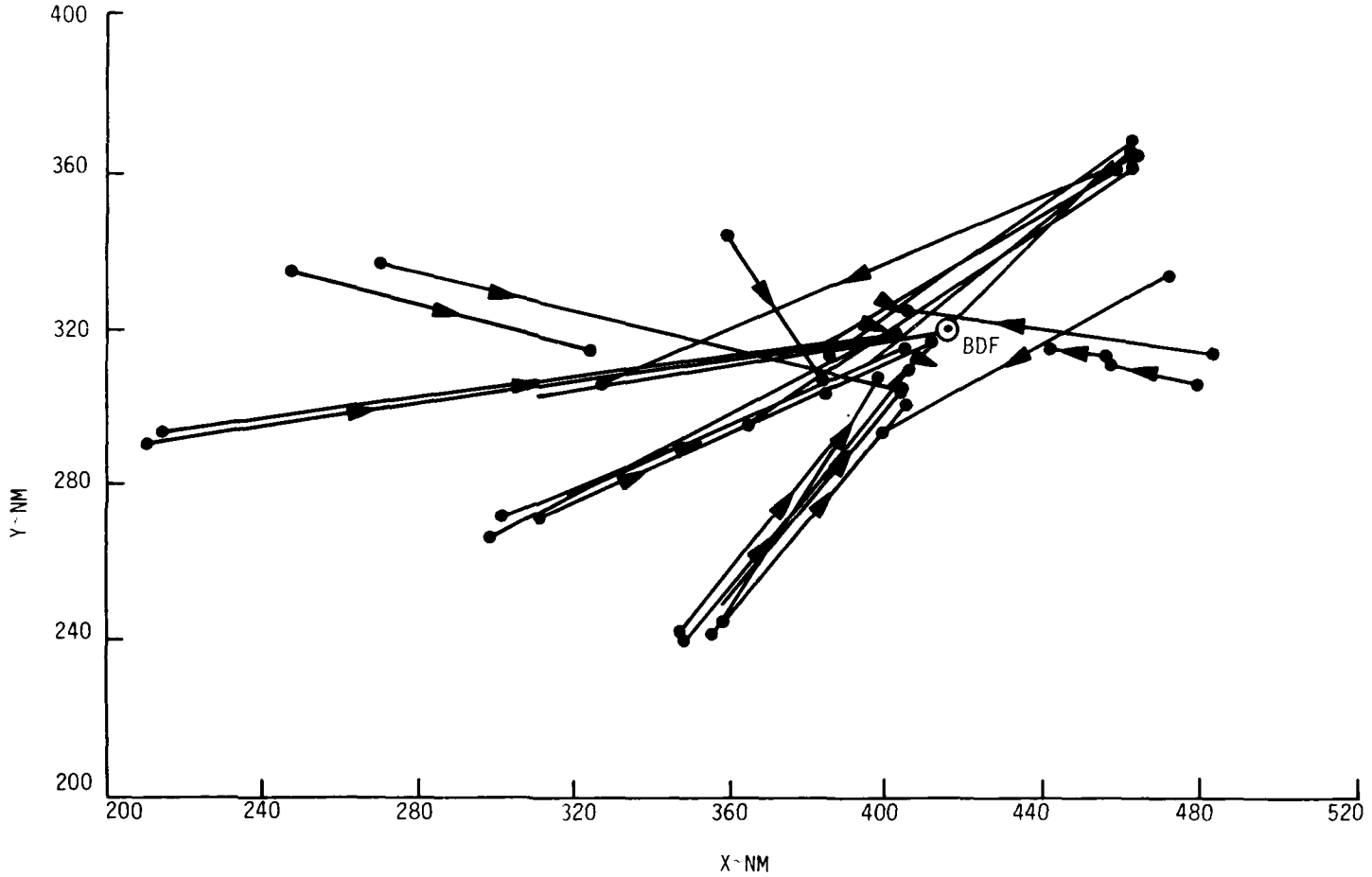


FIGURE 3-4. GROUND TRACKS OF TRAFFIC HANDED OFF TO BDF 1800-1900 GMT, 2-28-78

TABLE 3-6. AIRCRAFT ENTERING BDF 1800-1900 GMT, February 28, 1978

Time	Aircraft No.	Type of Flight	Hand-In Altitude	Hand-Out Altitude	Ground Speed
1800	1	J26 ORD Arrival	37,000 ft.	20,000 ft.	142.7NM/15 minutes
	2	J26 ORD Departures	16,000	31,000	94.5
	3	" " "	18,700	31,000	82.3
	4	Overflight	31,000	31,000	88.8
1815	5	Peoria Arrival	29,500	26,500	
	6	J64 ORD Arrival	37,000	25,100	144.5
	7	" " "	37,000	26,100	144.7
	8	" " "	37,000	33,000	140.7
	9	Overflight	31,000	31,000	88.3
	10	J26 ORD Departure	16,000	31,000	
	11	" " "	22,500	39,000	
	12	" " "	17,800	31,000	
1830	13	J18 ORD Arrival	33,000	26,900	137.0
	14	J105 ORD Arrival	33,000	29,600	127.7
	15	" " "	32,000	27,600	127.5
	16	Vectored ORD Arrival	29,000	28,400	122.7
	17	Overflight	33,000	33,000	120.5
	18	J26 ORD Departure	20,400	39,000	97.5
1845	19	Overflight	35,000	35,000	87.5
	20	J64 ORD Arrival	33,000	27,300	137.0
	21	J26 ORD Arrival	33,000	27,000	135.7
	22	" " "	29,000	24,000	118.5
	23	" " "	33,000	27,000	141.7
	24	" " "	33,000	24,700	131.7
	25	J105 ORD Arrival	33,000	23,800	107.8
	26	" " "	33,000	27,100	119.7
	27	J26 Overflight	35,000	35,000	91.0

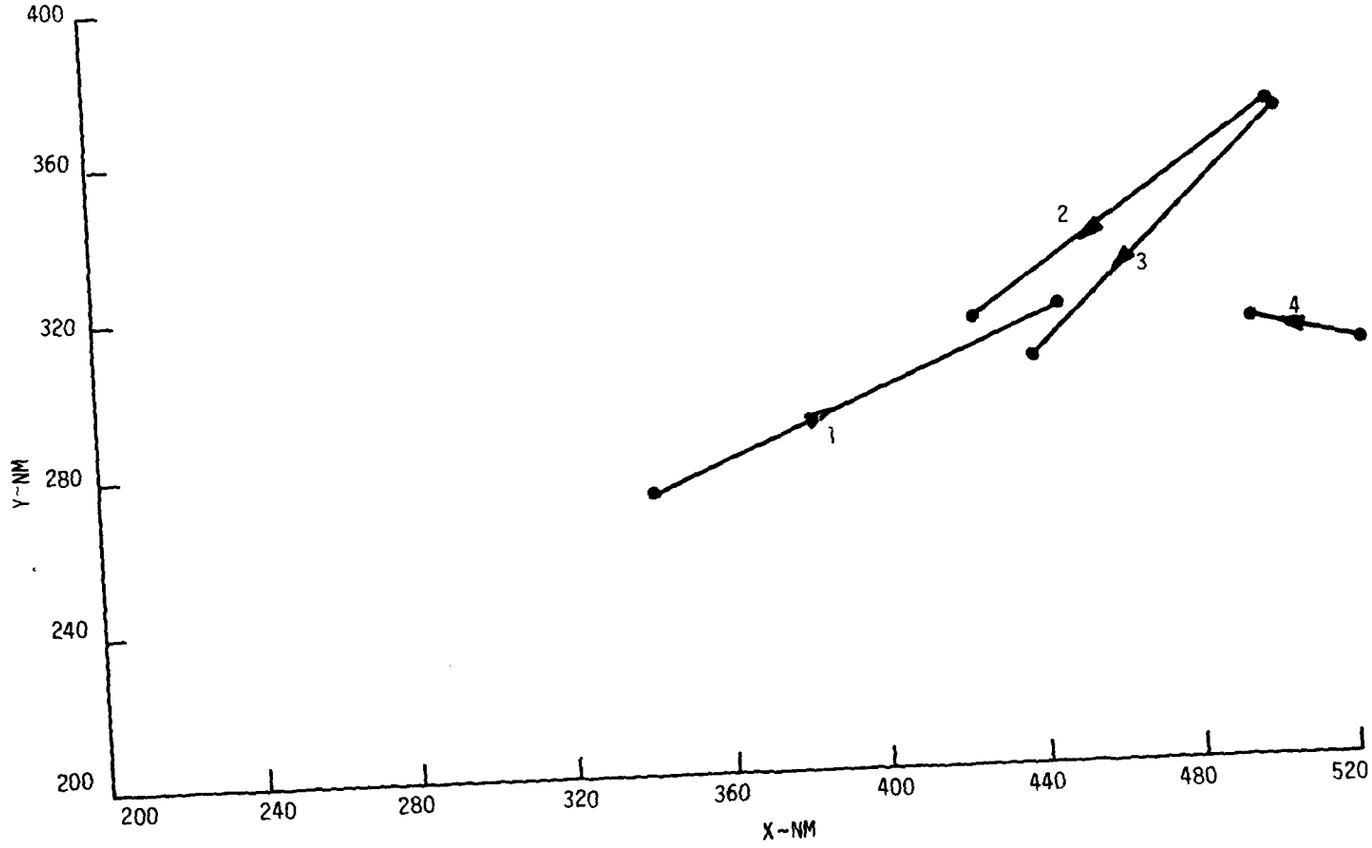


FIGURE 3-5. GROUND TRACKS OF AIRCRAFT ENTERING BDF 1800-1815 GMT, 2-28-78

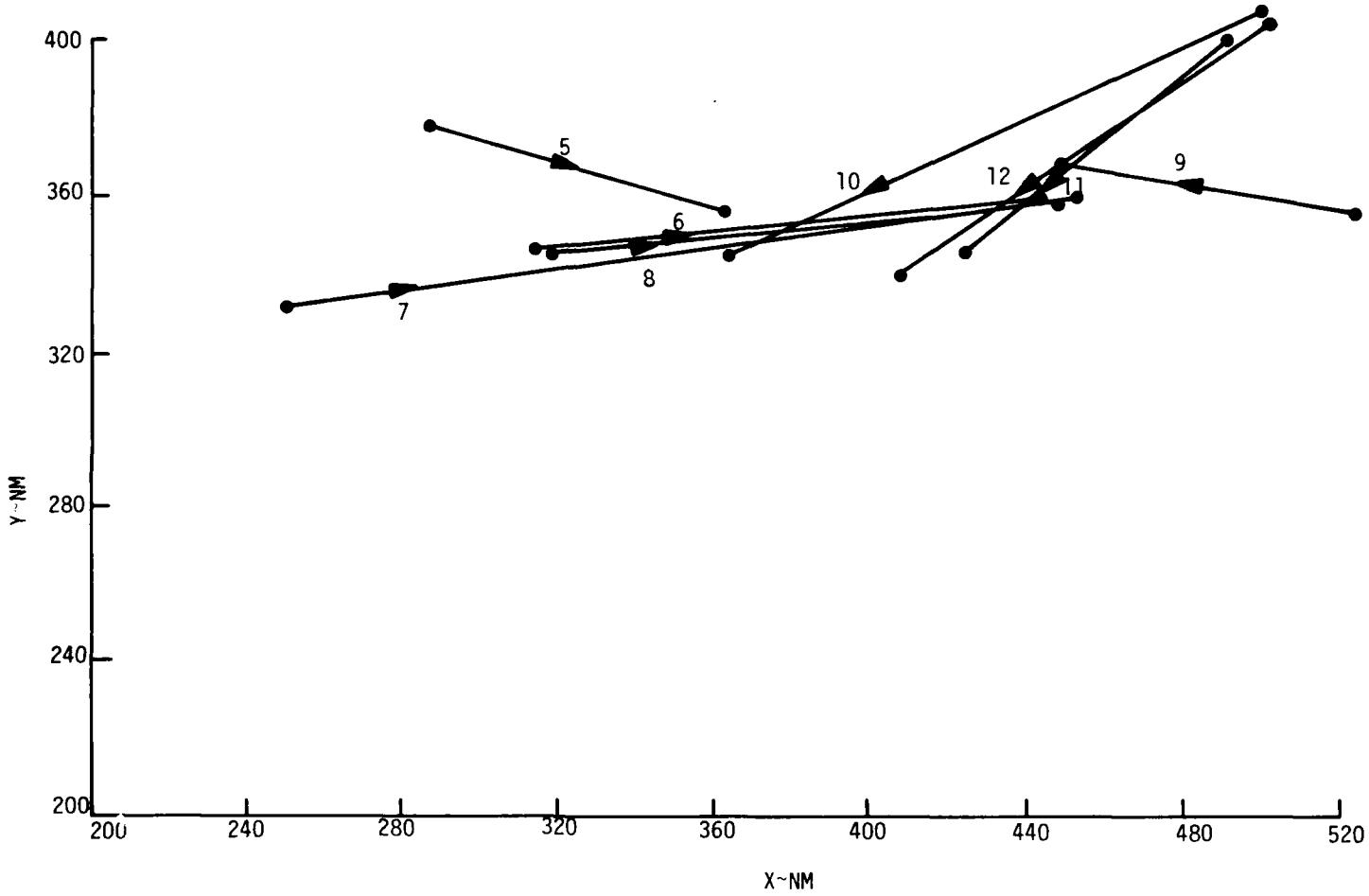


FIGURE 3-6. GROUND TRACKS OF AIRCRAFT ENTERING BDF 1815-1830

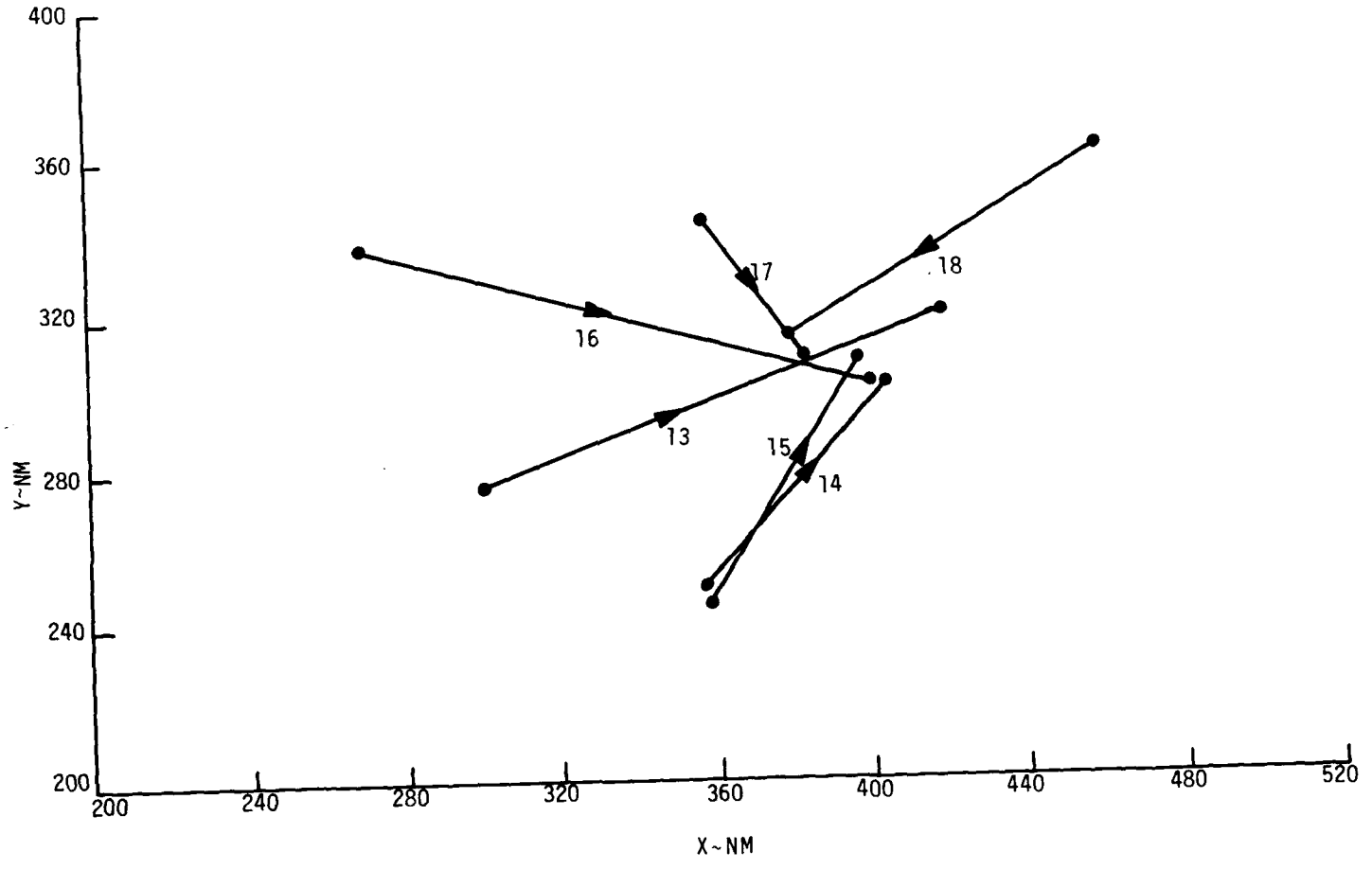


FIGURE 3-7. GROUND TRACK OF AIRCRAFT ENTERING BDF 1830-1845

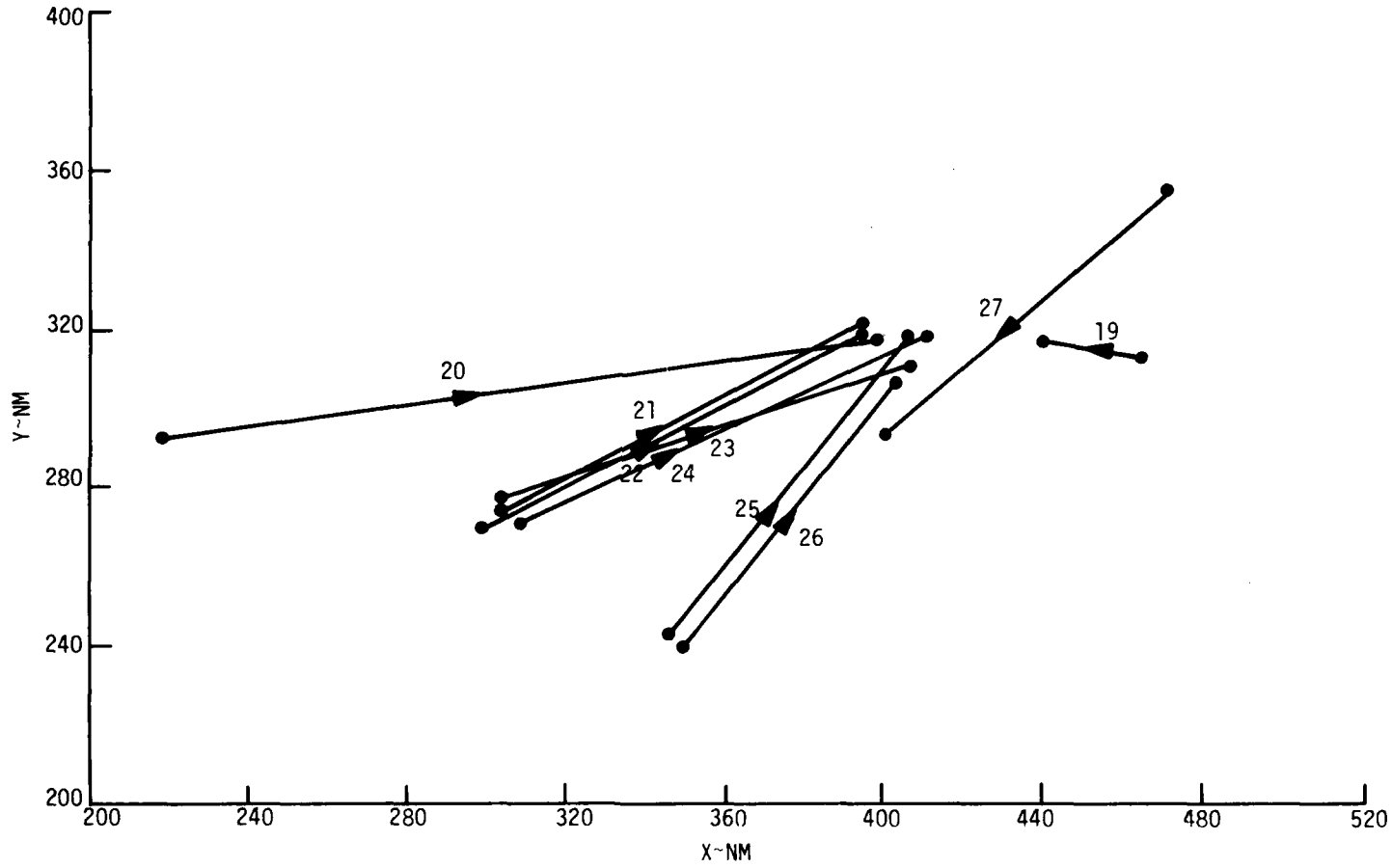


FIGURE 3-8. GROUND TRACK OF AIRCRAFT ENTERING BDF 1845-1900

Expected No. of Overtakes

None; 14 and 15 have the same speed

Expected No. of Crossings

13 with 14 and 15	C = .315
13 with 16	C = .165
16 with 14 and 15	C = .195
Total	C = .675

<u>1845 - 1900</u>

Expected No. of Overtakes

21, 22, 23 and 24	O = 0.527
25 and 26	O = 0.099
Total	O = 0.626

Expected No. of Crossings

21, 22, 23 and 24 with 25 and 26	C = 1.396
21, 22, 23 and 24 with 20	C = 0.644
25 and 26 with 20	C = 0.354
19 with 27	C = 0.253
Total	C = 2.647

As can be seen from the above, the expected number of crosing conflicts can exceed 1.0. In some cases, the expected number of conflicts is calculated to be greater than the minimum flow rate of the two intersecting routes. Obviously, this is illogical since the aircraft on at least one of the flight paths

would be diverted in some manner (speed, altitude, and/or ground track). Presumably the flight path with the least number of aircraft would be changed. Therefore, the expected number of conflicts at the intersection of two flight paths cannot exceed the lowest number of aircraft of either flight path.

Referring to the crossing conflict equation of Section 2.1.3:

$$\text{If } f_1 > f_2 \qquad (6)$$
$$\text{Then } Cmax \leq f_2$$

In the case of BDF, five hours of data were analyzed for potential conflicts. Regression analysis was performed on 20 samples each of expected number of overtake and crossing conflicts versus aircraft squared. In both cases, the correlation coefficient was approximately 0.1. The expected man-minutes of work for each 15-minute interval were then calculated and a regression analysis of conflict workload versus aircraft squared was performed. In this case, the correlation coefficient was 0.625. The same regression procedure was used for the other sectors.

In previous RECEP models, coefficients for the expected number of crossing and overtake conflicts were derived separately and workload was then calculated. During this study, it was found that higher correlation

coefficients were obtained by deriving a single workload coefficient. The reason for this is that there are time periods when the expected number of crossing and/or overtake conflicts is zero and the data sample becomes significantly smaller.

By performing a second order least squares regression on the 20 samples of conflict workload for BDF, a mean workload coefficient of 0.025 man-minutes per 15 minutes per aircraft was obtained. Table 3-7 contains the coefficients for all eleven sectors.

TABLE 3-7. CONFLICT WORKLOAD COEFFICIENTS

Sector	Conflict Workload Coefficient
JOT	0.0021
BDF	0.025
DBQ	0.0082
IOW	0.0065
MLI	0.025
WDPT	0.013
VAINS	0.018
RFD	0.028
FARMM	0.018
PIA	0.024
MCK	0.021

NOTE: Conflict Workload Coefficient units are man-minutes per fifteen minutes per (aircraft)^2.

4. VALIDATION ANALYSIS OF WORKLOAD DATA

4.1 INTRODUCTION

The principal purpose of this validation analysis is to determine whether a measure of controller workload, derived offline from automatic recordings according to specifications for the RECEP/ATF models, agrees with workload estimates made by controllers themselves.

A fundamental characteristic of the concept, "workload," is that it concerns the magnitude of an internal condition experienced by the working individual. Workload is not an observable effect about which all observers are certain to agree. Observers' workpace ratings are, nonetheless, being used in this analysis as a standard for evaluating the validity of a workload measure that is computed from offline recordings. Although we might simply assume our sample of workpace ratings is valid, and then apply it as an evaluation criterion, our conclusions would be more acceptable if we assess the validity of the ratings themselves and demonstrate objectively that they are probably valid.

There is no certain measure of the true value of the workload that controllers actually experience while they are observed, but we can at least test the consistency between the ratings and other information

acquired via questionnaires regarding typical sector differences in workload and control difficulty. The demonstrated logical consistency between controllers' ratings and controllers' questionnaire responses can then provide assurance that the subjective validation criteria are probably valid for evaluating the workload measure derived offline some time after the work occurred.

Our general approach is to perform various analyses that test the logical consistency among workload measures derived from three different sources: "Rated Workload" derived from workpace ratings, "Judged Workload" derived from questionnaire responses, and "Computed Workload" derived offline from data recordings. Whereas workpace ratings were made by controllers who observed the work as it occurred, questionnaire responses were made by controllers who referred to their past experience in the studied sectors in order to judge typical levels of workload and control difficulty. Although Rated Workload and Computed Workload both pertain operationally to work as it occurs, relationships involving these measures can presumably be used to estimate typical workload conditions in selected sectors. Measures of Judged Workload permit us to generalize explicitly beyond the sample of data that we collect. The three kinds of measures are thus applied in a series of subanalyses

whose results and implications converge logically to support two conclusions: (1) Computed Workload can provide a valid index of controller workload as it occurs, and (2) Computed Workload can provide a valid estimate of typical workload conditions in individual enroute sectors.

4.2 SUMMARY STATISTICS FOR SAMPLED SECTOR ACTIVITIES

Statistics that summarize control activities that occurred during 15 minute intervals for which Computed Workload was derived are given in Table 4-1 for workpace rated sectors and in Table 4-2 for unrated sectors. The statistics are for the following variables:

1. Traffic Flow Rate, the number of aircraft that entered the sector's jurisdiction.

2. Aircraft Under Control, the average number of aircraft for which full data blocks were displayed either because the aircraft was under the sector's jurisdiction, because the aircraft had been pointed out by another sector, or because the aircraft had been selected for monitoring by the controllers in the sector.

TABLE 4-1. STATISTICS FOR VARIABLES IN RATED SECTORS

SECTOR	TRAFFIC FLOW RATE (AIRCRAFT/INTERVAL)					AIRCRAFT UNDER CONTROL (AIRCRAFT)					TOTAL WORKLOAD (MINUTES)				
	N	MIN	MAX	MEAN	VAR	N	MIN	MAX	MEAN	VAR	N	MIN	MAX	MEAN	VAR
BDF (14)	24	3.0	12.0	6.4	6.5	24	3.6	12.8	9.2	6.2	C:24	3.6	20.2	12.8	19.3
											R:24	2.0	6.3	3.4	1.7
MLI (54)	24	0.0	7.0	3.7	2.8	24	4.0	11.0	7.9	3.6	C:24	2.9	12.7	7.9	6.7
											R:24	2.0	4.7	2.8	0.7
VAINS (57)	24	4.0	14.0	7.5	5.8	24	5.3	10.6	8.0	1.9	C:24	7.0	18.9	13.7	11.3
											R:24	2.3	7.0	5.1	1.1
FARMM (73)	24	1.0	12.0	6.2	10.4	24	3.8	12.4	7.7	4.8	C:24	6.1	22.0	13.2	16.1
											R:24	2.0	6.3	4.5	1.7
PIA (75)	24	1.0	8.0	4.2	3.9	24	4.6	15.6	8.8	7.2	C:24	4.5	21.3	10.7	15.7
											R:24	2.3	6.7	4.4	1.2

C: COMPUTED (MINUTES)
R: RATED ON WORKPACE SCALE (1-7)

TABLE 4-2. STATISTICS FOR VARIABLES IN UNRATED SECTORS

SECTOR	TRAFFIC FLOW RATE (AIRCRAFT/INTERVAL)					AIRCRAFT UNDER CONTROL (AIRCRAFT)					TOTAL COMPUTED WORKLOAD (MINUTES)				
	N	MIN	MAX	MEAN	VAR	N	MIN	MAX	MEAN	VAR	N	MIN	MAX	MEAN	VAR
JOT (13)	8	5.0	13.0	8.5	6.3	8	5.0	10.0	7.1	3.4	8	8.1	14.3	10.9	5.6
DBQ (28)	8	1.0	11.0	6.3	9.6	8	2.5	12.0	7.5	10.3	8	3.7	16.4	9.6	20.3
IOW (29)	8	1.0	7.0	3.5	4.3	8	3.8	14.3	9.3	12.5	8	3.0	14.0	8.2	12.5
WDPT (55)	8	4.0	14.0	8.8	12.5	8	4.5	10.1	7.7	4.8	8	6.5	15.0	10.9	11.7
RFD (72)	6	1.0	7.0	3.5	4.3	6	5.2	10.4	8.3	4.2	6	5.0	12.2	8.8	8.9
MCK (98)	8	1.0	7.0	3.6	6.6	8	4.1	13.1	8.5	7.5	8	3.3	14.0	8.2	10.9

3. Total Workload, an index of the amount of mental activity performed by the R controller. Total work is estimated by Rated and Computed Workload in rated sectors , but only by Computed Workload in unrated sectors. Rated Workload is an average value ranging from 1 to 7, integers that had been assigned to controllers' ratings in order to represent ratings from "Very Light" to "Very Heavy." Computed Workload is the sum of minutes for Routine, Surveillance, and Conflict Prevention Workload components.

In the data for all 11 of the studied sectors, the mean Aircraft Under Control ranged between 7.1 and 9.3 aircraft. Also, the mean workpace in the rated sectors ranged from 2.8, or approximately "Below Average," in MLI, to 5.1, or approximately "Above Average," in VAINS. Although the average values for different sectors were similar in magnitude, various systematic relationships pertinent to this validation analysis are present in the data.

Mean Computed Workload as a Function of Mean Workpace

A positive relationship between Computed Workload and Rated Workload can be found in Table 4-1. Figure 4-1 indicates that the least squares regression line describing the empirical relationship has a positive

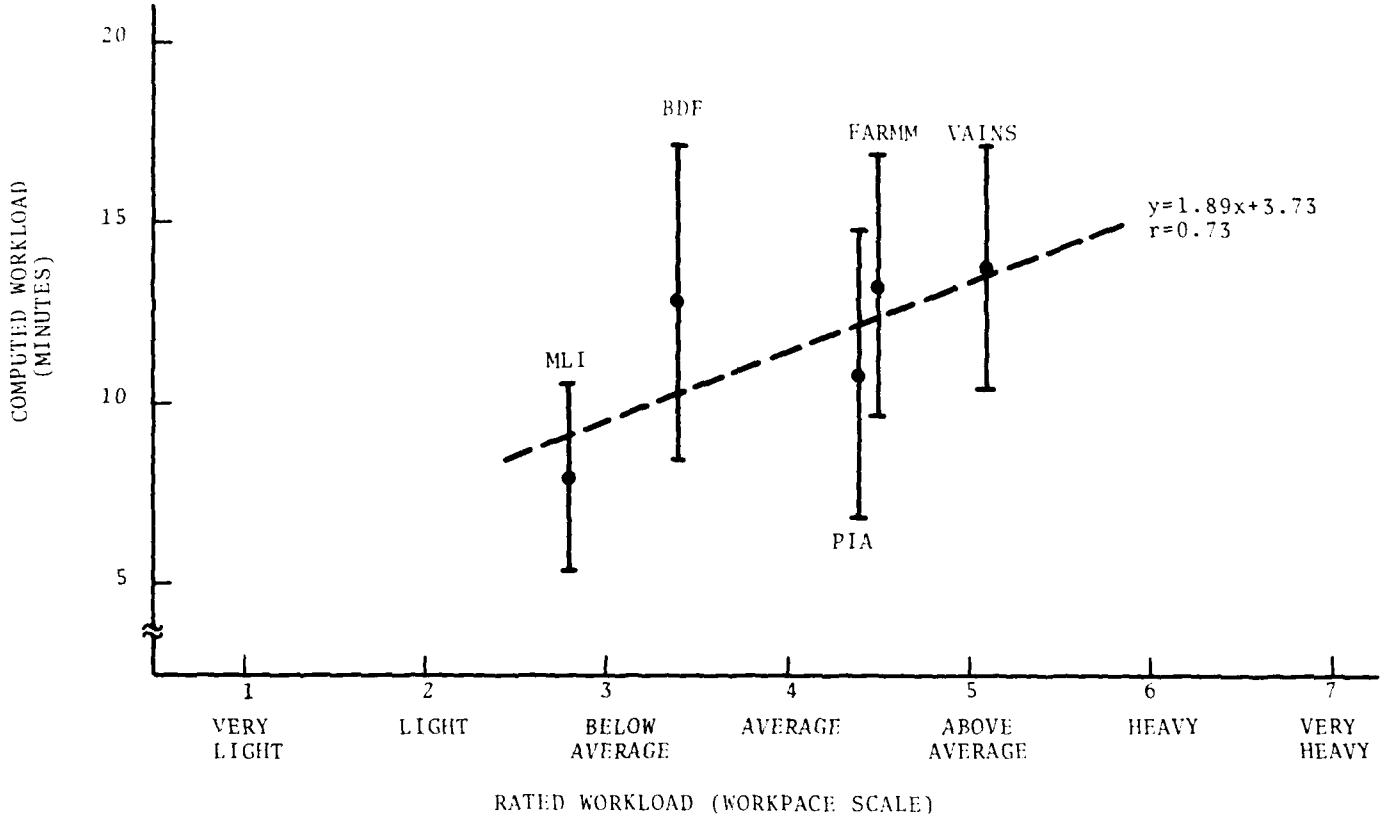


FIGURE 4-1. MEAN COMPUTED WORKLOAD AS A FUNCTION OF MEAN WORKPACE

slope as would be expected if the two variables measure the same thing. A statistical test of the hypothesis that the product moment correlation (r=0.73) between the means is equal to zero, was performed using the statistic,

$$t = r\sqrt{\frac{N-2}{r-2}} \quad . \tag{7}$$

The test indicates the observed relationship among the five sectors (N=5) can occur by chance almost 20 percent of the time. While this level of risk in drawing a faulty inference (i.e., "a positive relationship exists") may be acceptable for practical purposes, the observed relationship does not demonstrate that the two variables are probably equivalent in meaning. Other kinds of analyses are required for building a plausible case that Rated Workload and Computed Workload are equivalent for estimating controller workload.

The following analyses show:

1. Mean workpace ratings are consistent with what the raters evidently believed were typical traffic levels. This finding gives us confidence in the validity of the ratings.

2. Both the Rated and the Computed measures of workload are more strongly correlated with Aircraft Under Control than with Traffic Flow Rate. If the two workload measures were correlated with different measures of traffic (a conceivable outcome, given the existing literature), we would have less confidence that the measures reflect the same aspects of the control process.

3. Workload estimates based on the Rated and Computed measures of workload agree in showing how the studied sectors differ from each other in terms of control difficulty. This is evidence that the measures are valid for comparing workload in different sectors.

4. When values of Rated and Computed workload, for the same time intervals in an individual sector, are plotted together as functions of clock time (i.e., successive samples are given in the order of their occurrence), the values agree in showing whether workload increases or decreases. This is evidence that the measures can be used to assess workload changes over time within individual sectors.

After these validation analyses are presented, we focus on the problem of estimating the maximum workload in individual sectors.

4.3 WORKPACE RATINGS IN RELATION TO EXPECTED TRAFFIC LEVELS

It was noted in Table 4-1 that the mean workpace ratings ranged from somewhat "Below Average" in MLI to "Above Average" in VAINS. Though the five mean workpace values cover a limited range, they appear to be ordered quite systematically as a function of other variables.

In this case, let us assume that the mean ratings are consistent with typical operations in the rated sectors. A rating of "Average" (assigned the value, 4) is thus presumably anchored subjectively to what the raters believed was average in the long run. Since workload is strongly affected by the traffic level, as the next analysis indicates, a traffic level less than the average level would presumably be accompanied by a "Below Average" workpace rating, which we found in the data for MLI. Similarly, when traffic exceeds the average, workpace would be "Above Average," as we found in the data for VAINS. Following this line of thinking, we analyzed the data to see whether the traffic actually observed was more or less than the level the controllers believed to be average; the deviation was then used to predict the observers' mean workpace ratings.

In the analysis of data, the traffic level that Chicago controllers judged as producing "Average" workload was derived from the controllers' questionnaire responses (the Appendix, Interview 3). Each controller's workload-traffic judgments for a sector were described by a least squares regression line that was then used to estimate the number of aircraft typically under control for an "Average" workpace. Individual estimates from five controllers (per control area) were then averaged, and the mean was subtracted from the mean number of aircraft that were actually under control in the sector. The aircraft difference, the predictor variable, is plotted in Fig. 4-2 on the abscissa; the mean workpace rating is the predicted variable.

Figure 4-2 shows that mean workpace is systematically related to the difference between the observed traffic and the judged traffic for an "Average" workload. The least squares regression line describing the empirical relationship refers to the filled points that represent all the workpace and traffic data collected for the study (48 15-minute samples); unfilled points represent the subset of data (24 samples) reported in Table 4-1. Figure 4-2 shows that similar results are obtained whether all the workpace data are used or only the subset. From Fig. 4-2, we infer that the mean workpace ratings for the five rated sectors are

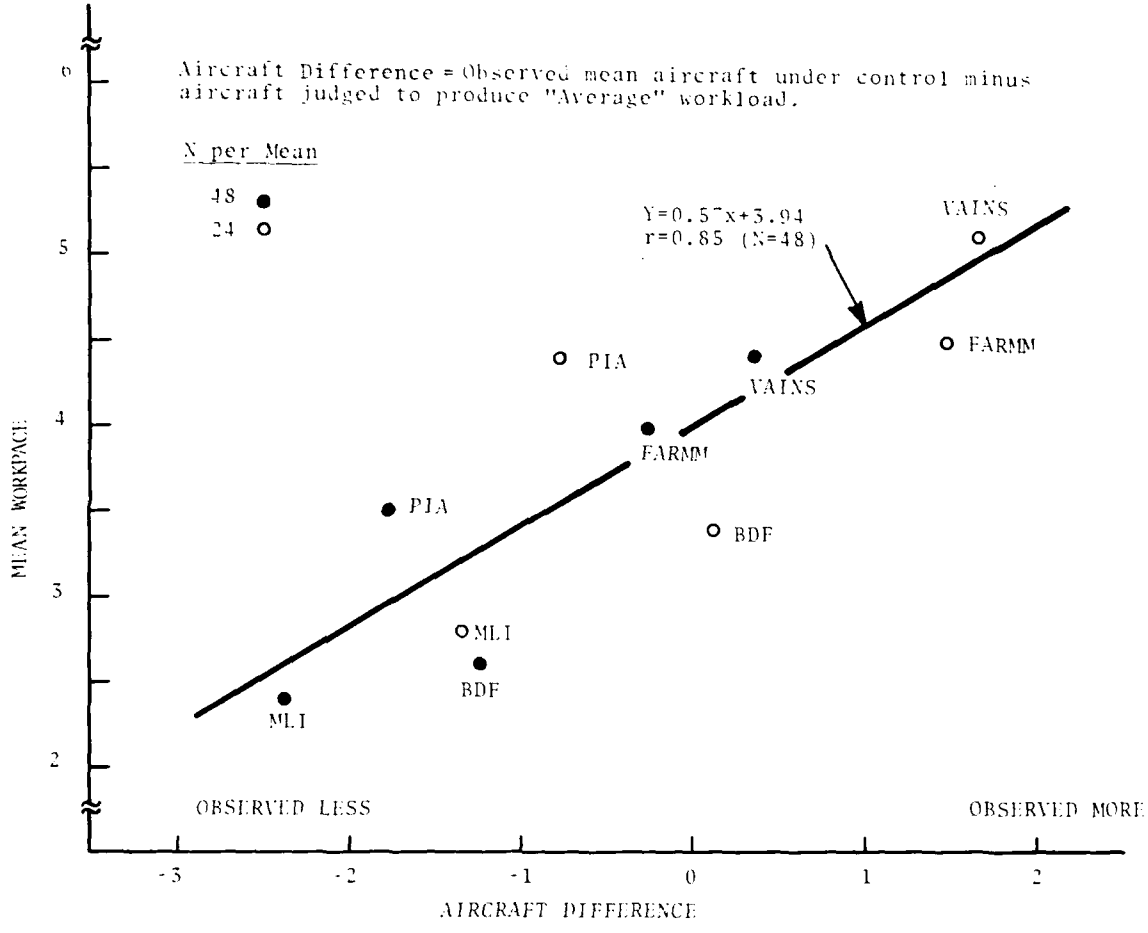


FIGURE 4-2. WORKPACE IN RELATION TO DEVIATIONS FROM EXPECTED AVERAGE TRAFFIC

consistent with what the raters believed are typical traffic levels in the rated sectors. This, of course, is precisely what we had hoped would be true, but could not guarantee operationally; much depended on the raters themselves.

4.4 CORRELATIONS BETWEEN WORKLOAD AND TRAFFIC VARIABLES

Having seen that the mean workpace ratings are an orderly function of the raters' expectations regarding the number of aircraft under control, we should ask whether workpace ratings, in particular, and measures of workload, in general, are strongly related to one or more measures of traffic. Our more general concern with the relationship between workload and traffic stems from a practical requirement; namely, the need to estimate workload for specified levels of traffic in individual sectors.

While analyzing data from the Chicago Center, we discovered a much stronger correlation between workpace and Aircraft Under Control (AUC) than between workpace and Traffic Flow Rate (TFR). Pursuing this interesting difference, we then found that measures of workload derived offline from automatic recordings are also more strongly correlated with AUC than with TFR in all 11 of the studied sectors. This consistency between Rated Workload and Computed Workload is one kind of evidence

suggesting that the two kinds of measures do indeed refer to the same aspects of the control process. After establishing that this effect is general in our data, we selected AUC as the traffic variable for precisely predicting workload by means of least squares regression equations fit to the data. In Table 4-3, product moment coefficients of correlation relate Rated Workload (workpace) and Computed Workload (Total and Routine) to TFR and AUC.

4.4.1 Rated Workload as a Function of Traffic

Rated Workload correlated 0.37-0.52 with TFR and 0.49-0.89 with AUC. In other words, linear regression with TFR accounted for up to 26 percent of the workpace variance; however, regression with AUC accounted for substantially more, up to 79 percent. In searching the literature for an analogous TFR-AUC difference to confirm the generality of our finding, we found in a recent analysis of data from 47 sectors at the Boston and New York Centers (Ref. 8) a difference of the same magnitude. The other correlations were between workpace ratings on a 16 category scale and either the traffic count per hour (r=0.49), which is a measure of traffic flow rate, or the peak traffic count per 10 minute interval (r=0.70), which is similar to

TABLE 4-3. CORRELATIONS BETWEEN MEASURES OF TOTAL WORKLOAD AND MEASURES OF AIRCRAFT TRAFFIC

WORKLOAD		RATED SECTORS									
		VS. TRAFFIC FLOW RATE IN					VS. AIRCRAFT UNDER CONTROL IN				
		BDF	MLI	VAINS	FARMM	PIA	BDF	MLI	VAINS	FARMM	PIA
RATED WORKLOAD (WORKPACE)	N = 48	0.52	0.51	0.44	0.48	0.37	0.75	0.67	0.85	0.85	0.77
	N = 24	0.48	0.52	0.41	0.47	0.43	0.67	0.49	0.89	0.78	0.77
COMPUTED WORKLOAD TOTAL	N = 24	0.59	0.49	0.40	0.44	0.54	0.90	0.96	0.90	1.00	0.92
ROUTINE	N = 24	0.44	0.37	0.38	0.44	0.38	0.68	0.83	0.78	1.00	0.71
		UNRATED SECTORS									
		VS. TRAFFIC FLOW RATE IN					VS. AIRCRAFT UNDER CONTROL IN				
		JOT	DBQ	IOW	WDPT	RFD	MCK	JOT	DBQ	IOW	WDPT	RFD	MCK
COMPUTED WORKLOAD TOTAL	N = 8*	0.61	0.74	0.36	0.45	0.46	0.74	0.92	0.97	0.97	0.98	0.98	0.97
ROUTINE	N = 8	0.60	0.63	0.20	0.37	0.56	0.69	0.71	0.92	0.87	0.93	0.92	0.83

*N = 6 for RFD

our measure of aircraft under control. The cited correlations were for a group of different sectors, whereas ours are for individual sectors. The high degree of agreement, despite various procedural differences between the present study and the recent cited study, attests to the generality of the finding that workpace is more highly correlated with AUC than with TFR.

4.4.2 Computed Workload as a Function of Traffic

Consistent with the pattern shown by Rated Workload, Computed Workload is also more strongly related to AUC than to TFR. Table 4-3 shows that for Routine Workload in rated sectors, linear regression accounts for less than 20 percent of the variance with TFR, but more than 46 percent with AUC. Again, substantially more variance is accounted for using AUC, which therefore permits more precise workload predictions.

Computed Routine Workload, as well as Surveillance Workload and Conflict Prevention Workload, are components of Computed Total Workload, which also shows a stronger relationship with AUC. But the very high

correlations in the case of Total Workload are due, in part, to the way that the other workload components were derived using AUC (see the preceding chapter for details). The same qualification applies to the Routine Computed Workload in FARMM; this workload component was derived as a function of AUC from VAINS, because voice communications data for FARMM were unavailable.

Before this analysis, it was conceivable that we would find that Computed Workload is highly correlated with Traffic Flow Rate and Rated Workload is highly correlated with Aircraft Under Control; these correlations were evidently not compared in previous research. The fact that both measures of workload are highly correlated with the same measure of traffic is important, because the agreement is one kind of evidence that suggests the two workload measures reflect the same aspects of the control process.

Having established that the relationship with Aircraft Under Control is general, we selected this traffic measure as the basis for predicting workload using least squares regression equations fit to the data. In the following

section, the linear equations fit to Rated, Computed, and Judged Workload are described.

4.4.3 Linear Workload-Traffic Functions

Linear functions relating workpace to AUC are given in Table 4-4. The strong linear relation indicated by the high correlations is reminiscent of results obtained previously in terms of peak aircraft under control at a number of air traffic control facilities (e.g., Ref. 9).

Scatterplots for linear functions that relate Computed Total Workload to AUC are illustrated in Figs. 4-3 and 4-4, for rated and unrated sectors, respectively. Because the workload and traffic variables are very highly correlated (r is at least 0.90), the workload associated with a given level of traffic can be estimated precisely.

Linear functions involving Judged Workload, derived from questionnaire responses expressed on the same scale as the workpace scale, are given in Table 4-5. For each studied sector, the workload-traffic judgments (the Appendix, Interview 3) of five controllers were combined into a single set of workpace-traffic pairs t

TABLE 4-4. WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL FUNCTIONS DERIVED FROM OBSERVERS' WORKPACE RATINGS

AREA	SECTOR	NUMBER OF OBSERVATIONS	WORKPACE-TRAFFIC CORRELATION	SLOPE	INTERCEPT
WEST WING	MLI	48	0.67	0.25	0.66
		24	0.49	0.21	1.17
	PIA	48	0.77	0.36	0.71
		24	0.77	0.31	1.65
WEST TERMINAL	VAINS	48	0.85	0.62	-0.18
		24	0.89	0.68	-0.37
	FARMM	48	0.85	0.52	0.54
		24	0.78	0.46	0.93
WEST HIGH	BDF	48	0.75	0.37	-0.27
		24	0.67	0.35	0.16

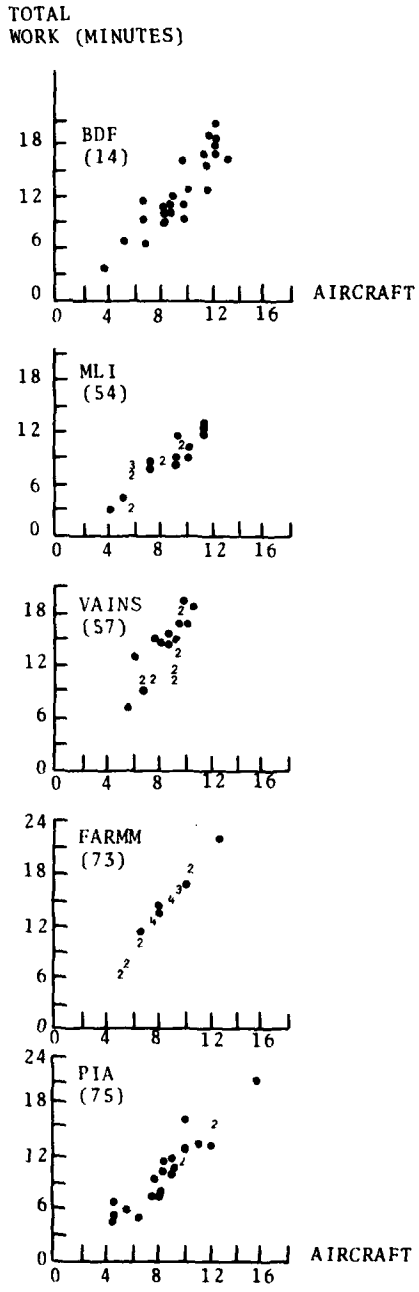
Note:

Two controller raters alternated between the two West Wing sectors.

Two controllers alternated between the two West Terminal sectors.

One controller rated the West High sector.

Sectors are listed in each area by increasing judged control difficulty.



SLOPE	1.59
INTERCEPT	-1.73
CORRELATION	0.90

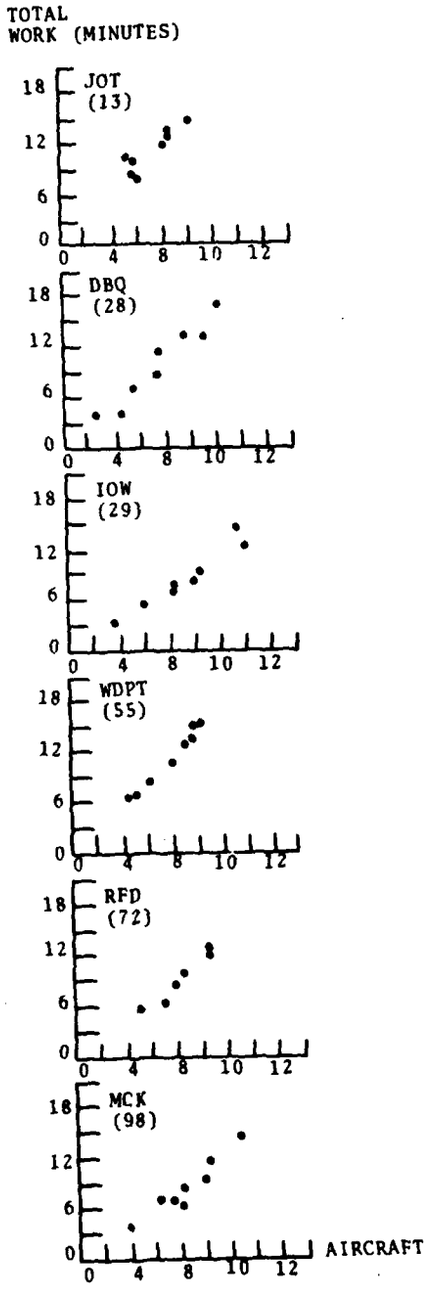
SLOPE	1.30
INTERCEPT	-2.41
CORRELATION	0.96

SLOPE	2.19
INTERCEPT	-3.82
CORRELATION	0.90

SLOPE	1.82
INTERCEPT	-0.93
CORRELATION	1.00

SLOPE	1.36
INTERCEPT	-1.21
CORRELATION	0.92

FIGURE 4-3. COMPUTED TOTAL WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL IN RATED SECTORS



	SLOPE	INTERCEPT	CORRELATION
JOT (13)	1.17	2.60	0.92
DBQ (28)	1.37	-0.65	0.97
IOW (29)	0.97	-0.77	0.97
WDPT (55)	1.53	-0.81	0.98
RFD (72)	1.43	-2.98	0.98
MCK (98)	1.17	-1.77	0.97

FIGURE 4-4. COMPUTED TOTAL WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL IN UNRATED SECTORS

which a linear least squares regression function was fit. Table 4-5 gives the slopes, intercepts, and correlations; correlations ranging from 0.79 to 0.92 indicate very precise linear relationships.

These three groups of workload-traffic functions will be used to estimate workload values in relation to additional judgments that controllers made regarding sector control difficulty.

4.5 WORKLOAD AS A FUNCTION OF SECTOR CONTROL DIFFICULTY

The concept of workload is associated with the idea of work difficulty, at least to the extent that a more difficult task can cause an individual to work harder. Working harder, the individual might feel more heavily "loaded" physically or mentally. During informal conversations with air traffic controllers regarding their control areas, the controllers sometimes differentiate among sectors in terms of the sectors' relative control difficulty as a cause for differences in workload. In order to obtain formal data that might be used as a tool for analyzing the validity of the workload measures collected in this study, we asked controllers to judge the relative difficulty of the studied sectors in their control areas (the Appendix, Interview 1).

TABLE 4-5. WORKLOAD AS A FUNCTION OF AIRCRAFT UNDER CONTROL FUNCTIONS DERIVED FROM QUESTIONNAIRE JUDGMENTS

AREA	SECTOR	WORKLOAD-TRAFFIC CORRELATION	SLOPE	INTERCEPT
WEST WING	MLI	0.84	0.29	1.27
	PIA	0.91	0.36	0.47
WEST TERMINAL	RFD	0.85	0.42	0.61
	WDPT	0.79	0.37	1.57
	VAINS	0.86	0.31	2.10
	FARMM	0.92	0.41	1.27
WEST HIGH	MCK	0.88	0.29	0.23
	IOW	0.84	0.30	0.68
	JOT	0.86	0.41	0.53
	BDF	0.85	0.36	0.66
	DBQ	0.84	0.34	0.42

Note:

In each area, five journeyman controllers judged the typical workload (workpace scale) produced by specified numbers of aircraft displayed simultaneously on the PVD in each named sector. The above parameters are for linear least square functions fit to the combined ratings. Sectors are listed in each area by increasing judged control difficulty.

4.5.1 Measures of Relative Sector Difficulty

The controllers assigned each studied sector to a position on a seven category scale (analogous to the workpace scale) according to the sector's relative control difficulty. Each controller was also asked to explain in his own words why he believes the sectors differ. Later, we assigned integers of 1-7 to the controllers' position responses. The responses for each sector were averaged over the five controllers who were interviewed.

Mean judgments for each sector are plotted in Fig. 4-5; the dispersion around the mean is based on the standard deviation of the five controllers' judgments. Why the sectors differ as shown is suggested in Table 4-6 by the list of the difficulty factors that the controllers cited. The number of controllers (maximum of five in each area) who cited each factor is given. We see in the table that the total number of difficulty citations for a sector tended to be higher, the higher the mean rating of sector difficulty. According to the controllers' difficulty citations, a typically high volume of traffic is one factor that contributes to the difficulty of some sectors.

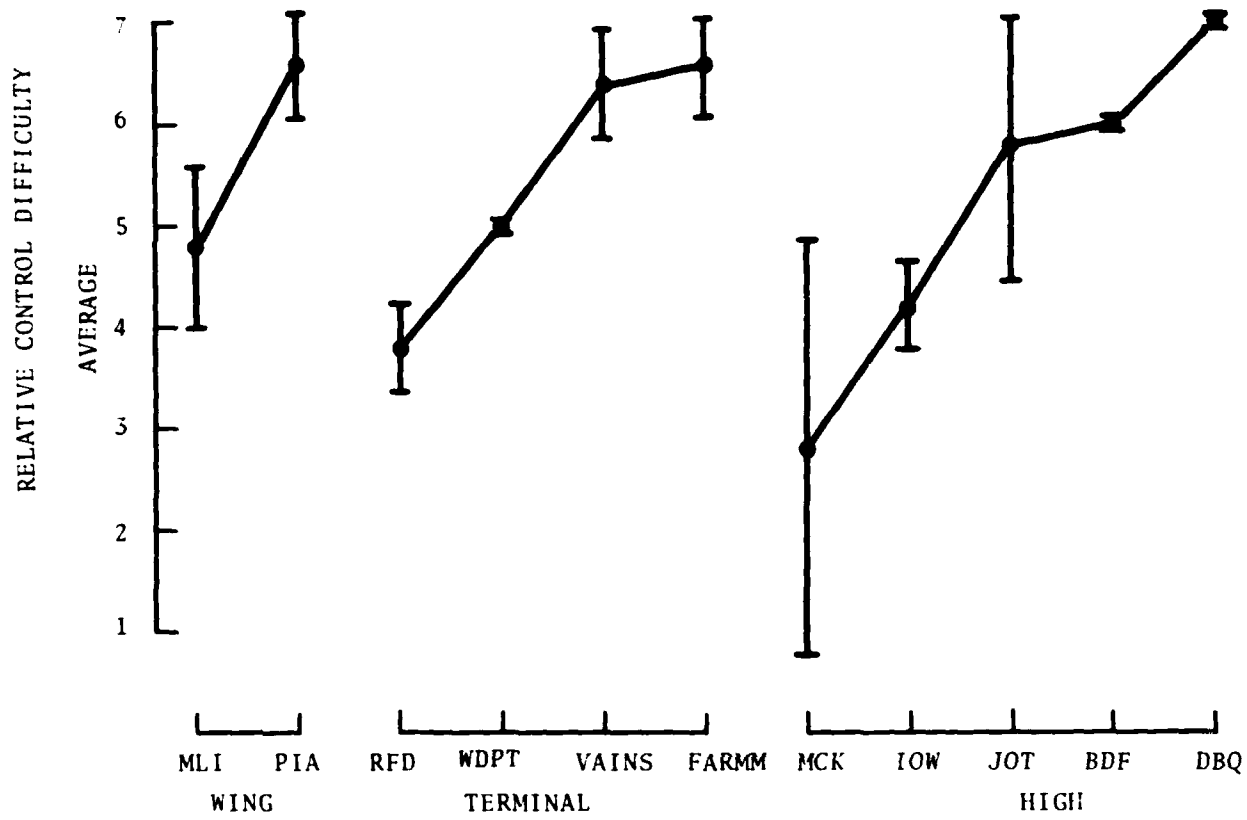


FIGURE 4-5. JUDGMENTS OF SECTOR CONTROL DIFFICULTY

TABLE 4-6. NUMBER OF CONTROLLERS CITING DIFFICULTY FACTORS IN CHICAGO SECTORS

DIFFICULTY FACTORS	WEST WING		WEST TERMINAL				WEST HIGH				
	PIA	MLI	FARMM	VAINS	WDPT	RFD	DBQ	BDF	JOT	IOW	MCK
Heavy Traffic Volume	3		5	5	2		3	1	2	1	
Small Airspace		2	2					2	3		
Brief Sector Flight Time			1	1	1						
Numerous Airports	2										
Quick Procedural Adjustments			1	2							
Much Intersector Coordination		2	1	1		1					
Complex Control (Merging, Spacing)	2		2	1	1		4	1	1	1	1
Holding	2										
Complex Aircraft Flight Paths	2										
Intersecting Flight Paths	2	1		1			1	2			
Aircraft Changing Altitude	1	1		2	2			3			
Mix of Aircraft Types	2					1					
Total Number of Controller Citations	16	6	12	13	6	2	8	9	6	2	1
Average Rating of Sector Control Difficulty	6.6	4.8	6.6	6.4	5.0	3.8	7.0	6.0	5.8	4.2	2.8
Total Citations Minus Traffic Volume	13	6	7	8	4	2	5	8	4	1	1

Subtracting the traffic volume citations from the total number of citations produces a rough measure of "residual" difficulty attributable to factors other than traffic.

Because the measure of residual difficulty excludes cited differences in traffic volume, the measure appears to be more appropriate than the mean difficulty rating for use as a predictor of workloads that are estimated for a fixed level of traffic. Nonetheless, the residual difficulty measure (based on controllers' unconstrained statements) shows no practical advantage over the mean difficulty rating (based on controllers' categorizations on a designated scale) in the present data; similar relationships are found when these measures are used to predict workload estimates for different sectors.

4.5.2 A Comparison Among Workload Estimators Relative To Control Difficulty

For a fixed level of aircraft, specifically 10 aircraft under control, workload-traffic functions for Rated Wordload (Table 4-4), Judged Workload (Table 4-5), and Computed Workload (Figs. 4-3 and 4-4), were used to calculate a workload for each studied sector. These

workload estimates are plotted in Fig. 4-6 as functions of the mean sector difficulty, and in Fig. 4-7 as functions of the residual sector difficulty citations (minus those for traffic volume).

In the figures, least squares lines are shown drawn through the estimates of Computed and Judged Workload for the sectors in each control area.

Figures 4-6 and 4-7 reveal some useful characteristics of the Computed Workload measure. First, the measure is evidently a sensitive index of sector control difficulty; workload is higher, the greater the sector control difficulty. Second, the measure is evidently a more sensitive index of sector control difficulty than Judged Workload; sectors which differ in terms of Computed Workload do not all differ in terms of Judged Workload. Third, the measure agrees with Rated Workload (workpace) as indicated by the consistent ordering between sectors; in the Wing area, MLI shows less Rated and less Computed work than PIA, and in the Terminal area, FARMM shows slightly less work than VAINS.

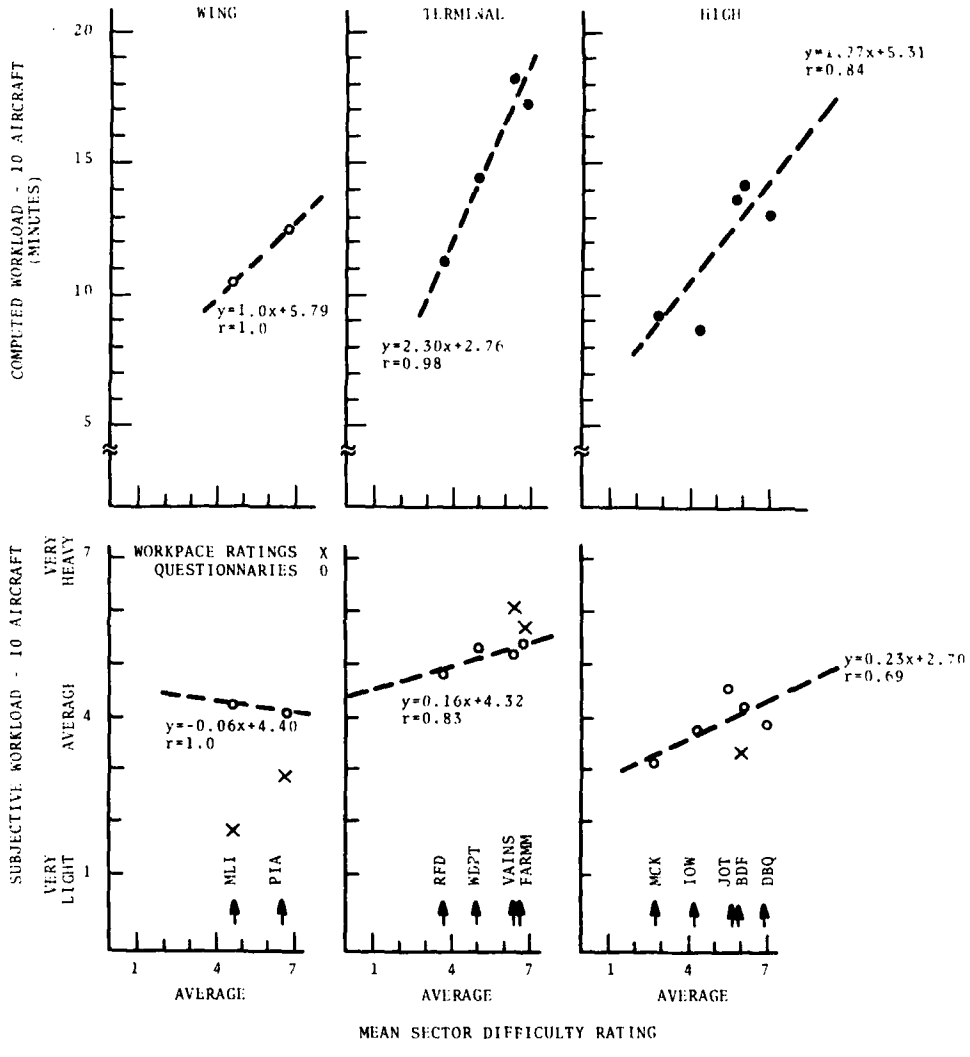


FIGURE 4-6. WORKLOAD ESTIMATORS RELATIVE TO RATED SECTOR DIFFICULTY

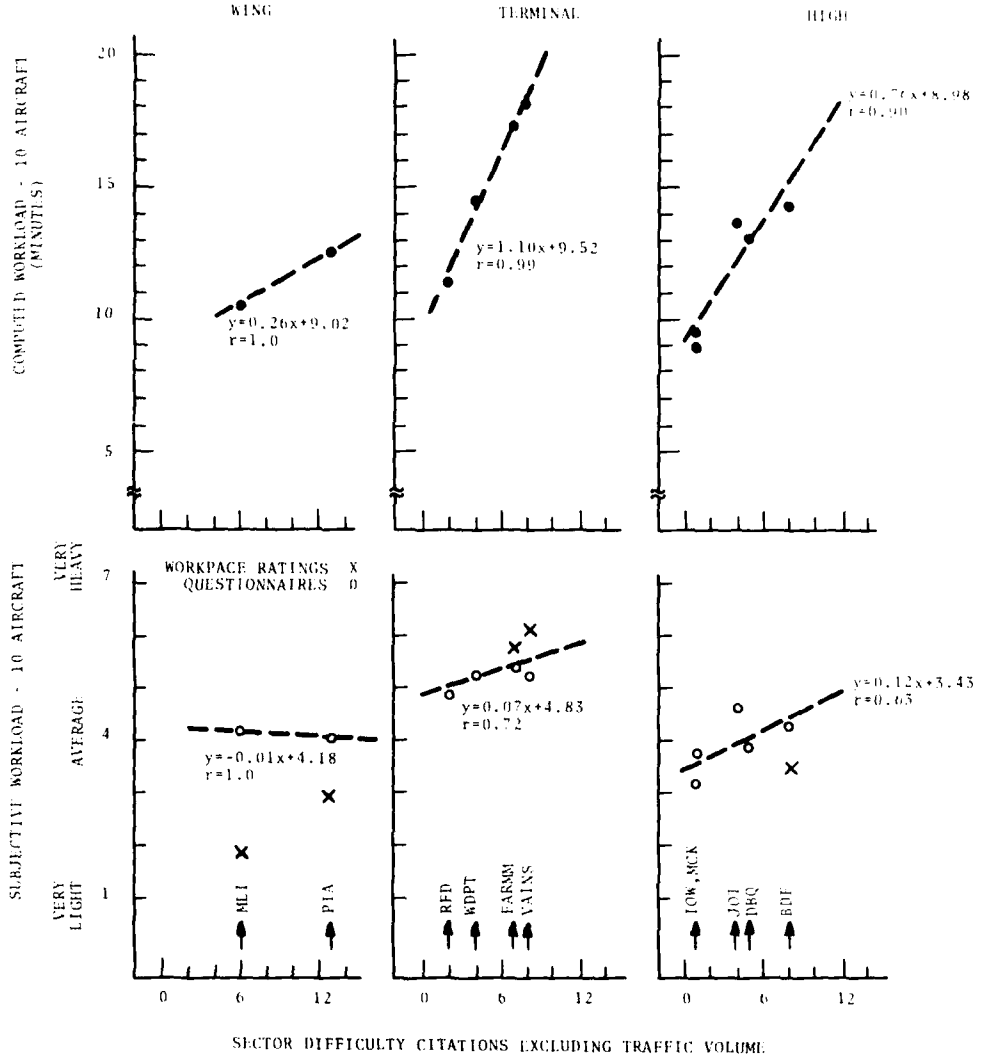


FIGURE 4-7. WORKLOAD ESTIMATORS RELATIVE TO SECTOR DIFFICULTY CITATIONS

The impressive consistency between Computed Workload and subjective measures that indicate sector differences is further evidence suggesting that Computed Workload is valid from a controller's point of view. Additional favorable evidence is produced by the next analysis, which concerns the sensitivity of Computed Workload to workload variations within an individual sector.

4.6 CORRELATION BETWEEN CONCURRENT MEASURES OF RATED AND COMPUTED WORKLOAD

Workpace ratings were made months before Computed Workload was derived offline from data that was recorded automatically while the rated control activities occurred. Therefore, in a real sense, we may ask whether Rated Workload predicted Computed Workload. The present approach to this question is to examine the degree to which concurrent values of Rated Workload and Computed Workload covary in a mathematical sense.

The product moment correlations between concurrent values of the two variables are listed in Table 4-7. In the table, correlations are given for Computed Total Workload, as well as each of the three workload components comprising the total, namely, Routine, Surveillance, and Conflict Prevention Workload. For

TABLE 4-7. COMPUTED WORKLOAD PREDICTED FROM RATED WORKLOAD (WORKPACE)

SECTOR	PREDICTED VARIABLE	r	$100xr^2$	b	a
BDF (14)	ROUTINE	0.69	47.6	1.39	1.84
	SURVEILLANCE	0.67	44.9	0.57	2.11
	CONFLICT PREVENTION	0.70	49.0	0.58	0.26
	TOTAL	0.75	56.2	2.55	4.21
MLI (54)	ROUTINE	0.30	9.0	0.50	2.36
	SURVEILLANCE	0.49	24.0	0.35	1.47
	CONFLICT PREVENTION	0.53	28.1	0.48	0.27
	TOTAL	0.42	17.6	1.33	4.10
VAINS (57)	ROUTINE	0.79	62.4	1.70	-0.93
	SURVEILLANCE	0.89	79.2	0.68	1.27
	CONFLICT PREVENTION	0.87	75.7	0.34	-0.52
	TOTAL	0.87	75.7	2.73	-0.19
FARMM (73)	ROUTINE	0.78	60.8	1.26	1.80
	SURVEILLANCE	0.78	60.8	0.75	1.08
	CONFLICT PREVENTION	0.76	57.8	0.36	-0.41
	TOTAL	0.78	60.8	2.36	2.46
PIA (75)	ROUTINE	0.78	60.8	1.56	-1.15
	SURVEILLANCE	0.77	59.3	0.64	0.17
	CONFLICT PREVENTION	0.74	54.8	0.82	-1.60
	TOTAL	0.83	68.9	3.01	-2.57

NOTE: Each computed workload variable was predicted using least squares linear regression; N = 24 for each fitted function.

r = product moment coefficient of correlation.
$100xr^2$ = percentage of variance accounted for assuming a linear prediction rule.
b = slope of least squares prediction function.
a = intercept of least square prediction function.

sectors BDF, VAINS, FARMM, and PIA, ratings accounted for an impressive, 56-76 percent of the Total Workload variance. For MLI, although the correlation (r=0.42) is reliably greater than zero (level of significance less than 0.05) as in the other sectors, only 18 percent of the Computed Workload variance is accounted for. We cannot ascertain in retrospect which of the two measures erred with respect to the workload that the R controller in MLI actually experienced.

The operational significance of these correlations is suggested more directly by Figs. 4-8 and 4-9, which illustrate the way that the two workload measures covary within each hour that VAINS (the highest correlation) and MLI (the lowest correlation) were observed. Clearly, Computed Workload has the capability of tracking Rated Workload to an impressive degree.

4.7 WORKLOAD AT CAPACITY

Evidence has been presented suggesting that Computed Workload is both a sensitive and a valid measure of controller workload in today's enroute sectors. Because the empirical workload-traffic function is essentially linear for a wide range of traffic levels, there is no indication in the function of an upper limit. As a result, other sources of information must

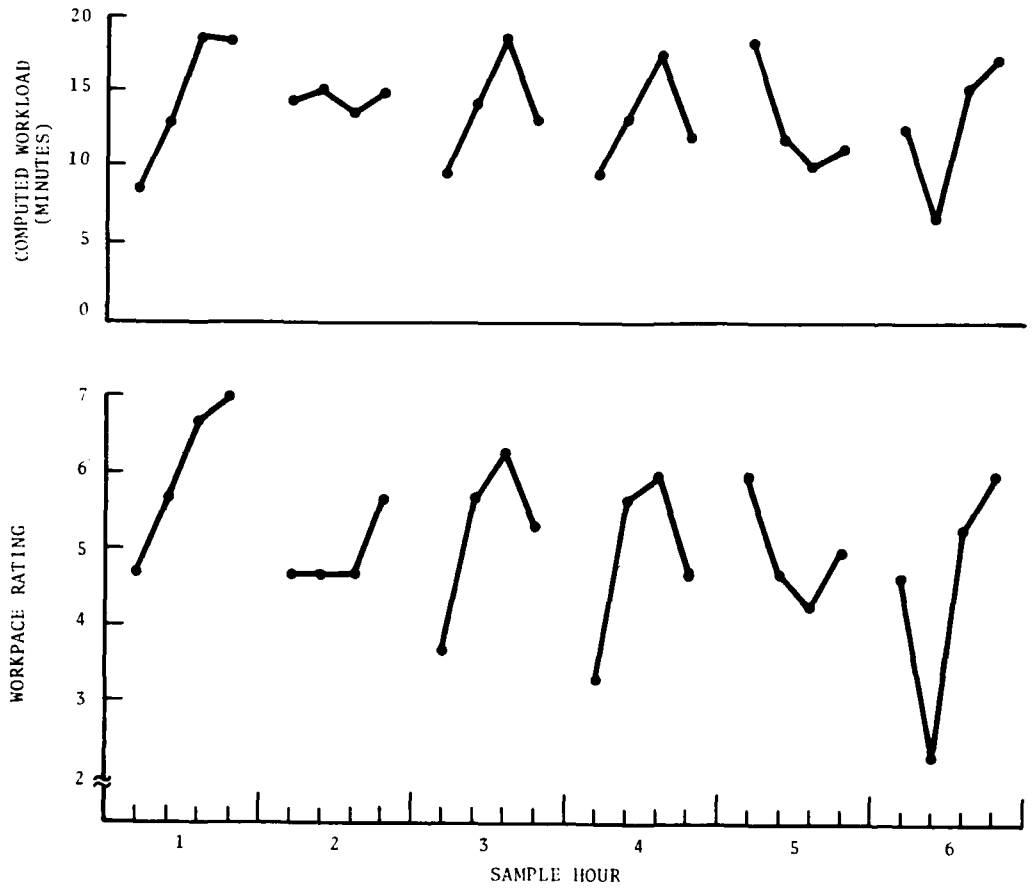


FIGURE 4-8. COVARIATION OF TOTAL COMPUTED WORKLOAD AND RATED WORKLOAD IN SECTOR VAINS

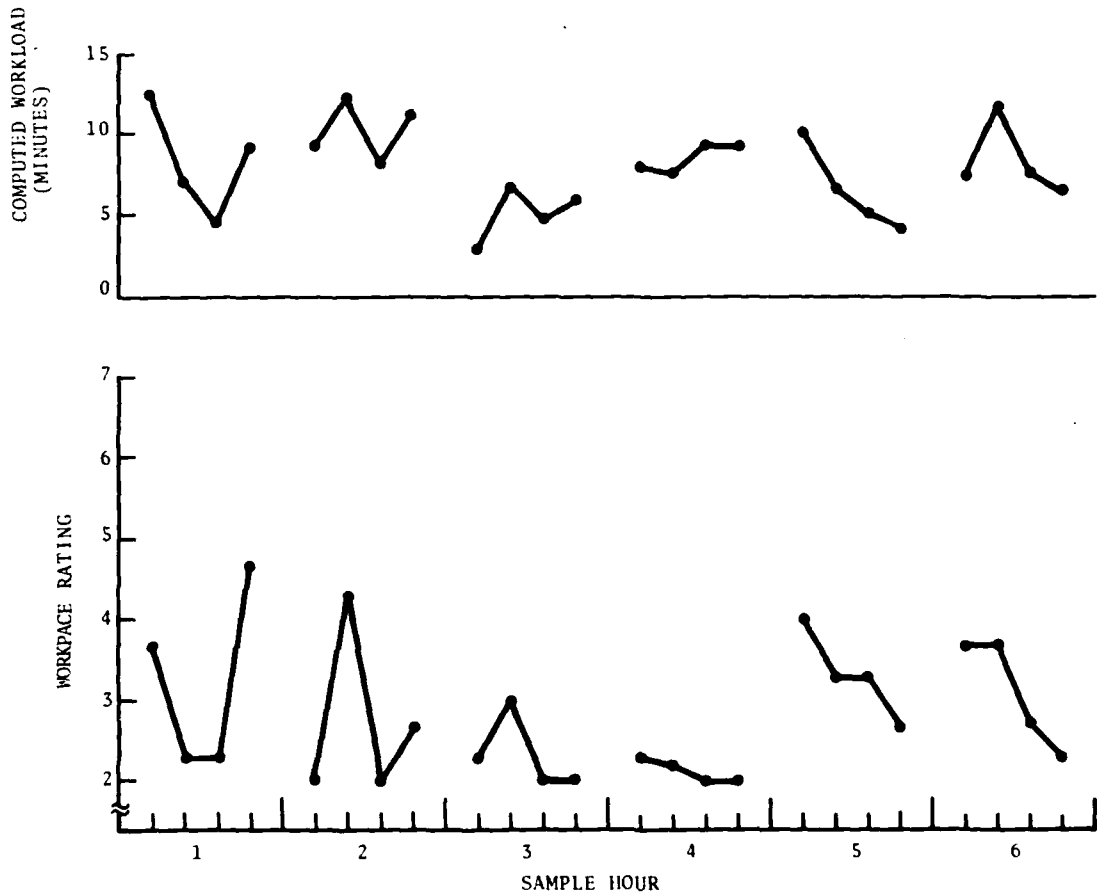


FIGURE 4-9. COVARIATION OF TOTAL COMPUTED WORKLOAD AND RATED WORKLOAD IN SECTOR MLI

be used to estimate the workload associated with traffic capacity.

Capacity is defined as the maximum number of aircraft that the average R controller can handle safely during an interval of time on the order of five minutes. This definition is consistent with the conditions that controllers who responded to the questionnaire on the workload-traffic relationship (the Appendix, Interview 3) assumed. The controllers' questionnaire responses are a potential source of the additional information that is needed.

Workload was judged on the workpace scale, which has an explicit upper limit, "Very Heavy," that might be used to estimate the capacity or near-capacity traffic level in a sector.

To perform this analysis, the linear workload-traffic functions for questionnaire judgments (Table 4-5) were used to estimate two traffic levels, one associated with "Average" workload, the other with "Very Heavy" workload. The traffic estimates are shown in Table 4-8. An analogous procedure was used to derive traffic levels from workpace ratings (Table 4-4);these traffic levels are given in Table 4-9.

TABLE 4-8. COMPUTED WORKLOAD FOR SELECTED WORKPACE VALUES DERIVED FROM QUESTIONNAIRE RESPONSES

AREA AND SECTOR	AIRCRAFT FOR "AVERAGE" WORKLOAD	COMPUTED WORKLOAD (MIN)	AIRCRAFT FOR "VERY HEAVY" WORKLOAD	COMPUTED WORKLOAD (MIN)
WEST WING				
MLI	9.41	9.82	19.76	22.90
PIA	9.81	12.13	18.14	23.46
WEST TERMINAL				
RFD	8.07	8.56	15.21	18.77
WDPT	6.57	9.24	14.68	21.65
VAINS	6.13	9.60	15.81	30.80
FARMM	6.66	11.19	13.98	24.51
WEST HIGH				
MCK	13.00	13.44	23.35	25.55
IOW	11.07	9.97	21.07	19.67
JOT	8.46	12.50	15.78	21.06
BDF	9.28	13.03	17.61	26.27
DBQ	10.53	13.78	19.35	25.86
MEAN		11.21		23.64

NOTE: Sectors are listed in each area by increasing judged control difficulty.

TABLE 4-9. COMPUTED WORKLOAD FOR SELECTED WORKPACE VALUES DERIVED FROM WORKPACE RATINGS

AREA AND SECTOR	AIRCRAFT FOR "AVERAGE" WORKLOAD	COMPUTED WORKLOAD (MIN)	AIRCRAFT FOR "VERY HEAVY" WORKLOAD	COMPUTED WORKLOAD (MIN)
WEST WING				
MLI	13.13	14.66	24.94	30.01
PIA	9.14	11.22	17.55	22.66
WEST TERMINAL				
VAINS	6.74	10.94	11.54	21.45
FARMM	6.65	11.17	12.41	21.66
WEST HIGH BDF	11.54	16.62	19.60	29.43
MEAN		12.92		25.04

NOTE: Sectors are listed in each area by increasing judged control difficulty.

There are apparently no published data to compare with the traffic estimated for "Very Heavy" workload. But we find assumed in a model applied to O'Hare International Airport operations that an approach controller's traffic workload "may never exceed 14 aircraft" (Ref. 10, p. B-15) under control at one time. Interestingly enough, the four sectors we studied in the West Terminal area, which interfaces with O'Hare, have "Very Heavy" traffic values close to 14 aircraft, specifically 13.98-15.81 aircraft. Our application of the "Very Heavy" traffic estimates to approximate traffic capacity could, therefore, be valid.

The traffic estimates were input to the workload-traffic functions for Computed Workload (Figs. 4-3 and 4-4), in order to calculate the amount of work for the two work levels. These workload values in minutes are shown in Tables 4-8 and 4-9 next to the input traffic levels used to calculate them.

Ideally, we would expect to see in Tables 4-8 and 4-9 a constant value of Computed Workload associated with "Average" workpace, and a higher constant value associated with "Very Heavy" workpace. In Table 4-8, we see that the workload values are within the range 8.56-13.78 minutes for "Average" workpace, and 18.77-30.80 minutes for "Very Heavy" workpace.

Similarly, in Table 4-9, the calculated workload values are 11.17-16.62 for "Average" and 21.45-30.01 for "Very Heavy" workpaces, respectively. All the reasons for this variability, which is partly due to judgmental factors, are not known, but constants can still be derived from these results for practical purposes.

To estimate a constant value of Computed Workload for future analyses that require a cutoff or criterion, as in the ATF model, we shall calculate a mean workload using the workload values for the different sectors. From Table 4-8 (for questionnaire judgments), we obtain mean workload values of about 11 and 24 minutes for "Average" and "Very Heavy" workpaces, respectively. These means are slightly lower than the values one could derive from Table 4-9 (for workpace ratings), specifically, 13 and 25 minutes.

These estimated values of workload might be applied in analyses of results from the ATF model, or in analyses of Computed Workload data. In such cases, the "Very Heavy" workload estimate would be used as an approximation of workload at capacity. The "Average" workload estimate could be used to detect when workload exceeds the sector average value.

4.8 CONVERGING LINES OF EVIDENCE REVIEWED

This analysis has presented evidence indicating:

1. The workpace ratings, the source of Rated Workload estimates, are consistent with what the raters believed are typical traffic levels in the studied sectors.

2. Computed Workload and Rated Workload are both more strongly related to Aircraft Under Control than to Traffic Flow Rate, suggesting they reflect the same aspects of the control process.

3. Computed Workload and Rated Workload are both orderly functions of judged sector control difficulty.

4. Computed Workload and Rated Workload are substantially correlated with each other; the former can track the latter quite closely as a function of time.

From these results, we conclude that Computed Workload is a sensitive, valid measure of R controller workload.

5. CONCLUSIONS

5.1 VALIDATION OF WORKLOAD ESTIMATES MADE BY CONTROLLERS

Two independent estimates of workload made by journeymen controllers were used as standards in evaluating RECEP as a workload model. They are workpace ratings made in real-time for specific time intervals and long-term judgments of workload based on past experience in working the sectors. The two estimates are in substantial agreement concerning the number of aircraft which produce various workload levels in the five sectors for which workpace ratings were taken. It is concluded that the two forms of estimates are consistent within themselves and therefore serve as valid standards for evaluating RECEP.

5.2 VALIDATION OF RECEP AS A WORKLOAD INDEX

Numerical values for controller workload as computed by RECEP are strongly correlated with workpace ratings taken simultaneously over a large number of test intervals. In four of the five rated sectors, workpace ratings accounted for 56-76 percent of the RECEP workload variance. Eighteen percent of the variance was accounted for in the fifth sector, MLI, where traffic was

significantly below average. In all five sectors, the RECEP workload values and the workpace ratings track each other as a function of time to an impressive degree. These findings lead to the conclusion that RECEP is a valid index of the level of workload within individual sectors.

Two estimates of sector relative control difficulty within each area of specialization were obtained from controller interviews and questionnaires. Workload values associated with a fixed number of aircraft under control were computed from three sources: RECEP, workpace ratings, and judged workload from questionnaire data. The workload values from all three sources were highly correlated with the two estimates of relative sector difficulty: i.e., the higher the sector difficulty, the higher the workload. RECEP workload appears to be a very sensitive indication of small differences in relative sector difficulty. These findings lead to the conclusion that RECEP values are a valid index for comparing workload from one sector to another.

5.3 VALIDATION OF RECEP AS A WORKLOAD PREDICTOR

Workload values obtained from RECEP computations, workpace ratings and judged workload are all highly corre-

lated with the mean number of aircraft under control (AUC). AUC accounts for greater than 80 percent of the variance in RECEP workload in all eleven sectors studies. Correlation coefficients relating AUC to workpace and judged workload range from 0.49 to 0.89. This finding is a strong indication that the three measures of workload capture the same aspects of the control process. It also leads to the conclusion that RECEP is a valid means of predicting workload within individual sectors for specified levels of traffic.

5.4 CALIBRATION OF RECEP AT CAPACITY WORKLOAD CONDITIONS

RECEP workload values measured over a large number of test intervals for eleven sectors are essentially a linear function of traffic and, therefore, give no indication of an upper, or capacity, limit. RECEP workload values for traffic levels associated with "very heavy" workload estimates obtained both from workpace ratings and from judged workload were investigated as a possible upper limit. Unfortunately, in both cases, the values varied widely from sector to sector. Thus, it would be necessary in future applications of RECEP/ATF to calibrate sectors individually for capacity conditions. This is an unsatisfactory solution. A mean value for all sectors which corresponds to "very heavy"

workload appears to be a more reasonable choice. Mean RECEP workload values of 24 and 25 minutes were obtained when derived from "very heavy" judged workload and "very heavy" workpace ratings, respectively. It is recommended that 24 minutes be used to represent capacity workload, recognizing that this is an average value for many sectors and controllers.

It is interesting to note that RECEP workload values at high traffic levels exceed 15 minutes during a 15-minute interval. This is attributable to the method used in computing workload. RECEP estmates the time spent on individual activities, both mental and physical. Many of these activities are performed simultaneously; thus, it is possible to exceed 15 minutes of work in 15 minutes of elapsed time. RECEP is an index of controller busyness rather than an aosolute measure of working time versus idle time.

APPENDIX: CONTROLLER SURVEY TO DETERMINE SECTOR WORKLOAD LEVELS

The three appended questionnaire forms were used to guide controlled interviews of air traffic controllers during the Chicago ARTCC RECEP validation tests. The forms were designed to provide long-term estimates of workload levels within sectors which were used to compare with short-term RECEP measures of workload and with workpace ratings. Questionnaires were answered in the presence of an interviewer who explained the meaning of each form and solicited qualifying information when it appeared relevant. Controllers responded for only those sectors in which they had had recent R-position experience. A two-controller team (R and D positions) was assumed. The three forms are attached and are self-explanatory. Forms 1 and 3 use a seven-point rating scale for easy comparison with workpace ratings.

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INTERVIEW 1: RELATIVE SECTOR CONTROL DIFFICULTY

Please select from the following list of sectors only those with which you have worked recently.

AREA														
SECTOR														

List these sectors below, beside the vertical scale provided. Arrange the sectors according to the degree of RELATIVE DIFFICULTY you believe typical R controllers working in them experience during typical busy periods. Assume conditions requiring a two-controller (R and D) team.

Briefly explain to the extent that you are able (you are of course aware that the cause of difficulty is not always easy to pinpoint) the order you use.

LEVEL OF RELATIVE DIFFICULTY	YOUR LIST	YOUR EXPLANATION
Most Difficult to Control ⇨		
Very Difficult ⇨		
Above-Average Difficulty ⇨		
Average ⇨		
Below-Average Difficulty ⇨		
Fairly Easy ⇨		
Easiest to Control ⇨		

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INTERVIEW 2: OVERALL SECTOR TRAFFIC FLOW

Please give the information requested below for sectors with which you have worked recently. Assume typical busy conditions requiring a two-controller (R and D) team.

AREA	SECTOR	SECTOR FLIGHT TIME Estimate from your own experience the average time in minutes an aircraft is under the sector's control; state any qualifications you wish.	SECTOR TRAFFIC CAPACITY Estimate from your own experience the maximum number of aircraft that might be handed off to the sector during one hour, without without causing a typical R controller to "go under" or "lose the picture;" state any qualifications you wish.

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INTERVIEW 3: SECTOR WORKLOAD GROWTH RATES

This interview asks the following kind of question: "When 20 aircraft are controlled at the same time by sector X, what degree of workload does a typical R controller experience?" This kind of question is asked for eight levels of aircraft traffic in each of several sectors. The degree of workload you decide is appropriate is selected from the following list of seven values:

VH = Very Heavy
H = Heavy
AA = Above Average
A = Average
BA = Below Average
L = Light
VL = Very Light

An example of the workload rating procedure is included below with the sectors to be considered. Only consider sections with which you have worked recently, and assume conditions requiring a two-controller (R and D) team.

TRAFFIC LEVEL: NUMBER OF AIRCRAFT UNDER CONTROL AT ONE TIME

AREA	SECTOR	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
example	X	VL	VL	L	A	A	H	VH	VH

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