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A Simulation Study of the Effects of Communication Delay on Air Traffic Control

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16. Abstract

This study was conducted to examine the impacts of voice communications delays characteristic of Voice Switching and Control System (VSCS) and satellite communications systems on air traffic system performance, controller stress and workload, and communications disruptions. To accomplish this a simulation was developed and performed at the Federal Aviation Administration (FAA) Technical Center. The simulation used scenarios constructed from records of live air traffic at five adjacent Atlanta Air Route Traffic Control Center (ARTCC) sectors. Nine full performance level air traffic control specialists from the Atlanta ARTCC sectors simulated participated as subjects. Four delay levels were employed corresponding to: current equipment with and without satellite link, and VSCS with and without satellite. Three levels of communications workload were used based on 70 percent, 90 percent, and 110 percent of reference values for the actual sectors. VSCS delays were not found to have any statistically significant impact on any measure. Satellite delays were found to be associated with a statistically significant increase in one kind of communication disruption (step-ons) at the highest level of communications workload used in the study.

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METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]\,^\circ F = y\,^\circ C$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5)\,y + 32]\,^\circ C = x\,^\circ F$

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

Preface

This study investigated the effects of communication delays imposed by the Voice Switching and Control System (VSCS) and satellite linked air traffic control communications. The delays were implemented in a simulation intercom at the Federal Aviation Administration Technical Center. Simulation scenarios were constructed from records of live air traffic at Atlanta Air Route Traffic Control Center. Full performance level air traffic control specialists from the sectors simulated participated in the simulation. The study focused on predicting whether increased stress, decrements in system performance and increased communication disruption would occur due to the delays characteristic of VSCS equipment and/or satellite systems, as compared to the systems used today.

The authors wish to recognize the contributions of the numerous individuals who made this study possible. We are particularly grateful to the supervisory controllers from Atlanta Center who worked extensively with us at many points in the study. Much of its success can be attributed to their assistance. We are also very grateful to the ATC specialists from Atlanta Center who served as controllers at the simulation and to Paul Brinegar from Washington Center and Dan Johnson from Chicago Center, who worked at the aircraft termination sector for part of the study. Many other individuals at Atlanta Center deserve our appreciation, especially Bob Owen, who scheduled controllers for their participation, and Gary Crosby, for sector descriptions. We also greatly appreciate the support of the Atlanta Center air traffic facility manager, Stan Ensley.

We also wish to acknowledge the assistance of many individuals at the FAA Air Traffic Plans and Requirements Service and Air Traffic Operations Service. Chuck Ullman was instrumental in making Atlanta Center personnel available for the study. Chuck Harrison and Chuck Ullman reviewed and made useful suggestions regarding the questionnaires, and participated in the process of readying the simulation scenarios. Roy Faber, Chuck Harrison and Robbie McGrath staffed the aircraft termination sector while observing the simulation. Al Henry and Dan Kerr provided expert advice from an operational perspective. Ron Morgan, acting manager, and Mitch Grossberg, both of the Advanced Systems and Facilities Division at ATR, deserve special credit for their involvement in the planning of the project and thorough review of an early draft of this report.

Michael Lam, who chairs the Satellite Communications Working Group, and Glenn Waugaman, manager of the Telecommunications Management and Operations Division, provided the necessary initial coordination and direction for the study. Mike Gariazzo, Michael Lam, Douglas Lee and Glenn Waugaman made valuable comments on an early draft of this report.

The study benefited greatly from the contributions of many resourceful people at the FAA Technical Center including John Aschenbach, Jack Bernstein, Ginger Carnes, Debbie Cook, Elliot Linsky, Dave Senn, Albert Schwartz, Scott Harris, Steve Stratoti and Dan Warburten. We appreciate the support of Howard Mason, manager of the Technical Facilities Division, Rene Matos, supervisor of Simulation Operations and Hugh Milligan, manager of ATC Facilities Operation, and his staff. The simulation scenarios were constructed by SRSA employees Bill Bamberg, Jim Miller and Kevin Walker. CRM employees Dick Algeo, Scott Cramer, Scott Doucett, Gwen Harris and Mary Schweiker ran the simulation and reduced the data. We also wish to express our appreciation for the patience and dedication of the 30 simulation operators who served in the role of pilots, including lead pilots Dee Algeo, Molly Amado and Mary Rozier. We also thank their supervisor, Joyce Landing, and SIR employee Henry Smallacomb, and the supervisor of the Pilot's Lab, George Kupp, Jr.

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Executive Summary

Introduction

The purpose of this study is to investigate the effects of the delays imposed by the use of geosynchronous satellites and the Voice Switching and Control System (VSCS) on air traffic controller/pilot communications, stress, and system performance. FAA satellite based systems now operate successfully in Alaska and the Caribbean under moderate traffic conditions. Conversations with supervisory staff at Transport Canada indicate that Canadian ATC systems also use satellite communications successfully. No operational experience is available for VSCS systems. This study provides information on the effects of communications delay under a wide variety of conditions.

The study examines the effects of satellite and VSCS communication delays on simulated air traffic control system performance. Four delays were implemented in the simulation, those imposed by the present system alone (Today), VSCS alone (VSCS), Today with Satellite (Today + Sat), and VSCS with Satellite (VSCS + Sat).

The nine-day simulation was conducted at the FAA Technical Center. Simulation scenarios were constructed from recordings of actual air traffic at Atlanta Air Route Traffic Control Center (ARTCC). Five adjacent sectors of the ARTCC were simulated. Three sectors were designated test sectors and the two others were considered non-test sectors. The test sectors included one low altitude sector (Sinca Low) and two high altitude sectors (Dublin High and Macon High). The study focused only on events related to the test sectors. The non-test sectors were used to support the test sectors by realistically receiving and transferring aircraft. The subjects were nine full performance level (FPL) air traffic control specialists currently working in the Atlanta Center area containing the sectors simulated, assisted at the data controller positions by an equal number of FPL controllers from the same center. Thirty simulation operators, who had been trained by the FAA Technical Center, performed in the role of pilots.

Three levels of communications workload were established by creating three scenarios with different numbers of aircraft. These air traffic load numbers were based upon Atlanta Center traffic load norms for the actual sectors. Each of the 28 test sessions included one of the four types of delay and one of the three levels of communications workload.

The following areas were examined for potential effects of delay:

- System performance
- Communications disruptions
- Controller stress, effort and attention requirements

System performance measures included

- Separation infringements
- Numbers of aircraft handled

Communications disruptions consist of "step-ons" and verbal mistakes.

- Step-ons comprise Pilot-Controller/Controller-Pilot step-ons (the pilot blocks the transmission by the controller or the controller blocks the transmission by the pilot), and Pilot-Pilot step-ons.
- The verbal mistakes recorded consist of wrong information that was corrected in the same transmission, and uncorrected wrong information.

Estimates of controller stress and attention were assessed through questionnaires filled out by the controller subjects and by operations observers (supervisory FPL controllers from the Atlanta ARTCC).

Of these, communications disruptions and especially step-ons (call blocking) were considered to be the most sensitive measure of the effect of delay.

This study focused on predicting whether the delays characteristic of VSCS equipment and/or satellite systems, as compared to the systems used today, would cause deterioration in system performance, increased controller stress, and increased communications disruptions. Three hypotheses were tested in this study:

- System performance is degraded with increased delay.
- Controller stress increases with delay.
- Communications disruptions increase with delay.

Results

System Performance

- No statistically significant differences were found between any of the delay conditions, satellite or VSCS, in measures of separation infringements or numbers of aircraft handled.

Controller Stress

- No statistically significant differences were found between any of the delay conditions in measures of stress, effort, or attention.

Communications Disruptions

- No statistically significant increases in communications disruptions were found which could be attributed to simulated VSCS delay conditions.
- No statistically significant differences in verbal mistakes were found between any of the delay conditions.
- Statistically significantly more Pilot-Controller/Controller-Pilot step-ons were recorded for satellite conditions than non-satellite conditions at the highest workload levels tested.

Conclusions and Recommendations

Increased step-ons were found at the highest workload levels under satellite delay conditions. The question remains: *Will the observed increase in step-ons, under satellite delay conditions at high communication workloads translate into inferior real-world system performance?* This matter can best be resolved by making a separate field study using satellite communications within sectors with high communications activity.

1. Introduction

The purpose of this study is to investigate the effects of the delays imposed by the use of geosynchronous satellites and the Voice Switching and Control System (VSCS) on air traffic controller communications, workload, and system performance. The study was conducted with full performance level (FPL) controllers using the real time air traffic control simulation facilities at the Federal Aviation Administration Technical Center. [1]

This study focuses on predicting whether increased communications disruptions, increased controller stress, and degradation in system performance will occur with the delays characteristic of VSCS equipment and/or satellite systems, as compared to systems used today. The tests were conducted under conditions that realistically simulated pilot contention, with air traffic loads that would produce a range of communications loads. Five adjacent en route sectors south of Atlanta were chosen for the simulation. Performance was studied in three "test sectors": simulations of Dublin High, Macon High and Sinca Low. Two other sectors (simulations of Clark Hill Ultra High and South Departure Low) supported the test sectors in the simulation. The simulations consisted of scenarios constructed from recordings of air traffic in the corresponding actual sectors.

The subjects were FPL controllers who normally work in the Atlanta Center area containing the sectors corresponding to the simulated sectors. Their performance was observed by supervisors from Atlanta Center. Their communications were observed and taped by personnel from the Transportation Systems Center. The supervisors and subjects filled out questionnaires following each simulation session. In addition, a variety of data was recorded automatically by the simulation computer systems. It was anticipated that these efforts would provide a valid and reliable statistical basis for decisions which pertain to the use of the VSCS and satellite communications systems in future ATC communications.

1 The study was previously described in the document *ATC Voice Communications Delay Test Plan* (G. Spanier, 17 October 1989), circulated by the Federal Aviation Administration Technical Center. (See Appendix A)

The communications systems that were simulated impose three types of delay:

- A "ground-to-air set-up delay" occurring between the time the controller's microphone is keyed and the time that a message can be accepted by the ground transmission system. The message is "clipped" (i.e., the initial segment is lost) if it begins before the set-up delay elapses.
- A "ground-to-air propagation delay" occurring between the time the message enters the system and the time the message is received. The message is delayed until the transmission is propagated through the system.
- An "air-to-ground propagation delay" occurring between the time the pilot makes a transmission and the time it is received at the en route center. The message is delayed until the transmission is propagated through the system.

Four combinations of set-up and propagation delays were studied, corresponding to the delay values associated with:

1. currently used systems (Today)
2. future systems incorporating elements of currently used systems and Voice Switching and Control System equipment (VSCS)
3. currently used systems incorporating satellite links (Today + Sat.)
4. future systems incorporating elements of currently used systems and VSCS equipment with satellite links (VSCS + Sat)

The delay values that were used were developed by the FAA Technical Center (See Appendix B for a description of the considerations used to determine these). The delays range from those corresponding to current equipment (225 msec ground-to-air set-up delay and no air-to-ground delay) to satellite delays that include 260 msec propagation delays in both the air-to-ground and ground-to-air directions plus set-up delays.These delays were implemented in an intercom system at the Federal Aviation Administration Technical Center simulation facility.

The following three hypotheses were tested in this study:

- System Performance is degraded with increased delay.
- Controller stress increases with delay.
- Communications disruptions increase with delay.

These hypotheses cannot be tested with equal sensitivity in this study. The test of system performance degradation depends to a large extent on our ability to detect changes in the frequency of separation infringements. These infringements occur very infrequently in the real world (For Atlanta historically, less than one for every 30,000 aircraft handled [2]). Our study provides fewer than 5,000 aircraft handled. Therefore it would take a very major change in the frequency of infringements due to communications delay to be statistically significant.

Changes in stress are readily measurable but in this simulation the level of stress and workload is due directly to the number of aircraft handled and is only an indirect side-effect of communications disruptions, particularly step-ons.

In this study the frequency of step-ons is by far the most sensitive measure of the impact of communications delay. Step-ons are a direct result of delay, occur with sufficient frequency in the real-world to be statistically testable, and are probably the source of the other problems we are testing for.

2 FAA Office of Aviation Safety. *Profile of Operational Errors in the National Airspace System*, 1987

2. Method

2.1 Overview

The study was conducted with current, qualified, full performance level (FPL) controllers using the real time air traffic control simulation facilities at the FAA Technical Center. Nine FPL controllers from the area of specialization corresponding to the test airspace participated in the radar-controller (R-controller) positions as subjects. They were responsible for all communications with pilots. An equal number of FPL controllers from Atlanta Center staffed the data positions (D-controllers). They handled all ground-to-ground communications.

Supervisors from other areas of specialization at Atlanta Center observed the performance of the R-controllers. Thirty simulation operators, trained to serve in the role of simulation pilots, also participated. All communications were observed by trained personnel from the Transportation Systems Center. Data relating to controller stress, system performance, and communications disruption were recorded by the observers, the R-controllers, and the simulation computer system.

There were 28 test sessions during the three-week study. A different controller team participated each week for three days. There were three sessions each day, except for one day when there were four. The fourth session was added because of equipment problems during the first session of the first day.

2.2 Background

Communication delays have the potential for causing problems in air traffic control (ATC) communications. One type of communications disruption is the "step-on." In a step-on, one party blocks a communication from another party by starting a communication after the other starts one, but before it is completed.

Pilot-controller step-ons occur if a pilot blocks a call from the controller. Communications delays can cause this type of step-on if a pilot initiates a transmission between the time the controller keys the microphone to transmit information to that pilot, and the time the controller's message arrives. Because neither one can receive a message while keying the microphone, all or part of the incoming message may be lost.

Delay can also cause controller-pilot step-ons if the pilot initiates a transmission but the controller is unaware of it on account of equipment and propagation delays and initiates a transmission before the pilot's transmission can be received. Here the controller blocks the transmission by the pilot.

Pilot-pilot step-ons are not expected to be affected by delay because no delay was imposed on the intercom channels that connected pilots in the same sector. This arrangement accurately simulated actual operations. Pilot-pilot step-ons (as well as some controller-pilot and pilot-controller step-on) probably result from message overlap during periods of frequent communication. In an operational environment, a pilot-pilot step-on results in a "squeal" such that the controller cannot comprehend the overlapping portions of the pilots' transmissions.

2.3 Test Airspace

The test airspace involved five contiguous en route sectors based upon particular Atlanta ARTCC sectors. Performance was studied in three "test sectors." These three were supported by two "non-test sectors," which realistically transferred and received aircraft. Performance in the non-test sectors was not studied. The test sectors were developed from recordings of live air traffic in corresponding sectors described by Atlanta Center as follows: [1]

Dublin High: "Air carrier aircraft generate the majority of traffic handled by this sector. This sector provides IFR arrival service to the Atlanta Terminal area and, at the same time, handles a large amount of en route traffic. A moderate amount of traffic is generated by aircraft transitioning to/from Macon, GA/Robins AFB and adjacent airports. Traffic flow is predominantly northwest/southeast with numerous departures from Atlanta and arrivals to the East Coast interspersed with Atlanta area arrivals. The high complexity of this sector is created by Atlanta terminal area arrivals entering the sector at several locations that require spacing while continuing to provide service to en route traffic. A large amount of coordination is required with the Sinca sector in order to achieve the required intrail spacing. The unique characteristic of this sector, which increases the complexity, is the requirement for the controllers to change altitudes of a large percentage of aircraft to conform with letters of agreement and traffic flow. These situations add to the sector's complexity and necessitate careful planning and coordination. This sector daily works F-15 aircraft to/from Robins AFB."

Macon High: "This sector provides IFR service from the Atlanta terminal area with a mixture of a proportionate amount of en route traffic. Traffic flow is predominantly north/south with a moderate amount of crossing traffic. Military operations generate additional traffic which must be blended with normal traffic. The unique characteristic of this sector is the fact that controllers are required to change altitudes on all J45 traffic. Obviously this built-in head-on situation increases the sector's complexity and necessitates careful planning and coordination."

Sinca Low: "This sector provides IFR arrival service to the Atlanta terminal area and, at the same time, handles a proportionate amount of en route traffic. Traffic flow is predominantly northwest/southeast. Military operations generate a moderate amount of traffic which must be blended with the traffic flow. Controllers are required to provide arrival spacing for the Atlanta terminal area which requires careful planning and a large amount of coordination with the Dublin High altitude sector."

The two non-test sectors correspond to Clark Hill Ultra-High and South Departure Low. In addition, an aircraft termination sector was included in the simulation to represent a termination point for the aircraft. Aircraft disappeared from simulated radar following transfer to this sector. Airspace diagrams for the actual sectors are reproduced in Figure 1 (Dublin High), Figure 2 (Macon High), and Figure 3 (Sinca). An extended low altitude view of the sectors simulated is reproduced in Figure 4. Ratings of the realism of the simulated air traffic are provided in Appendix C.

1 Quoted sector descriptions were obtained from Atlanta ARTCC, 1989. Dublin High and Sinca Low have since been changed at Atlanta Center.

2.4 Independent Variables

2.4.1 Delay

The following values were obtained from the FAA Technical Center. The Today delay condition simulated current equipment delays by imposing on the simulation intercom circuitry a 225 msec ground-to-air set-up delay, no ground-to-air propagation delay, and no air-to-ground propagation delay. The VSCS condition simulated delays characteristic of VSCS and associated equipment by imposing a 99 msec ground-to-air set-up delay, a 70 msec ground-to-air propagation delay, and a 70 msec air-to-ground propagation delay. Today + Sat provided a 225 msec ground-to-air set-up delay, a 260 msec ground-to-air propagation delay, and a 260 msec air-to-ground propagation delay. VSCS + Sat imposed a 99 msec ground-to-air set-up delay, a 330 msec ground-to-air propagation delay, and a 330 msec air-to-ground propagation delay.

The delay values are shown in Figure 5. The total height of the stacked bars shows the interval during which a pilot could unknowingly block the message of a controller who is calling immediately after another pilot's call. Only air-to-ground and ground-to-air delays were simulated; ground-to-ground communications delays may be characteristic of VSCS and satellite links, but were not imposed due to limitations of the simulation facility. In the simulation, pilots whose microphones were unkeyed could hear other pilots in their sector with no delay.

ATLANTA ARTCC

EFFECTIVE: 11/28/89

SECTOR 20 - DUBLIN HIGH - FL240-FL330

34 02 20
81 46 40

33 53 20
81 51 00

32 54 00
81 50 30

32 33 45
81 56 00

32 10 00
82 20 00

31 54 50
82 44 30

32 44 00
83 33 40

33 07 45
83 53 40

33 44 30
83 48 15

33 46 30
82 50 00

33 51 10
82 28 50 to point of beginning

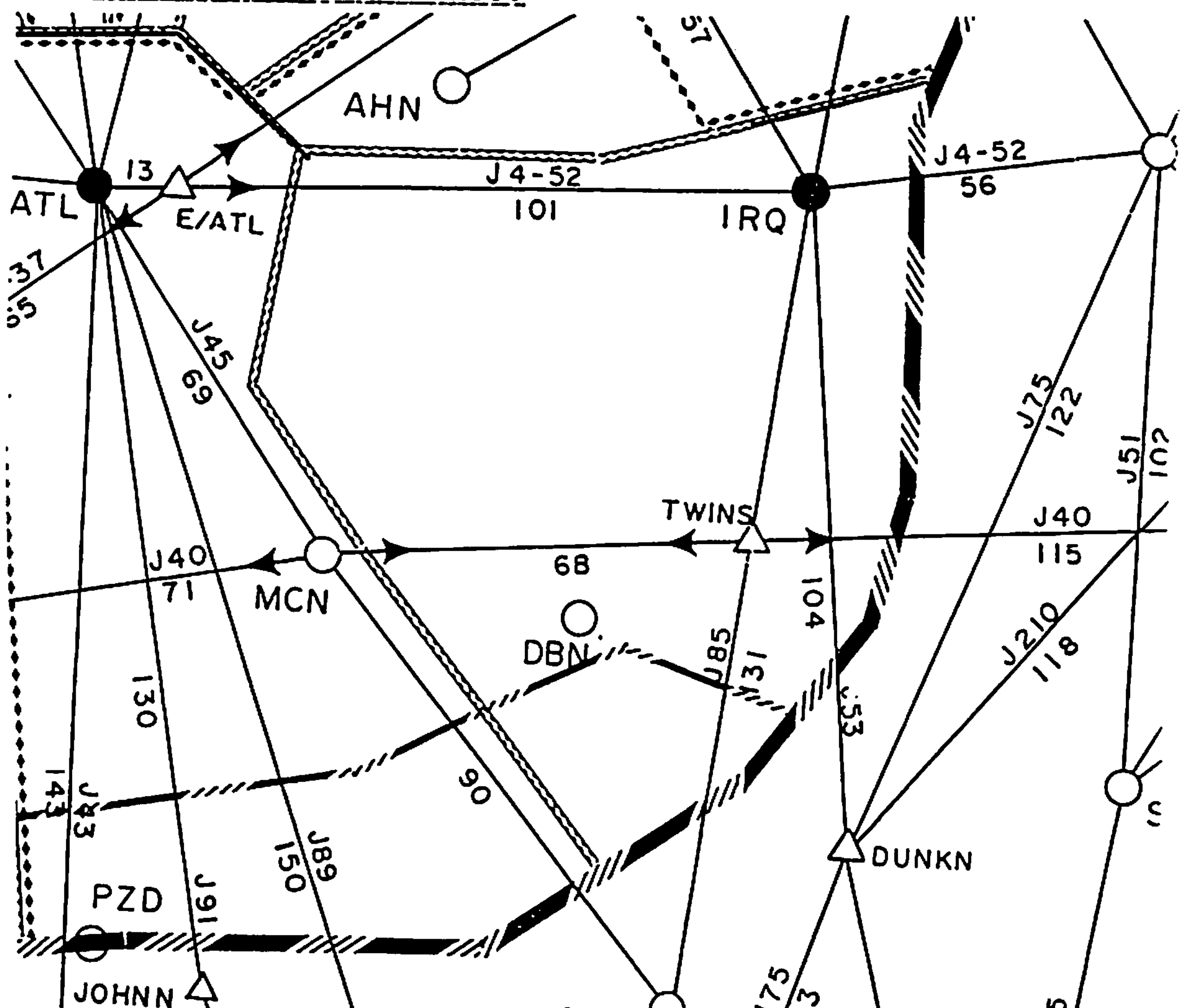


Figure 1. Airspace Diagram for Dublin High

EFFECTIVE: 11/28/89

SECTOR 22 - MACON HIGH - FL240-FL330

34 00 00
85 00 00

34 01 06
84 42 12

34 02 06
84 26 00

34 03 00
84 11 30

33 44 30
83 48 15

33 07 45
83 53 40

32 44 00
83 33 40

31 54 50
82 44 30

31 41 00
83 06 45

31 41 00
84 06 00

31 37 40
84 32 15

33 00 30
84 43 00

33 22 00
85 00 00 to point of beginning

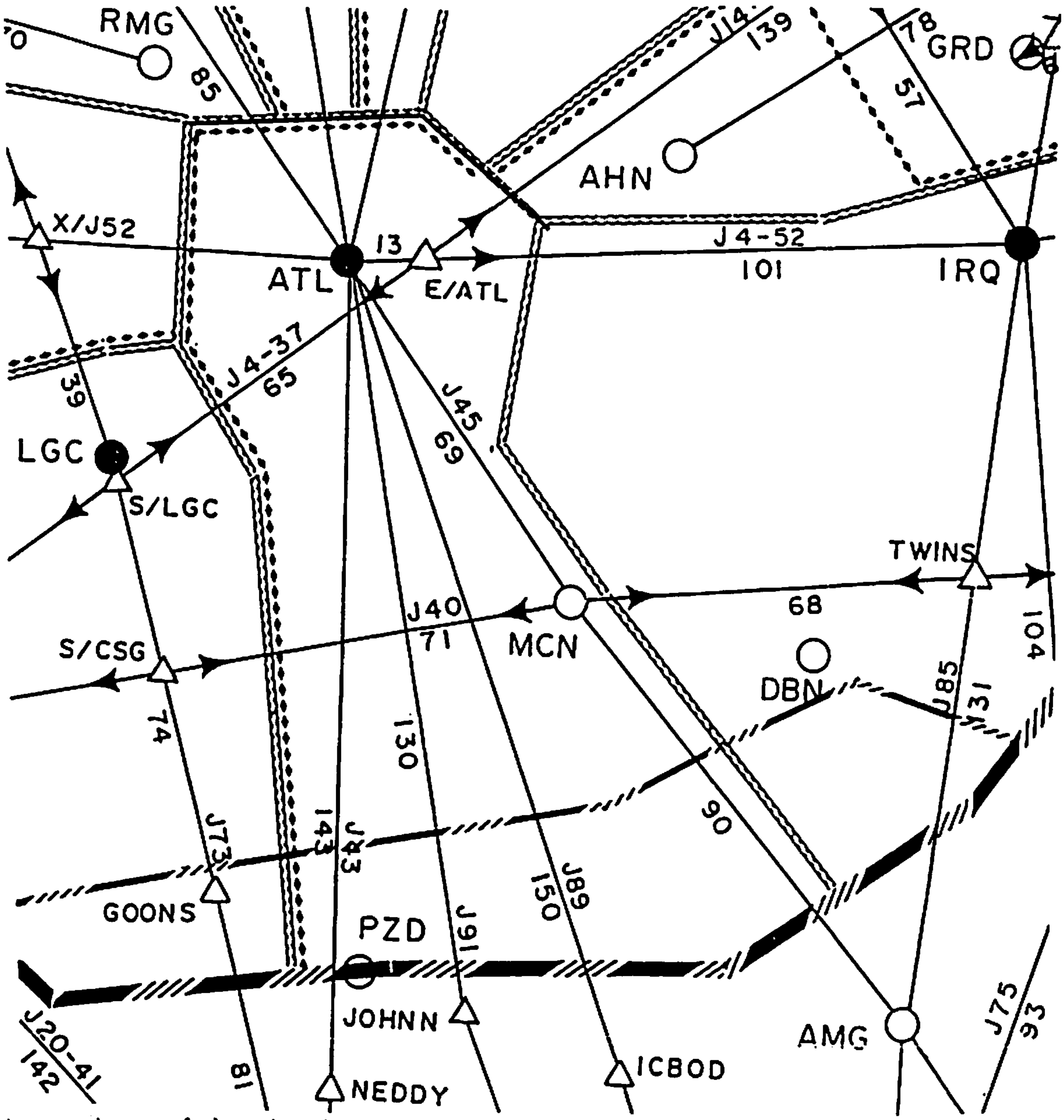


Figure 2. Airspace Diagram for Macon High

EFFECTIVE: 11/28/89

SECTOR 19 - SINCA - Surface - FL230

33 30 30
82 54 30

33 00 00
82 42 00

32 53 15
82 39 45

32 37 15
82 40 07

32 26 50
82 38 45

32 16 40
83 06 00

32 44 00
83 33 40

33 07 45
83 53 40

33 22 00
84 05 15

33 26 15
83 53 00

33 27 50
83 38 00 to point of beginning

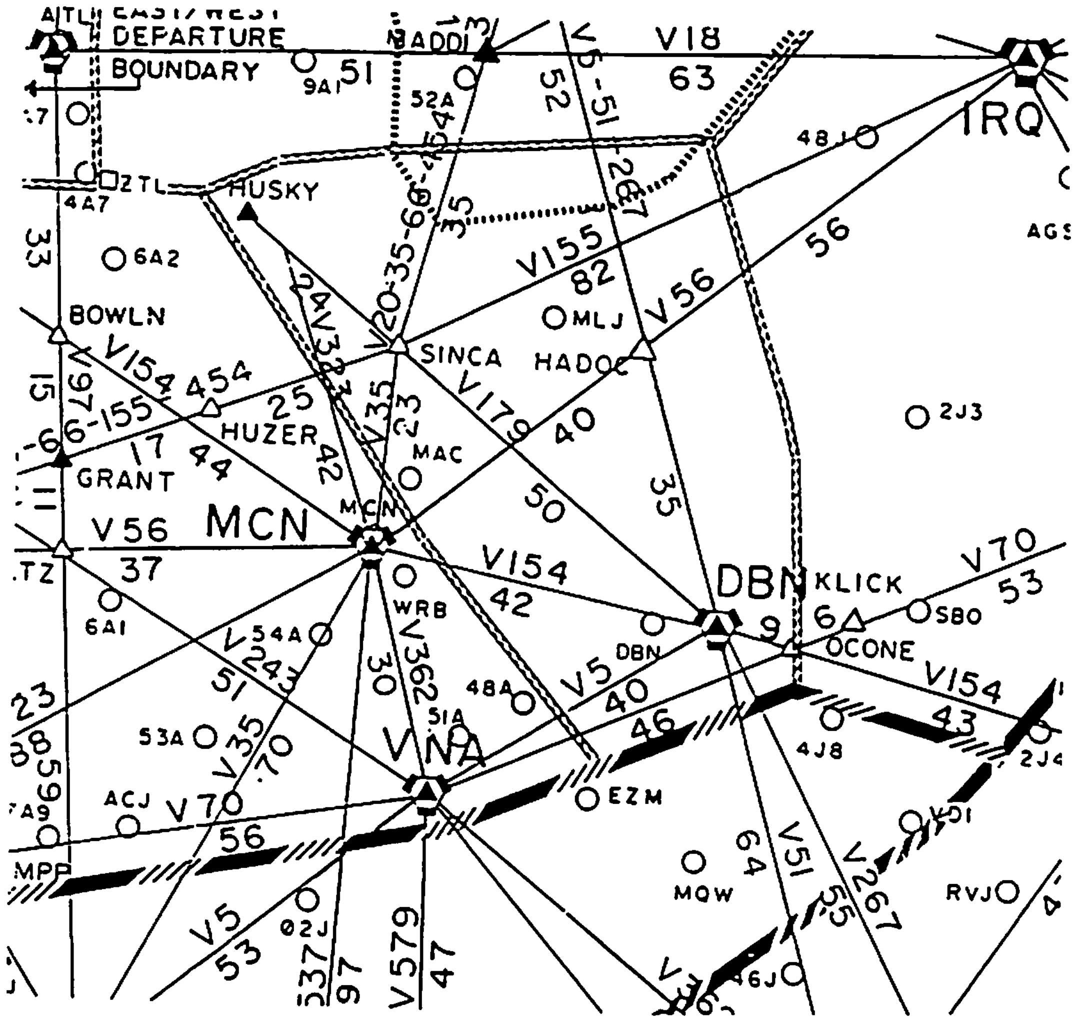


Figure 3. Airspace Diagram for Sinca Low

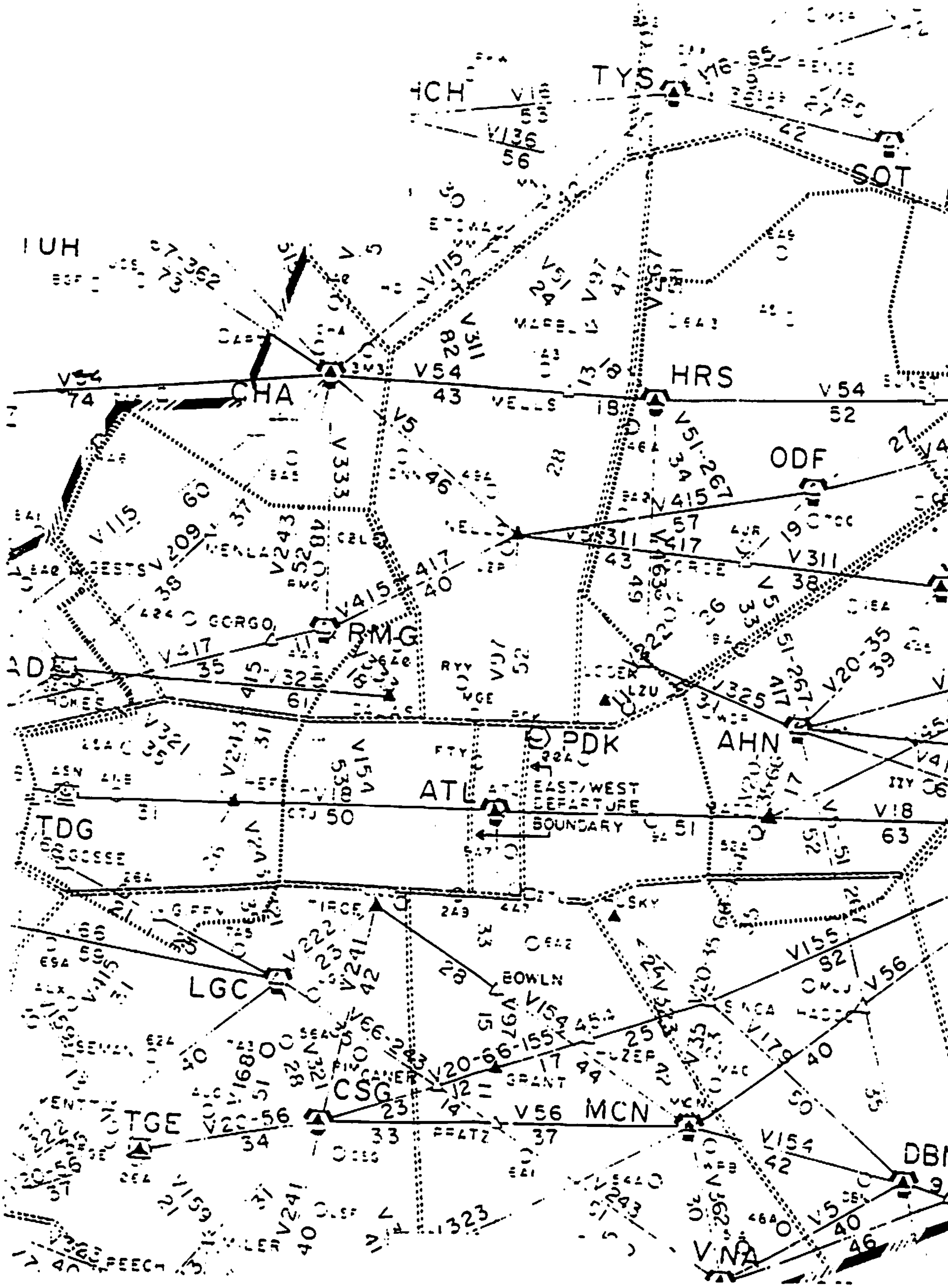


Figure 4. Extended Low Altitude View of Simulated Locations

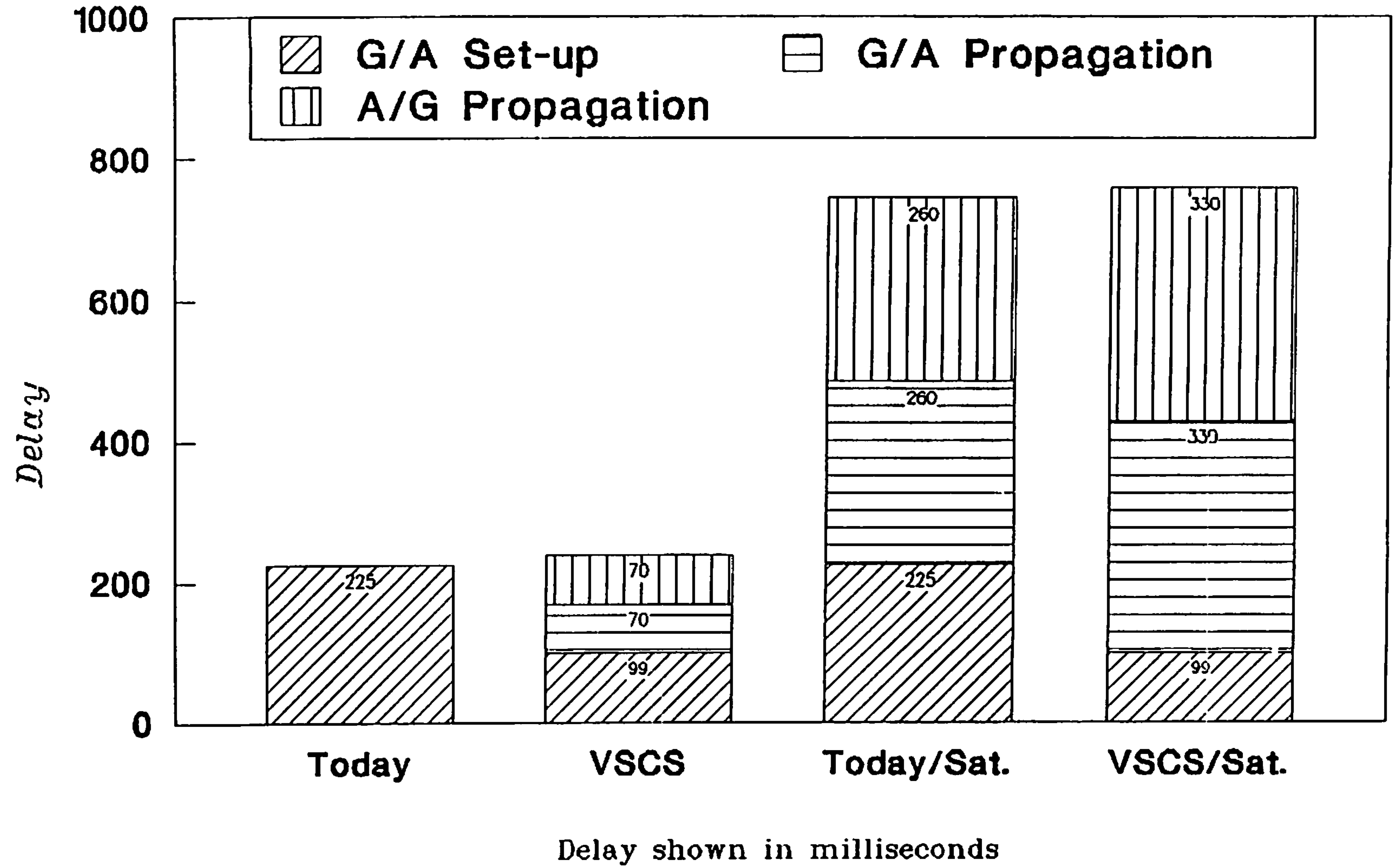


Figure 5. Duration of Delay

2.4.2 Communications Workload

Communications workload levels were based upon traffic load reference values for the three test sectors. The 100% "peak" values were obtained from Atlanta Center. The manner in which these average values were calculated is described in the Test Plan (Appendix A). The 100% reference values for Dublin, Macon and Sinca were 12.0, 10.0, and 12.0, respectively. These values represent the number of aircraft in the sector during a five minute interval.

Three levels of communications workload were developed for the study: "Medium load" was 70%, "high load" was 90%, and "very high load" was 110%. Prior to the study, operations observers (supervisory controllers from Atlanta Center) assessed the realism of the communications load levels. The communications loads were accordingly supplemented with additional pilot calls (e.g., requests for direct routing). Thirteen calls were added for the high load condition and fourteen for very high load. Tables 1 and 2 present the resulting numbers of aircraft and communications at each level of communication workload for the three sectors.

2.4.3 Sector and Subject

The sector variable is intended to capture sector differences. The subject variable is intended to account for differences among the R-controllers.

2.5 Sequence of Test Conditions

The sequence of test conditions is shown in Table 3. Sector assignments, which are described below, are indicated as letters in this table. Each controller team participated in sessions corresponding to one row, and consisted of three pairs (each with an R-controller and a D-controller).

The first session of each week's testing began with a low delay condition (Today or VSCS) to prevent any potential disorientation caused by the high delay conditions from affecting the low delay conditions. Following this session, the 12 combinations of delay and communications workload were presented in an order that would result in the maximum number of sessions between occurrences of the same delay, occurrences of the same communications workload, and occurrences of the same sector assignments. Nonetheless, some conditions were repeated in neighboring sessions.

Three sessions were presented each day, except for the second day of the third week when a fourth session was presented. This fourth session, which was not in the planned sequence of sessions, incorporated the VSCS delay at the very high level of communications workload, with sector assignment "a." It is not shown in Tables 3 and 4. This session, moreover, was added because of equipment problems during the first session.

Table 1. Mean Traffic Density by Communications Workload and Sector

Communications Workload	Dublin High	Macon High	Sinca Low
Medium	7.37	7.48	7.87
High	10.54	10.49	10.17
Very High	13.7	11.13	13.92

Note: Numbers indicate aircraft within the sector over a five minute interval.

Table 2. Mean Communications Activity by Load and Sector

Communications Load		Dublin High	Macon High	Sinca Low
Medium	Per Session	133.50	97.38	164.25
	Per Minute	2.02	1.47	2.47
High	Per Session	210.25	153.25	239.25
	Per Minute	2.98	2.18	3.39
Very High	Per Session	297.33	180.44	275.44
	Per Minute	4.12	2.50	3.81

Note: Communications Activity as indicated by controller microphone keypresses (push-to-talk activity).

Table 3. Sequence of Test Conditions

Team And Week	Session Number								
	1	2	3	4	5	6	7	8	9
1	0VH c	1H a	3M b	2VH a	0H b	0M a	3H c	1VH b	2M c
2	1H c	0M a	2VH b	3M c	0H b	0VH c	2H a	1M b	3VH a
3	1M c	3VH a	2H c	0M b	3H b	0VH c	2M a	1VH b	0H a

The delay conditions are Today (0), VSCS (1), Today+Sat (2) and VSCS+Sat (3). The communication workload conditions are Medium (M), High (H), and Very High (VH). Sets of controller-sector pairings are indicated by the letters a, b, and c. Each cell represents three observations, one at each sector.

2.6 Counterbalancing

2.6.1 Subjects, Delay, and Communications Workload

All of the 28 simulation sessions combined one of four delay conditions (Today, VSCS, Today + Sat, and VSCS + Sat) and one of three communications workload conditions (Medium, High, and Very High). Every delay and load combination was presented twice, except for the three Today delay conditions (one with each traffic load), each of which was presented three times, and the VSCS delay condition at the very high communication workload level, which was also presented three times. Each combination was presented concurrently in all three test sectors.

Every controller worked at the same sector during three sessions, once with each of the three levels of communications workload. Controllers participating during the third week also participated in the added (fourth) session on the second day.

The combinations of delay and communications workload presented to the three teams of subject controllers during their respective test weeks (one team each week) are shown in Table 4. The information in Table 4 can be derived from Table 3.

Table 4. Assignment of Controller Teams to Test Conditions

Team and Week	Communication Workload			Sector Assignment
	Medium	High	Very High	
1	0	1	2	a
	3	0	1	b
	2	3	0	c
2	0	2	3	a
	1	0	2	b
	3	1	0	c
3	2	0	3	a
	0	3	1	b
	1	2	0	c

The delay conditions are Today (0), VSCS (1), Today +Sat (2) and VSCS+Sat (3).

2.6.2 Subjects and Sector

The R-controllers were assigned at random to their first sector, and then rotated from one sector to another according to a pre-arranged schedule. The D-controllers were paired with the R-controllers throughout the week (three days) during which they participated, and rotated with them. The controllers who worked at the non-test sectors remained at those sectors for the entire week.

The sector rotation schedule consisted of three sets of controller-sector pairings. In the first set ("a" in Tables 3 & 4), R-Controller 1 was assigned to Sector 1, R-Controller 2 to Sector 2, and R-Controller 3 to Sector 3. In the second set ("b" in Tables 3 & 4), R-Controller 1 was assigned to Sector 2, R-Controller 2 to Sector 3, and R-Controller 3 to Sector 1. In the third set ("c" in Tables 3 & 4), R-Controller 1 was assigned to Sector 3, R-Controller 2 to Sector 1, and R-Controller 3 to Sector 2. The three sets of sector assignments are summarized in Table 5.

Table 5. Assignment of Controllers to Sectors

Assignment	R Controller No.	Sector
a	1	1
	2	2
	3	3
b	1	2
	2	3
	3	1
c	1	3
	2	1
	3	2

2.7 Dependent Variables

Three categories of dependent variables were chosen:

(1) controller stress

(2) system performance

(3) communications disruption

The stress category consists of the demands made on the attention of the controller, stress itself, and overcontrol, i.e., acting on the problems too early.

System performance includes separation infringements, the number of aircraft handled, and smoothness of air traffic flow. Separation infringements are violations of aircraft proximity standards. Aircraft are said to be "handled" following contact by the controller. Smoothness of air traffic flow is defined by the extent of any disruption in the orderly movement of aircraft.

Communications disruption consists of step-ons, corrected verbal mistakes, and uncorrected verbal mistakes. Step-ons are defined as overlapping transmissions. Corrected and uncorrected verbal mistakes include such events as uttering incorrect call signs or frequencies. Corrected mistakes are those corrected in the same transmission; uncorrected mistakes include those corrected in a later transmission and uncorrected mistakes. Section 2.10.3 elucidates the manner in which data relating to the dependent variables was collected.

2.8 Equipment

2.8.1 Facility

The test bed consisted of three elements of the FAA Technical Center: the En Route System Support Facility (ESSF), the Host Computer System Support Facility (Host SSF), the NAS Simulation Support Facility (NSSF), and the AMECOM communications system.

The Host SSF consisted of processing and peripheral support equipment which is identical to present en route center equipment, especially the IBM 3083 central processor and its direct support units and peripheral devices, their interfaces and processors. Keyboards, displays, terminals, and printers were all identical to current field equipment. Software was identical to that used in real en route centers for both actual operations and data collection and analysis. A 9020E computer (IBM 360/65) was used as the display channel processor for the generation of surveillance plan view information and other alphanumeric data on plan view (simulated radar) displays (PVDs).

The NSSF Controller Laboratory consisted of processors, interface equipment, and displays to perform three major simulation functions: (1) the generation of flight paths, plans, and strips for simulated aircraft, (2) the scripted prompting and direction of simulator pilots to fly those flight paths and interact with the controllers and (3) the generation of the targets and associated alphanumeric data to the Host SSF as simulated radar data inputs.

The AMECOM communications system consisted of audio communication control, distribution and recording configured to provide the operational intercom, interphone, and air-ground inter-sector and intra-sector communications among controllers, and between controllers and simulation pilots. Digital recordings of controller microphone keying (push-to-talk switch actions) and channel selections, as well as analog recordings of receptions and transmissions by each controller, were provided.

The AMECOM system was modified to provide time-coordinated and allocated transmitter turn-on and propagation delays. It was further modified to provide an auditory cue to controllers, corresponding to a side-tone change in received audio when the transmitter was enabled. All delay effects and values were independently controlled and calibrated prior to each session.

As in actual ATC communications, when either the controller or pilot keyed the microphone, others transmitting on the same "frequency" became inaudible. Thus each of the pilots assigned to the same sector (and communications channel) could hear all of the communications on that channel except when that pilot's microphone was keyed. However, unlike the real world, pilot-pilot step-ons did not result in a distracting squeal and blocking; rather, the two voices could both be heard.

The simulated sector frequencies (e.g., 111.1) were realistic, but not the same as those used at Atlanta Center. These "frequencies," which were used to realistically transfer aircraft between sectors, designated the intercom channels connecting the controller and pilot positions. [2]

2.8.2 Data Recording Equipment

Each of the observers used a Radio Shack 100 lap-top computer programmed for recording step-ons and mistakes. These events and the time of each entry were recorded by single keystrokes. A map light was attached to each lap-top so that its screen could be read in the realistically dim light without causing glare on the PVD. Voice recordings of all pilot and controller voice communications (by sector) were made with cassette tape recorders from observer positions in the pilot laboratory. Data was also recorded by the simulation computer system. This data included numbers of aircraft handled, controller transmissions, and separation infringements.

2 See for further details *FAA National Airspace System En Route System Support Facility Laboratory Handbook.* NASP-5204-04, 1989

2.8.3 Simulation Scenarios

Scenarios representing the three levels of communications workload differed primarily because of flights added to the high and very high load scenarios. Scenario development involved acquisition and adaptation of data on actual Atlanta Center traffic. Scenarios were constructed for typical conditions in the test sectors. Events that occur less than once per month, such as emergency lifeguard flights and other emergencies, were not included. Weather incidents were also left out. Supervisory controllers from Atlanta Center (the operations observers) assisted with scenario development.

2.9 Personnel

Information concerning the communications workload and delay conditions was not revealed to the participants or observers. All were told that the tests were being conducted to investigate the effects of equipment delays.

2.9.1 Controllers

Nine test sector R-controllers participated as subjects in the study, three each week. They all had at least two years of FPL experience, with a mean of 5.9 years, working at the Atlanta ARTCC area containing the corresponding actual sectors. They were current and qualified on those sectors. Nine other controllers (three each week) from other areas of the same ARTCC were paired with the R-controllers to serve as D-controllers. In addition, six Atlanta Center controllers (two each week) worked at the two non-test sectors during the simulation. Former controllers assisted at the non-test sectors and the aircraft termination sector. The sectors and personnel are shown in Figure 6.

The test sector controllers were acquainted with features of the simulation prior to their first session so that irrelevant differences would not interfere with their performance. In this initial briefing they were told, for example, about sector "frequencies," rates of simulated climb and descent, and the operation of the aircraft termination sector.

2.9.2 Simulation Pilots

Thirty trained non-pilot personnel participated in the role of pilots. A former commercial airlines pilot supplied additional instruction for this simulation. Seven pilot positions were established for Dublin High and Macon High, and ten for Sinca Low. Six pilots staffed the non-test sectors.

2.9.3 Operations Observers

The operations observers were three supervisory controllers from Atlanta ARTCC who were currently specializing in areas other than the one containing the test sectors. Each had at least five years of experience in air traffic control work, with a mean of 13.3 years. These controllers were familiar with the simulation from having assisted with scenario development, and participated in the initial briefings of the test sector controllers. They also participated in the development of the questionnaires.

Prior to the first simulation session, the operations observers were randomly assigned to a sector, where they remained throughout all three weeks of simulation testing. They reviewed definitions of the events they were to record just prior to the beginning of the first simulation session and any questions about the event categories were answered at that time. These measures were taken to assure consistent data recording.

Figure 6. Simulation Sectors and Personnel

2.9.4 Communications Observers

Three trained observers in the NSSF Pilot Laboratory listened through earphones to all of the communications within the pilot laboratory and between the pilot and controller laboratories. Each was assigned at random to a sector prior to the tests, and remained there throughout all of the simulation testing.

2.10 Procedure

2.10.1 Test Sessions

The simulated air traffic was to be controlled as it would have been in an actual operational environment. The R-controllers handled all of the communications with pilots, while all ground-to-ground communications were to be handled by the D-controllers.

The pilots in each sector made scripted calls to the controller through headset microphones. The message content and time of these scripted pilot calls were provided on the pilots' visual display units. The pilots were instructed to respond rapidly, but to refrain from speaking when another voice could be heard. They controlled the simulated aircraft by entering commands on a keyboard.

It was anticipated that the simulated air traffic would build gradually to its assigned level, with higher levels requiring more time. Thus, lengthier simulation sessions were provided at the higher traffic loads so that sessions with all three traffic loads would be at their assigned levels for approximately the same time.

The simulation sessions ranged in duration from 61 min. to 82.5 min., with a scheduled half hour break between sessions. Sessions corresponding to the four delay combinations lasted for means of 69.33 min. (Today), 70.00 min. (VSCS), 70.17 min. (Today + Sat), and 72.2 min. (VSCS + Sat). Sessions corresponding to the three communication workload levels lasted for means of 66.62 min. (medium), 70.75 min. (high), and 72.7 min. (very high).

2.10.2 Pilot Contention

Realistic contention among pilots for a busy communication channel and hence realistic estimates of pilot-controller step-ons requires a one-to-one correspondence between pilots and aircraft. The assignment of several pilots to each sector was intended to increase contention for access to the communications channels. Seven pilots were assigned to both Dublin High and Macon High; ten were assigned to Sinca Low. In addition, pilots in the same sector were assigned to alternate seats to mask visual cues to communications channel use.

Aircraft entering a sector were assigned to the pilot with the fewest aircraft. Up to twenty, seventeen and nineteen aircraft per five minute interval were handled in Dublin High, Macon High and Sinca Low, respectively. Therefore, pilots in Dublin and Macon were responsible for no more than three aircraft simultaneously, while those in Sinca were responsible for no more than two[3].

3 These maximum aircraft-to-pilot ratios were obtained by dividing the highest number of aircraft in each sector per five minute interval by the number of pilots in the sector. Average aircraft-to-pilot ratios can be obtained by dividing the mean traffic density values given in Table 1 by the corresponding number of pilots per sector.

2.10.3 Data Collection.

Communications between the pilot and controller positions were monitored from the NSSF Pilot Laboratory by the three communications observers, each of whom listened through headphones to communications in a different one of the three test sectors (Figure 7). The communications observers recorded pilot-pilot, pilot-controller, and controller-pilot step-ons. The location of their headphone connections enabled them to hear all of the communications in their respective sectors regardless of whose microphones were keyed. Taped voice recordings were later used to verify their data.

Their location in the NSSF Pilot Laboratory caused the communications observers to hear (and tape) controller communications following the relevant delay and pilot communications without the delay. For this reason some pilot calls were heard to arrive first when the controller was in fact the first to transmit. The controller-pilot and pilot-controller step-on categories were accordingly merged into a single "pilot-controller/controller-pilot" step-on category.

The communications observers in the NSSF Pilot Laboratory could hear all of the step-ons, but the step-ons recorded by the operations observers in the Enroute Laboratory were limited to controller-pilot step-ons caused by the controller keying the mike during the reception of the pilot message, and pilot/pilot step-ons occurring when the controller's mike was not keyed. The operations observers could not hear pilot-controller or pilot-pilot step-ons when the controller's mike was keyed or controller-pilot step-ons caused by the controller keying the mike during the delay interval of an incoming pilot message. For this reason the number of step-ons recorded by the communications observers in the Pilot Laboratory may differ from those recorded by the operations observers in the Enroute Laboratory. The accurate counts of step-ons made in the Pilot Laboratory are used for the analysis of the delay effects.

In the Enroute Laboratory an operations observer was positioned in front of each sector, observing the PVD and listening to the communications channel used by the radar controller (Figure 8). The operations observers recorded the number of callbacks each step-on required and verbal mistakes made by the R-controller. Mistakes were classified according to whether they were corrected in the same transmission or not. Step-ons were classified by the number of additional calls needed to communicate the blocked message. A step-on could require zero, one or two callbacks. Pilot-pilot step-ons required fewer callbacks than would be needed in actual operations because, as noted, the simulation did not produce blocking. For this reason these data underestimate the real world number of additional calls caused by step-ons. They are used as an indication of the additional communications workload caused by step-ons in the simulation.

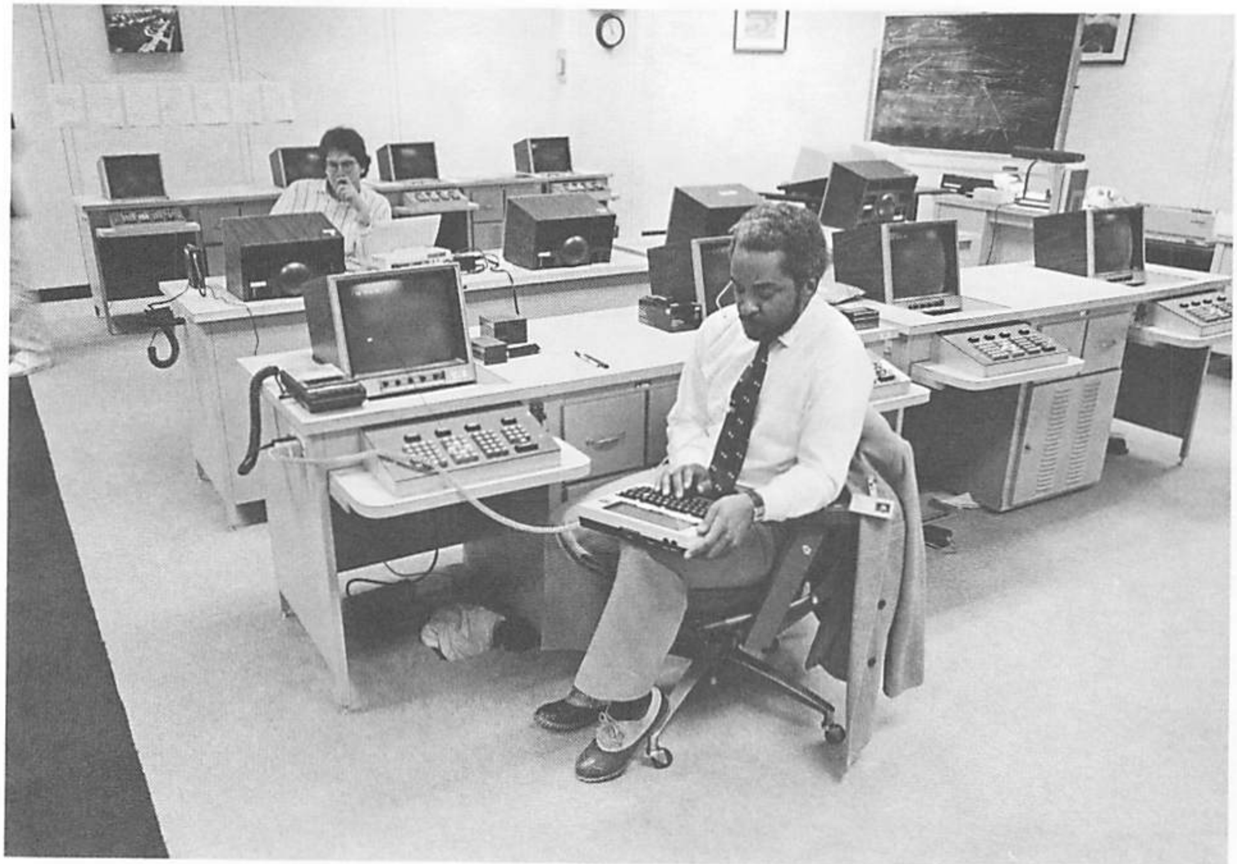


Figure 7. Communications Observer and Data Recording Equipment

Figure 8. Operations Observer and Data Recording Equipment

Certain data were automatically recorded by the computer system. These included the number of separation infringements and counts of aircraft handled. Separation infringements were defined for the study as occurring when two aircraft had a horizontal separation of less than five miles and a vertical separation of less than 1950 ft. if either aircraft was above Flight Level 290 (29,000 ft. altitude), or 950 ft. vertical separation if both were at or below Flight Level 290. This condition had to persist continuously for 24 secs. for one infringement to be counted for a pair of aircraft. Both of the conflicting aircraft also needed to be within one or more test sectors for the infringement to be counted. Aircraft were counted as "handled" following contact between pilot and controller.

Questionnaires were completed immediately following each session by both controllers and operations observers. These instruments were used to record a variety of subjective impressions of the preceding session, including perceptions of controller stress, the amount of attention or concentration required during the preceding session, smoothness of traffic flow, realism of the simulation, and other information. The questionnaires are presented in Appendix D.

3. Results

3.1 Overview

The primary results of interest were the effects of delay on communications disruption, particularly step-ons. Effects of delay on stress, verbal mistakes, and system performance probably result from step-ons, so the analysis of these effects is likely to be less sensitive than the analysis of step-ons.

The test of system performance degradation depends to a large extent on our ability to detect changes in the frequency of separation infringements. These infringements occur very infrequently in the real world. It would take a very major change in the frequency of infringements due to communication delay to be statistically significant.

Changes in stress are readily measurable but in this simulation the level of stress and workload is due directly to aircraft handled and is only an indirect side-effect of communications disruptions, particularly step-ons.

Controller-pilot and pilot-controller step-ons may result from any type of communication delays if they are of sufficient magnitude. Step-ons are likely to result in losses of information which necessitate repeated transmissions. They may thereby subject the controller to increased workload and brief lapses or redirection of attention. Also, critical communications may be lost when there is insufficient time for the blocked information to be retransmitted.

Communications Disruption

VSCS - No statistically significant increases in communications disruptions were found which could be attributed to simulated VSCS delays.

Satellite - Step-ons - More pilot-controller/controller-pilot step-ons were recorded for satellite conditions than non-satellite conditions. The greatest increases were between the satellite and non-satellite conditions at the highest (very high) workload; these were statistically significant. The smaller increases in step-ons found between satellite and non-satellite conditions, recorded at the medium and high communications workload, approached significance.

In Macon High (a sector which had much lower communications rates at all workload levels than Sinca Low and Dublin High) there were no significant differences in step on rate between satellite and non-satellite conditions.

Satellite-Verbal mistakes - No significant differences in verbal mistakes were found between satellite and non satellite conditions.

Controller Stress

VSCS and Satellite - No statistically significant differences were found in measures of stress, effort, or attention between any of the delay conditions, VSCS or Satellite.

System Performance

VSCS and Satellite - No statistically significant differences were found in measures of separation infringements or numbers of aircraft handled.

The following sections describe the results of the statistical analyses and the constraints and limitations on their interpretation. The results of the measures of communications disruptions and system performance are described first, followed by controller and operations observer ratings of controller stress. Table 6 presents the abbreviations used in the following tables and appendices. Tables 7, 8, and 9 show the results for the main dependent variables. Table 8 shows effects of delay. Table 9 shows the effect of communications workload. Appendix C contains a discussion of the statistical checks to ensure the validity of the simulation. A discussion of the analysis procedures can be found in Appendix E. Appendix F contains the output of the statistical program upon which the description of the results is based.

Table 7 shows the statistical significance of the regression analyses. The independent variables and interactions of interest are in the column headings of the table; the dependent variables are in the row headings. The cells contain values each representing the probability that a difference in a particular dependent variable is due to chance rather than a systematic effect. For example, the .0001 at the intersection of Load and CM indicates the probability that differences in corrected verbal mistakes among the three communications load conditions are due to chance. The two columns under Model indicate the probability that all differences in the analysis of a particular dependent variable are due to chance (Prob) and the proportion of the variation in the data for a particular dependent variable that is captured by all of the independent variables in the analysis (R-Sqr). Tinted cells contain probability values that indicate statistically significant differences. The choice of $p < .01$ for significance reflects the large number of comparisons that are made in each regression analysis.

Table 6. Nomenclature

STEPS:	Step-Ons	Pilot blocks controller transmission or controller blocks pilot transmission.
PP:	Pilot - Pilot Step-Ons	Pilot blocks pilot transmission.
CM:	Corrected Mistakes	Controller corrects mistake in same transmission to pilot.
UM:	Uncorrected Mistakes	Controller makes uncorrected mistake in transmission to pilot.
S0:	Step-Ons	Step-on not requiring message repetition because the pilot's message could be understood despite step-on.
S1:	Step-Ons	Step-on requiring one repetition because a pilot's message could not be understood.
S2:	Step-Ons	Step-on requiring two repetitions because neither pilot's message could be understood.
COM:	Push-to-Talks	Communication activity as measured by number of controller push-to-talks (microphone activations).
NPLANES:	Number of Planes	Number of aircraft handled.
PROX:	Separation Infringements	Two aircraft with insufficient separation.

Note: STEPS and PPs were recorded in the NSSF Pilot Laboratory. S0s, S1s and S2s were recorded in the En Route Laboratory.

Table 7. Regression Analyses of Objective Measures

MEASURE	SUBJ	DELAY	LOAD	SECTOR	D*S	D*L	MODEL	
							PROB	R-SQR
STEPS	.4672	.0011	.0001	.0081	.1307	.0454	.0001	.669
PP	.1401	.7370	.0038	.2497	.4014	.7274	.1351	.420
CM	.0001	.9502	.0001	.0001	.8458	.8338	.0001	.723
UM	.0496	.2981	.0249	.0610	.9321	.0295	.0114	.514
S0 + S1 + S2	.0288	.0258	.0001	.0001	.4153	.0188	.0001	.747
NPLANES	.1505	.3201	.0001	.0001	.9967	.0262	.0001	.872
PROX	.7284	.9856	.0132	.0498	.5219	.7264	.1817	.454

Note: Tinted cells indicate $p < .01$.

Table 8. LS Means of Objective Measures by Delay

Measure	Delay			
	Today	VSCS	Today / Sat.	VSCS / Sat.
STEPS	2.190	2.369	4.944	4.833
PP	1.413	1.471	1.667	1.167
CM	2.94	3.28	3.00	3.11
UM	0.266	0.600	0.778	0.333
S0 + S1 + S2	3.14	2.93	4.74	3.50
COM	194.16	190.80	191.06	194.30
NPLANES	42.30	44.30	44.83	43.73
PROX	0.532	0.522	0.556	0.444

Table 9. Means of Objective Measures by Communications Load

Measure	Communication Load			
	Medium	High	Very High	All
STEPS	1.70	2.37	6.07	3.38
PP	0.74	1.52	1.93	1.40
CM	1.26	3.19	4.74	3.06
UM	0.07	0.59	0.67	0.44
S0 + S1 + S2	1.59	3.33	5.33	3.42
COM	131.71	200.92	251.07	196.80
NPLANES	34.19	45.88	53.48	45.32
PROX	0.286	0.292	1.000	0.556

3.2 Limitations on the Results

A number of factors inherent in the simulation limited the sensitivity of the study. Thus small differences which approached significance in the study might have been reached the threshold of statistical significance in a longer study.

As noted in section 2.8.1 pilot-pilot step-ons in the simulation did not produce blocking. For this reason the data underestimate the real world number of additional call-backs caused by step-ons.

When a pilot-pilot step-on occurs in the real world both transmissions are blocked and the controller hears a distracting squeal. Lack of a squeal may have reduced the stress experienced by the controllers.

The sensitivity of the analysis of separation infringements is restricted by the number of sessions possible in the study. In the real-world so few infringements occur that meaningful statistical analysis is very difficult.

3.3 Communications Disruptions

3.3.1 Step-ons

Data for the analyses of step-ons were recorded by the communications observers. Retransmission (callback) data was recorded by the operations observers.

Pilot-pilot step-ons - Multiple regression analyses found no statistically significant effects of delay on pilot-pilot step-ons. Examination of the LS (least square) means did not indicate increased pilot-pilot step-ons in any of delay conditions (see Table 10). No delay effects were expected because calls made by one pilot were heard by another with no delay.

Table 10. Pilot-Pilot Step-Ons (LS Means)

	Delay			
Load	Today	VSCS	Today+Sat	VSCS+Sat
Medium	0.89	0.52	1.37	0.11
High	1.33	1.61	2.02	1.21
Very High	2.02	2.28	1.61	2.18

Controller-pilot/pilot controller step-ons - The regression analysis indicated that there was a statistically significant effect of delay and a statistically significant delay by communications workload interaction. The effect of subject was statistically non-significant. A Tukey HSD analysis was conducted to compare the individual cells. It revealed that there were significantly more controller-pilot/pilot controller step-ons in either of the very high communication workload satellite delay conditions than in either of the very high communication workload non-satellite delay conditions (see Figure 9).

An initial regression analysis found no statistically significant differences ($p > .25$) for comparisons at medium and high communication workload of all satellite vs non-satellite conditions. A second analysis suggested by the data compared both of the satellite conditions with both of the non-satellite conditions, and dropped comparisons at very high workload . This procedure, which increased statistical power, led to differences that approached statistical significance at $p=.04$. Taken as a whole the analyses confirm neither the presence nor the absence of a statistically significant effect of satellite delay at the medium and high levels of communications workload.

VSCS - The differences between Today and VSCS, and between Today + Satellite and VSCS + Satellite, were attributable only to chance variation in the subjects' performances, rather than any delay effects . P-diffs, which show the probability that the difference between a pair of conditions is due to chance, are presented in Table 11 for all of the comparisons between conditions with VSCS and conditions without VSCS. The P-diffs show that there is no suggestion of a significant difference between any of the conditions with VSCS and the conditions without VSCS.

At the very high level of communications workload:

- The Today delay resulted in an LS mean of 3.90 step-ons, the VSCS delay resulted in an LS mean of 3.29 step-ons.
- The Today + Sat delay resulted in an LS mean of 9.75 step-ons.
- The VSCS + Satellite delay resulted in an LS mean of 9.07 step-ons.

At the very high level of communications workload:

- The addition of satellite delays to the Today delay condition resulted in a 150% increase in controller-pilot/pilot-controller step-ons.
- When added to the VSCS delay condition, satellite delays resulted in a 176% increase in this type of step-on.

At the medium and high levels of communications workload:

- The increase in step-ons from non-satellite to satellite delays evident in Figure 9 approached significance, but cannot be confirmed as statistically significant given the limited sample size possible in this study.

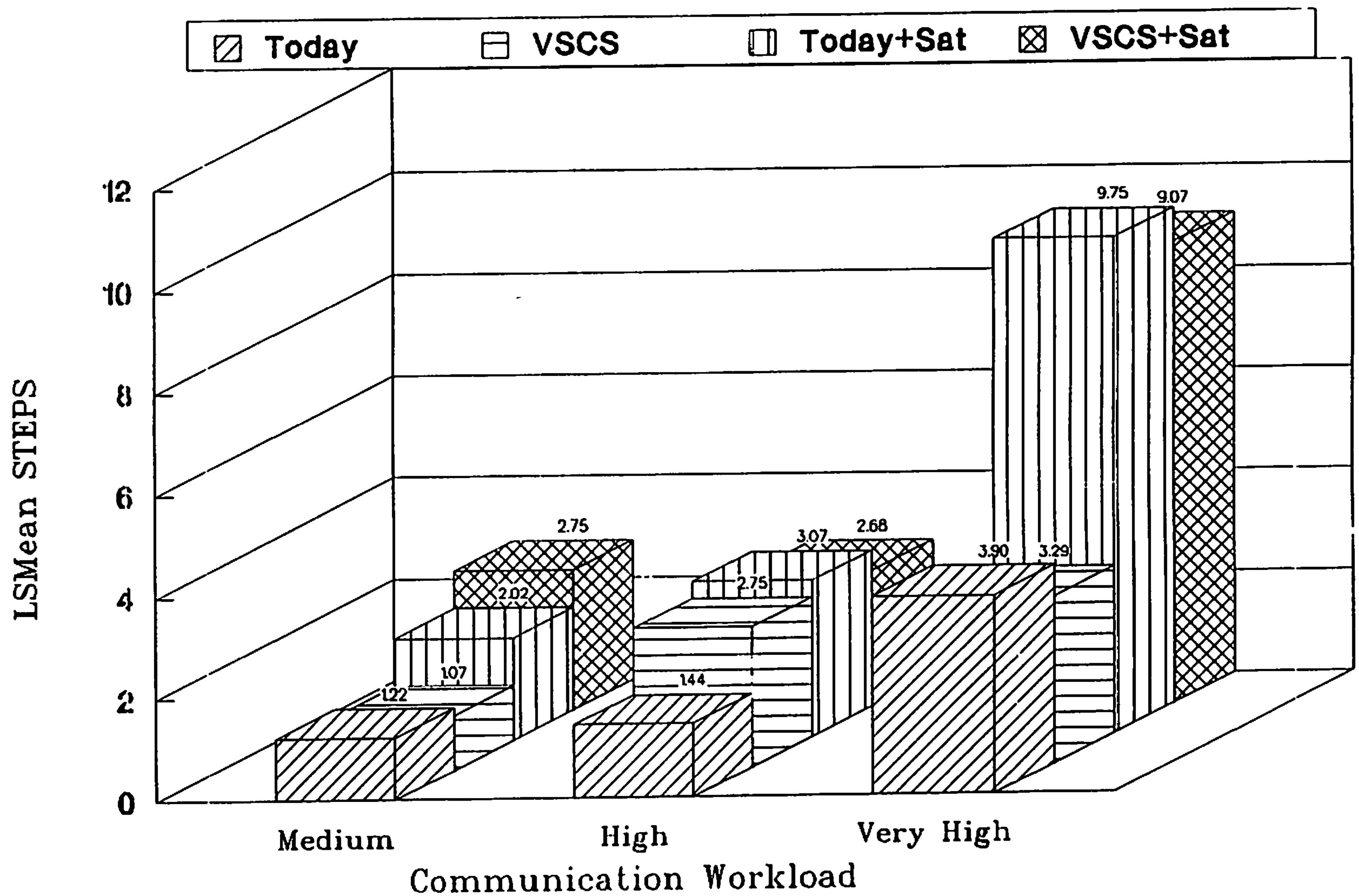


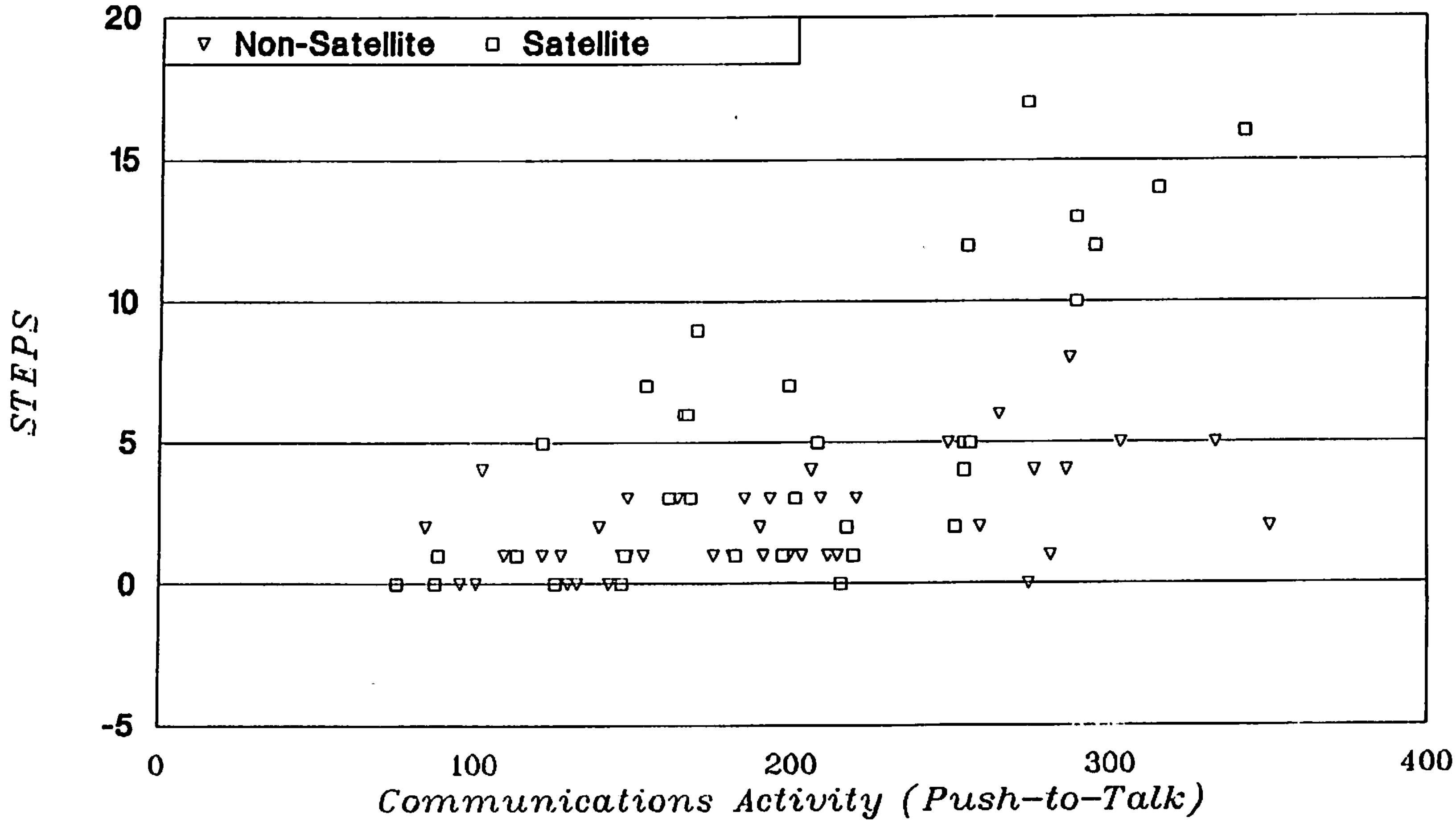
Figure 9. LS Mean Steps vs. Delay and Communications Workload

Table 11. Chance Probability Values for Steps with and without VSCS.

		Today vs. VSCS	Today+Sat vs. VSCS+Sat
Sector	Dublin	.98	.81
	Macon	.76	.18
	Sinca	.95	.37
Communication Workload	Medium	.91	.65
	High	.37	.81
	Very High	.68	.67
Overall		.83	.90

Step-ons as a function of communications activity - The design used in this study manipulated communications work load by changing air traffic levels. The assumption used was that high traffic loads would result in high communications workloads. This was true; however, the levels of traffic (medium, high, very high) generated different levels of communications activity, i.e., microphone push-to-talk keying for the different sectors for the same levels of traffic. In particular much lower levels of communications activity or workload were found for the Macon High simulation than for Sinca Low and Dublin High (see Table 2).

The number of push-to-talks per session was used as an analog of communications workload in sector analyses of controller-pilot/pilot-controller step-ons. Before discussing the sector data it is important to examine the relationship between push-to-talks and step ons for all sectors combined. Figure 10 is a scatter plot where the number of step-ons is plotted against the push-to-talks per session. The triangles represent the non-satellite delay conditions, the squares the satellite delay conditions.



STEPS are controller-pilot and pilot-controller. Non-satellite includes Today and VSCS. Satellite includes Today+Sat. and VSCS+Sat.

Figure 10. Scatterplot of Steps vs. Communications Activity

At almost all levels of push-to-talk activity the step-on rates appear to be higher for the satellite conditions than for the non-satellite conditions. Figure 11 is the same data aggregated into three levels of push to talk; in each sub-group the satellite delay step-ons are approximately two to three times as high as the non-satellite step-ons. Examination of Figures 12, 13 and 14 indicate that this relationship is found both for Sinca Low and Dublin High, but not for Macon High. This may be because the simulated traffic loads for Macon High produce much less communications activity than those for the other two sectors.

Re-transmissions (Callbacks) - The operations observers' counts of step-ons were also subjected to a multiple regression analysis. The effect of delay on the number of step-ons approached statistical significance ($p = .026$) as did the interaction of delay with communications workload ($p = .019$). The effect of communications workload and variation due to sector were statistically significant. Table 8 shows more step-ons due to satellite than non-satellite delay conditions. While these data could differ from those collected in the Pilot Laboratory, as explained in section 2.10.3, the results are generally consistent (in any event the Pilot Laboratory data are to be considered the more accurate).

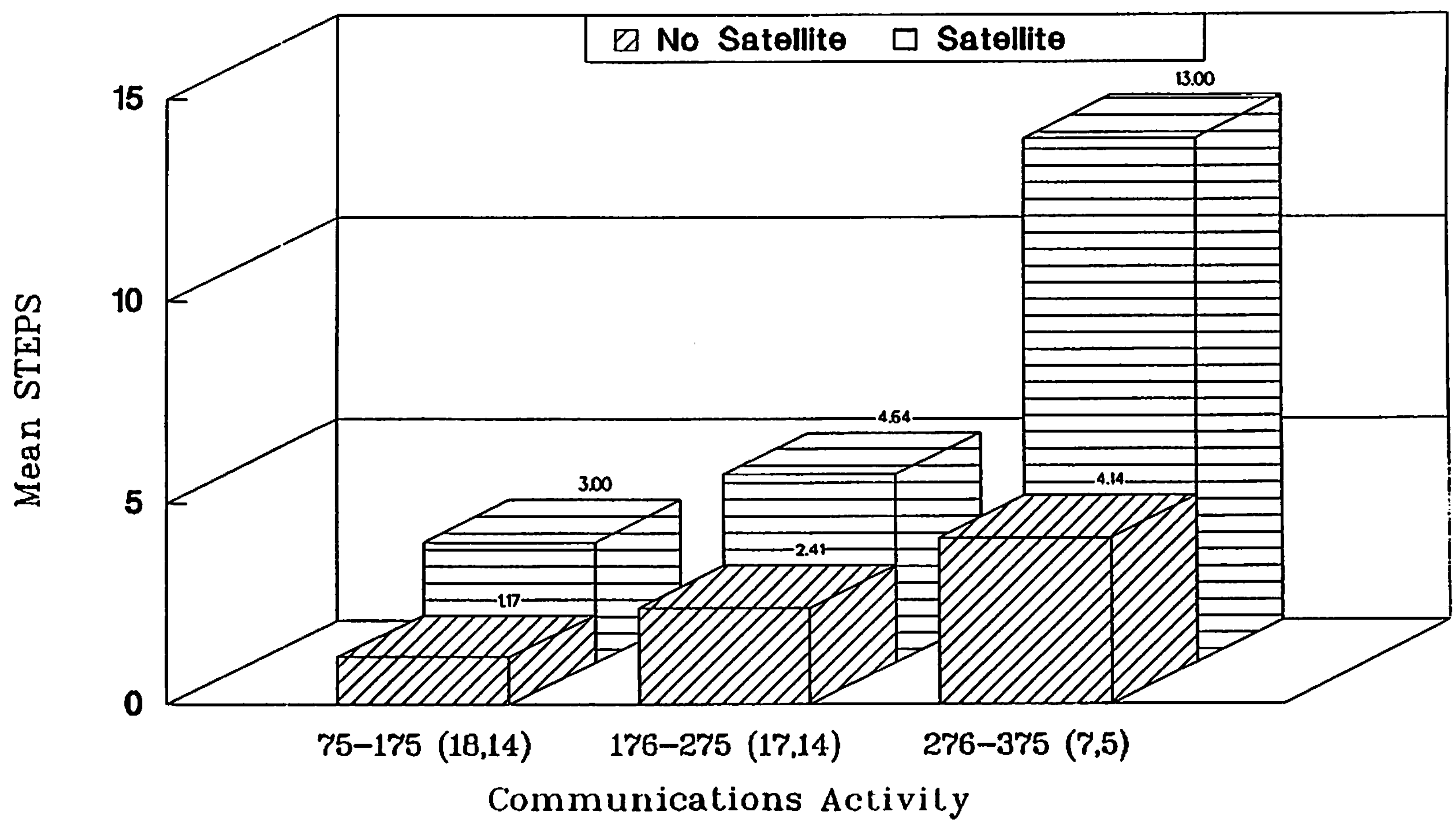
These data are used to assess the additional communications workload caused by step-ons in the simulation. One of the likely effects of step-ons is the need for the sender to retransmit information which might have been lost due to the step-on. At worst, step-ons can generate callbacks that would themselves be blocked by further step-ons. Three categories of step-on were recorded by the operations observers depending on the number of additional calls made.

The mean numbers of step-ons requiring zero, one, and two additional calls were 1.67, 1.70, and 0.06, respectively, per session and per sector. These results mean that 48.7% required no additional calls, and 49.6% of the step-ons required one additional call. Only 1.7% of the step-ons required two additional calls. Thus, on the average, a stepped-on message required 0.53 additional calls. As noted in section 2.10.3, the number of call backs required due to blocking during the simulation were probably less than those which would occur in the real-world because the simulation did not include blocking during pilot-pilot step-ons.

3.3.2 Corrected and Uncorrected Verbal Mistakes.

Operations observers recorded the R-controllers' corrected and uncorrected verbal mistakes. Neither showed a statistically significant effect of delay, regardless of whether the mistakes were analyzed separately or together. Figure 15 depicts the results for corrected mistakes. The values corresponding to Figure 15 are shown in Table 12. The regression analysis of the corrected mistake data shows that communications workload, sector, and subject all affected this dependent variable.

Whereas corrected verbal mistakes were those corrected in the same transmission as the mistake, uncorrected mistakes included those corrected in a later transmission as well as those that were not corrected. The effect of communications workload on uncorrected mistakes approached significance ($p = .025$). However, there were too few uncorrected mistakes (only 36 in the entire study) to anticipate statistically significant results.



Numbers in parentheses indicate the number of observations for the No Sat and Sat conditions respectively

Figure 11. Steps by Communications Activity Grouping

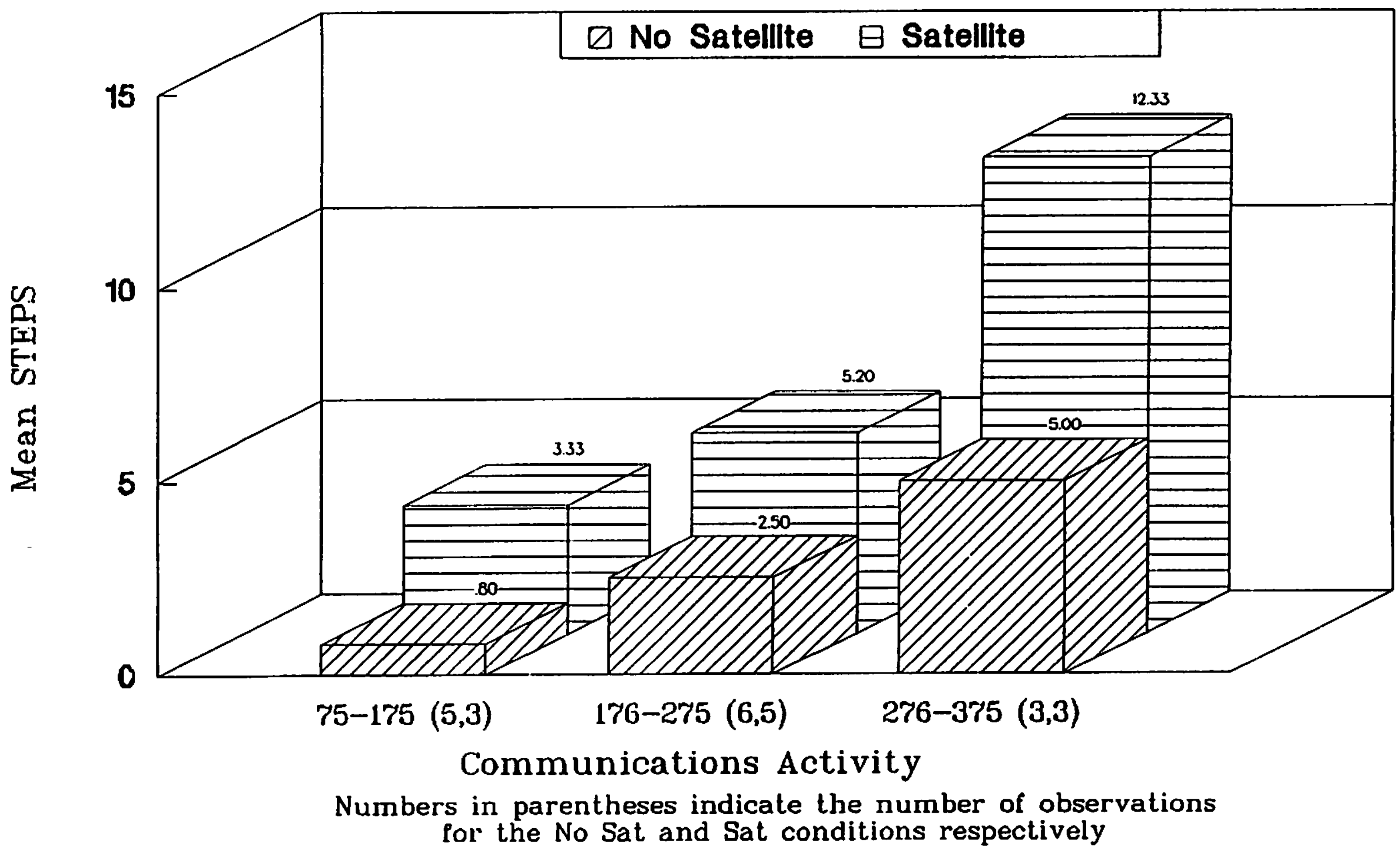


Figure 12. Steps by Communications Activity Grouping for Dublin High

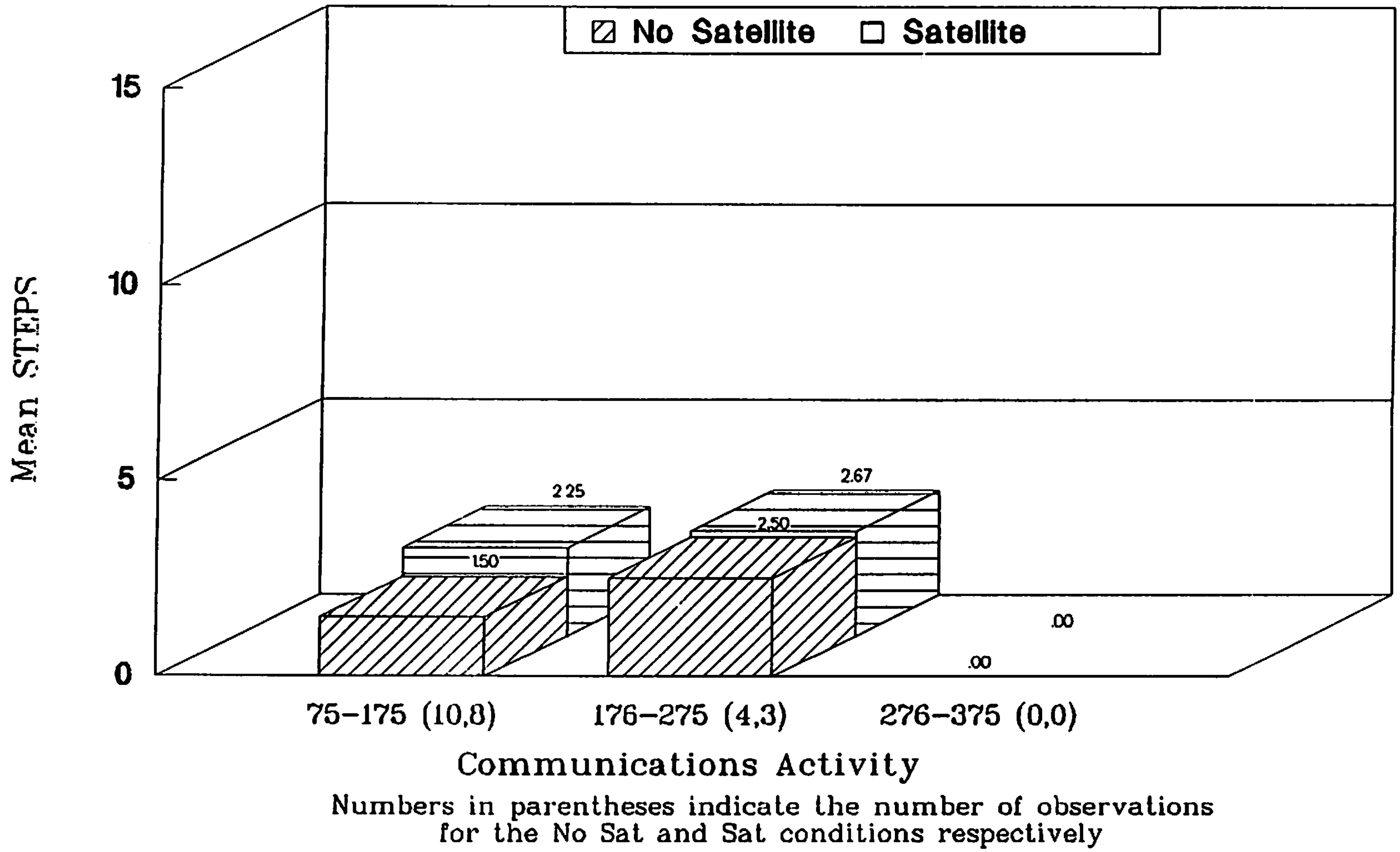


Figure 13. Steps by Communications Activity Grouping for Macon High

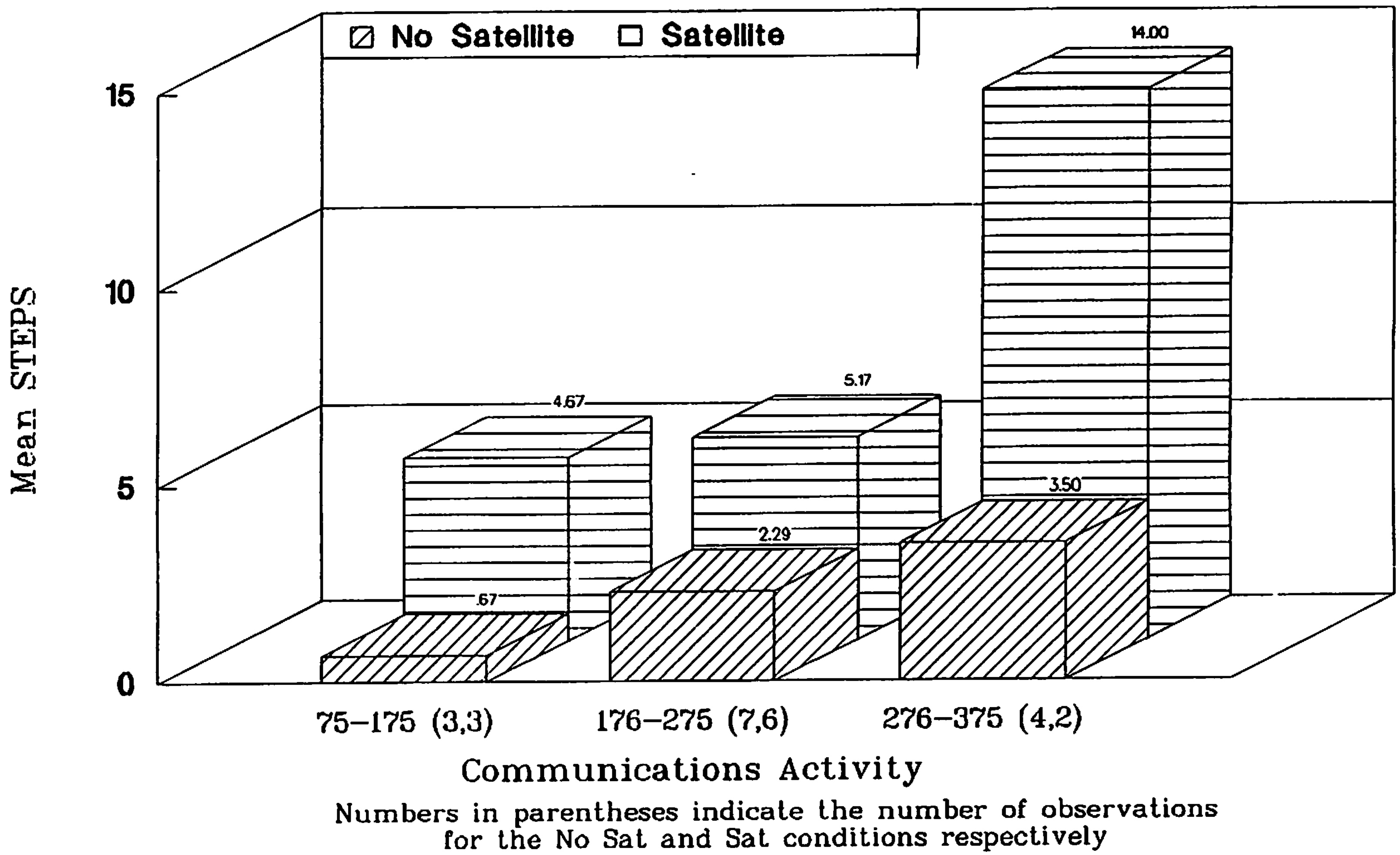


Figure 14. Steps by Communications Activity Grouping for Sinca Low

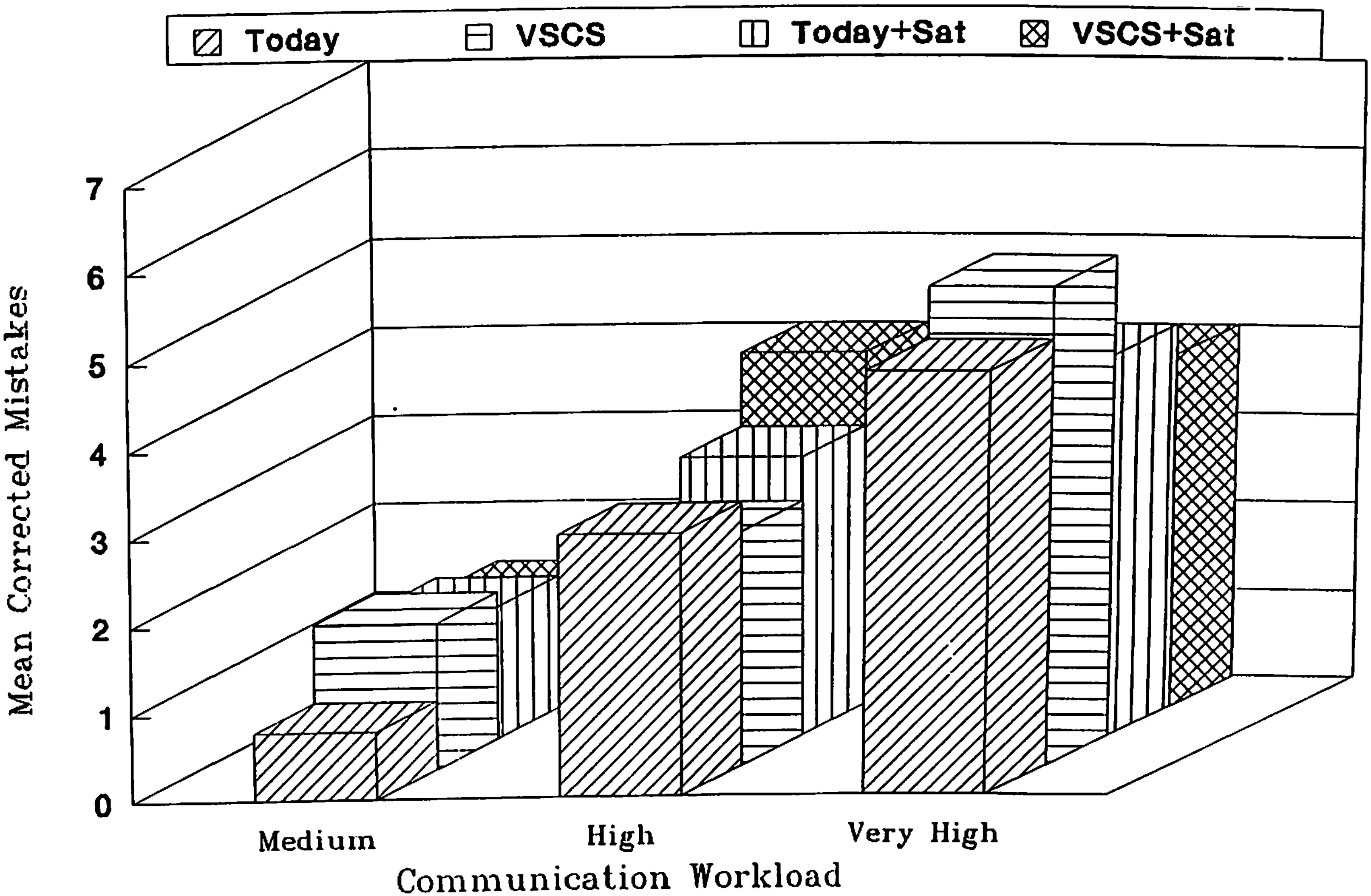


Figure 15. Mean Corrected Mistakes per Session

Table 12. Mean Corrected Mistakes per Session

	Delay			
Load	Today	VSCS	Today+Sat	VSCS+Sat
Medium	0.78	1.67	1.50	1.37
High	3.00	2.66	3.17	4.00
Very High	4.83	5.44	4.33	4.00

3.4 Estimates of Controller Stress

Two items measuring controller stress were included in the questionnaires filled out by the R-controllers and operations observers. One item asked the controllers to rate the amount of stress that they experienced in the preceding simulation session and the observers to rate the amount of stress the controllers appeared to experience; the other item asked both the R-controllers and the operations observers to rate the amount of attention and concentration required to control the air traffic during the preceding session. Delay showed no statistically significant effects on the responses to these questions ($p > .14$), except for a marginal delay by load interaction ($p = .022$), apparently due to less stress reported in the Today+Sat. condition at very high load. Stress and attention were found to increase significantly with communications workload ($p < .0001$). There were also significant differences in stress ratings associated with differences between sectors ($p < .0001$) and subjects ($p = .003$) in the controller self report ratings but not in the observer's reports ($p = .095$ for sectors and $p = .040$ for subjects). Attention was found to differ between sectors ($p = .0005$) and subjects ($p < .0001$), but only as rated by the controllers ; the observer ratings differed marginally between sectors ($p = .010$). Figures 16-19 and Tables 13-16 present the stress and attention results.

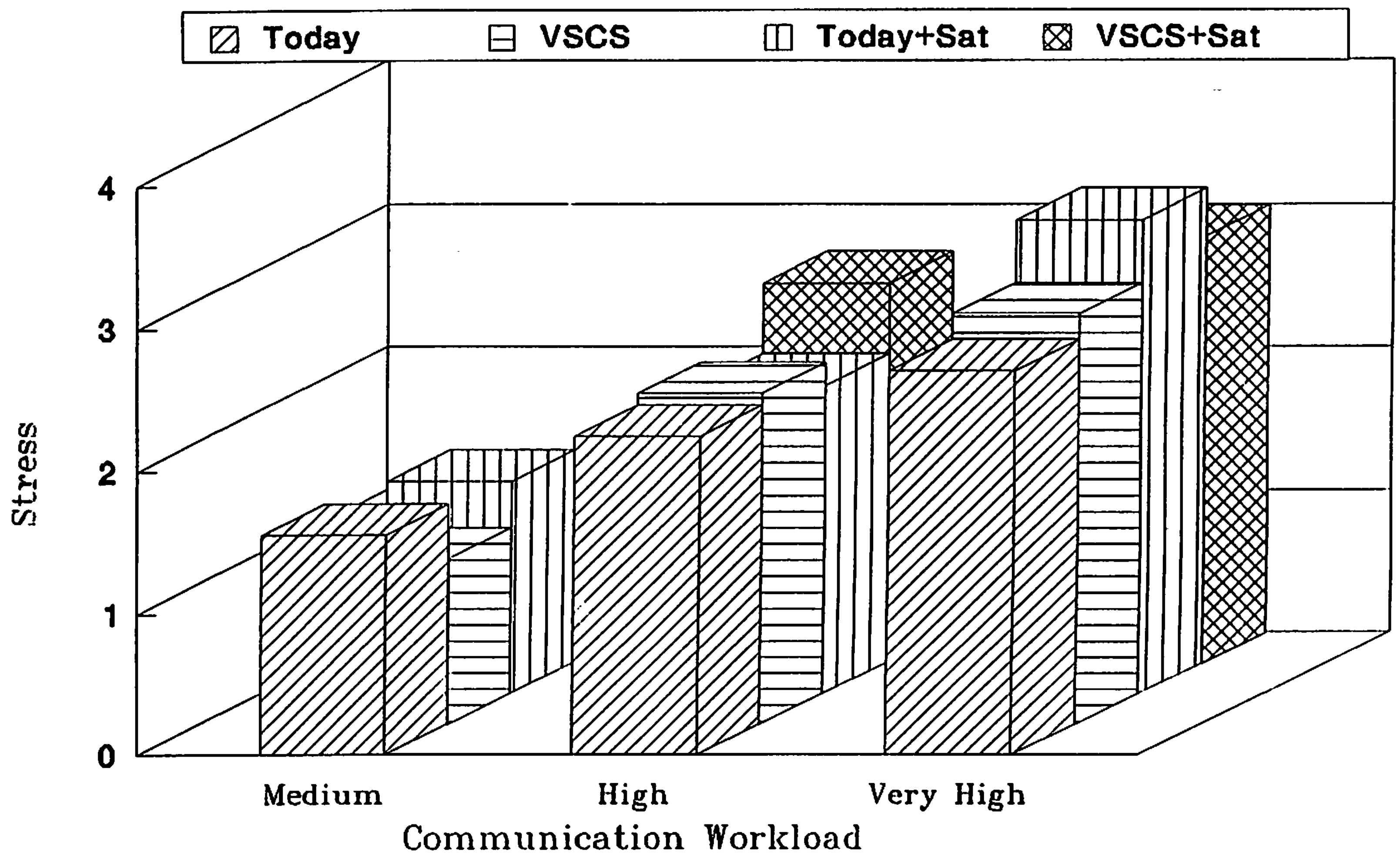


Figure 16. Mean Controller Stress as Reported by Controllers

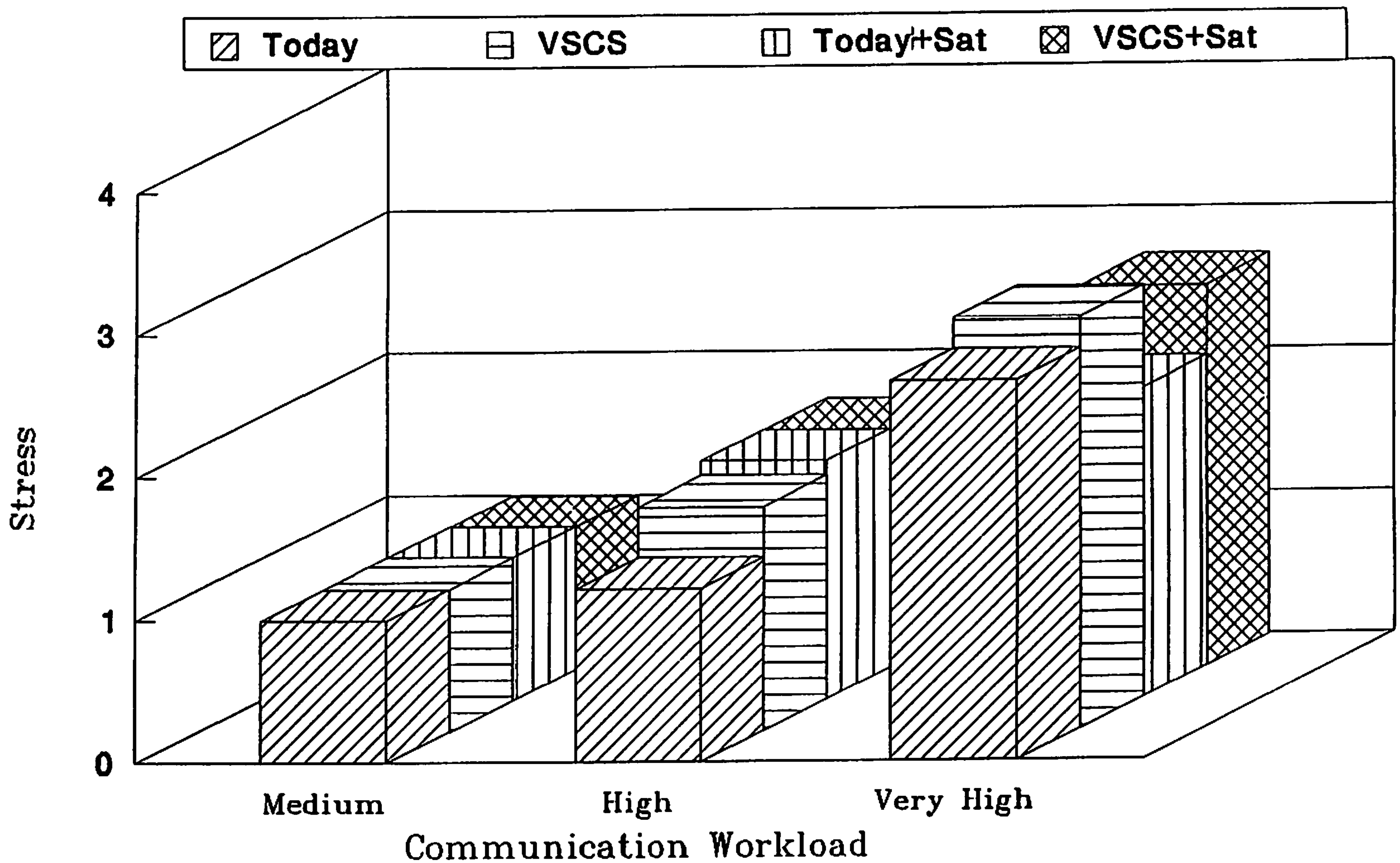


Figure 17. Mean Controller Stress as Reported by Observers

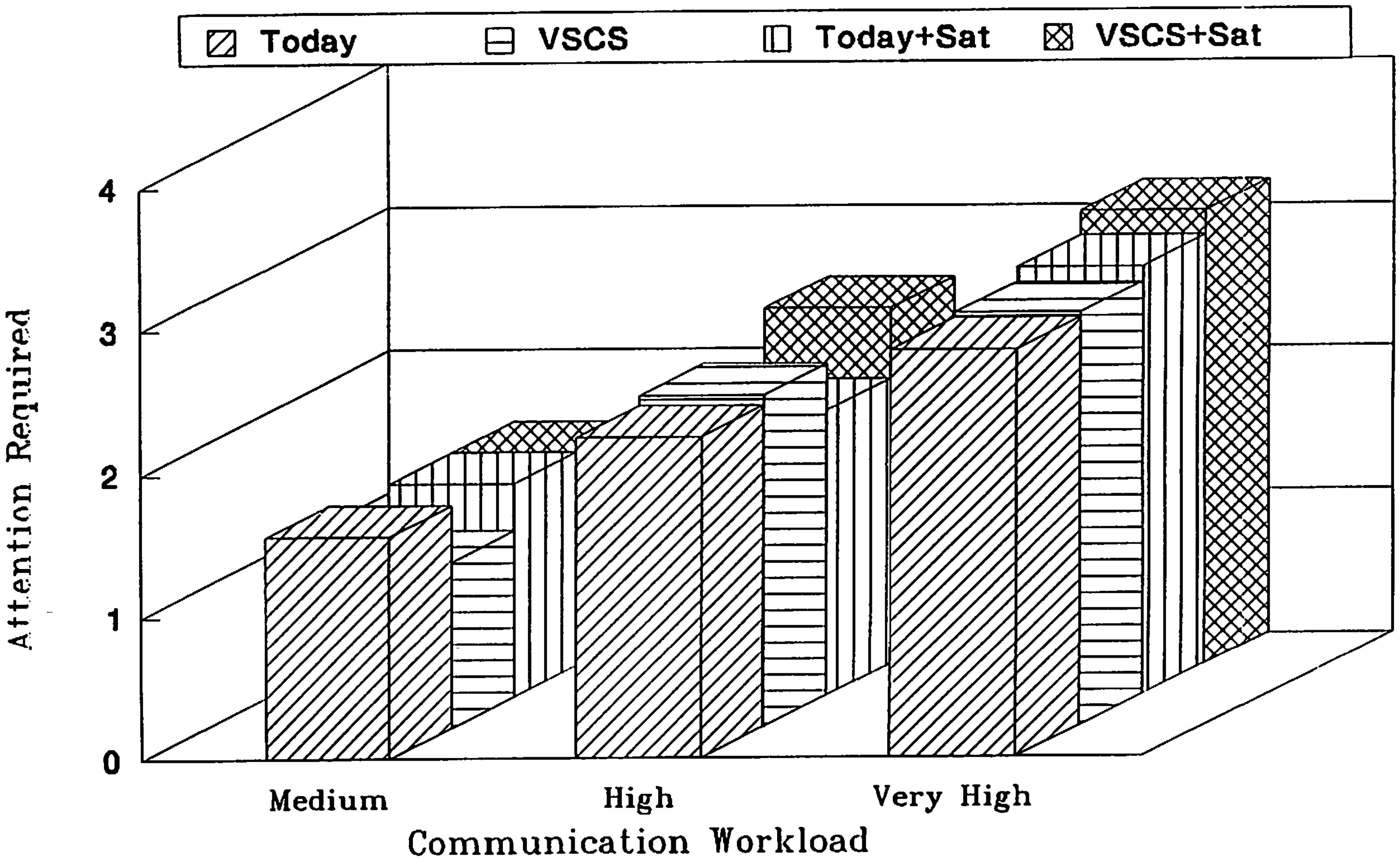


Figure 18. Mean Attention Required as Reported by Controllers

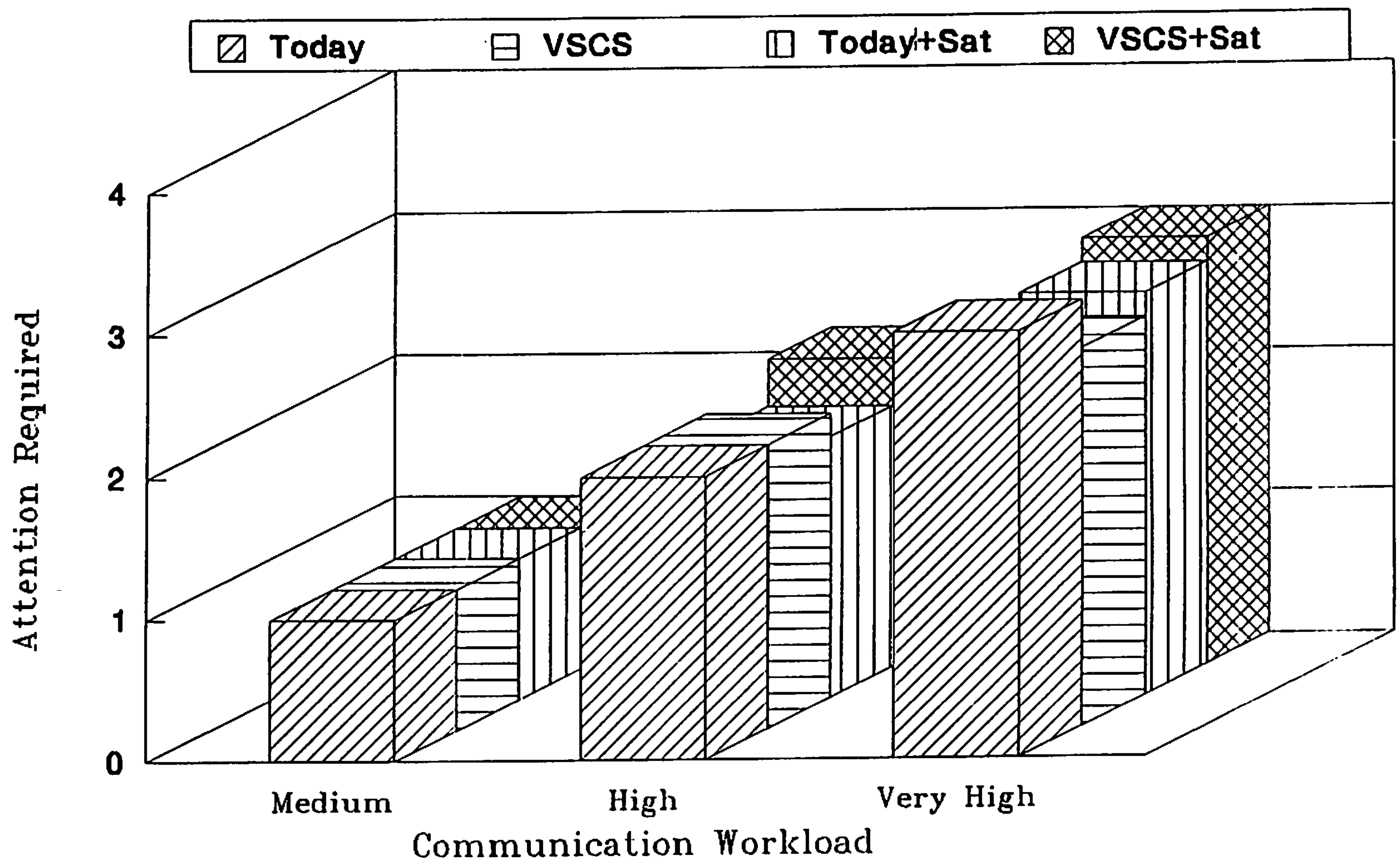


Figure 19. Mean Attention Required as Reported by Observers

Table 13. Stress as Reported by Controllers

	Delay			
Load	**Today**	**VSCS**	**Today+Sat**	**VSCS+Sat**
Medium	1.56	1.17	1.50	1.17
High	2.25	2.33	2.17	2.67
Very High	2.71	2.89	3.33	3.00

Mean ratings on a 5-pt. scale: 1=no stress and 5=excessive stress.

Table 14. Stress as Reported by the Operations Observers

	Delay			
Load	**Today**	**VSCS**	**Today+Sat**	**VSCS+Sat**
Medium	1.00	1.00	1.00	1.00
High	1.22	1.57	1.67	1.67
Very High	2.67	2.89	2.17	2.67

Mean ratings on a 5-pt. scale: 1=no stress and 5=excessive stress.

Table 15. Attention Required (Reported by Controllers)

	Delay			
Load	**Today**	**VSCS**	**Today+Sat**	**VSCS+Sat**
Medium	1.56	1.17	1.50	1.50
High	2.25	2.33	2.00	2.50
Very High	2.86	2.89	3.00	3.17

Mean ratings on a 4-pt. scale: 1=Little; 2=Moderate; 3=High; 4=Too High.

Table 16. Attention Required (Reported by Observers)

	Delay			
Load	**Today**	**VSCS**	**Today+Sat**	**VSCS+Sat**
Medium	1.00	1.00	1.00	1.00
High	2.00	2.00	1.88	2.17
Very High	3.00	2.67	2.83	3.00

Mean ratings on a 4-pt. scale: 1=Little; 2=Moderate; 3=High; 4=Too High.

Two items related to stress asked the R-controllers to indicate the importance of various sources of difficulty in the preceding session and the operations observers to rate any tendency toward overcontrol in the performances of the R-controllers.

Sources and Levels of Difficulty - Figures 20-22 illustrate the rated importance of various sources of difficulty for each type of delay and communications workload level.

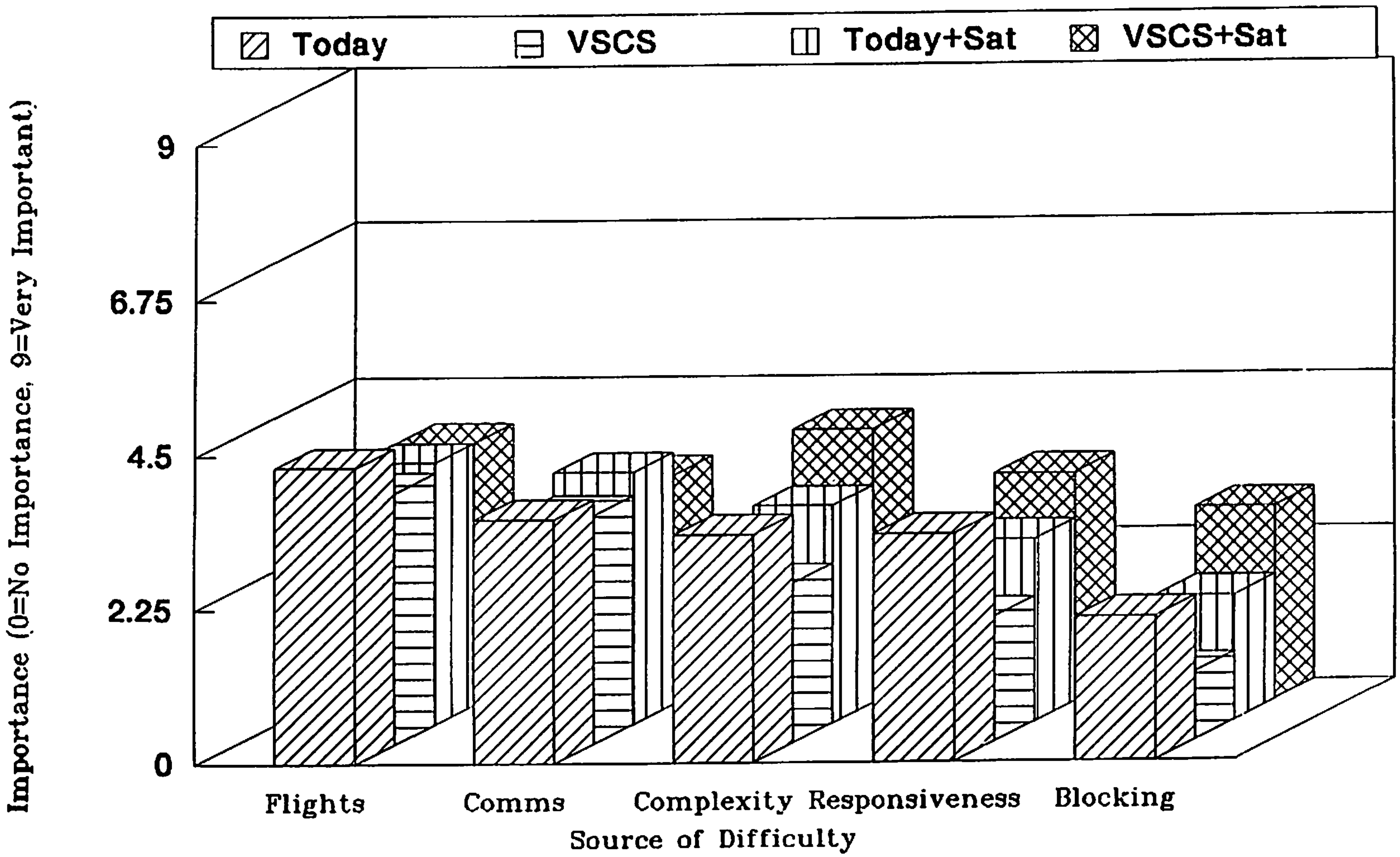


Figure 20. Mean Response to "Sources of Difficulty" Question: Medium Load

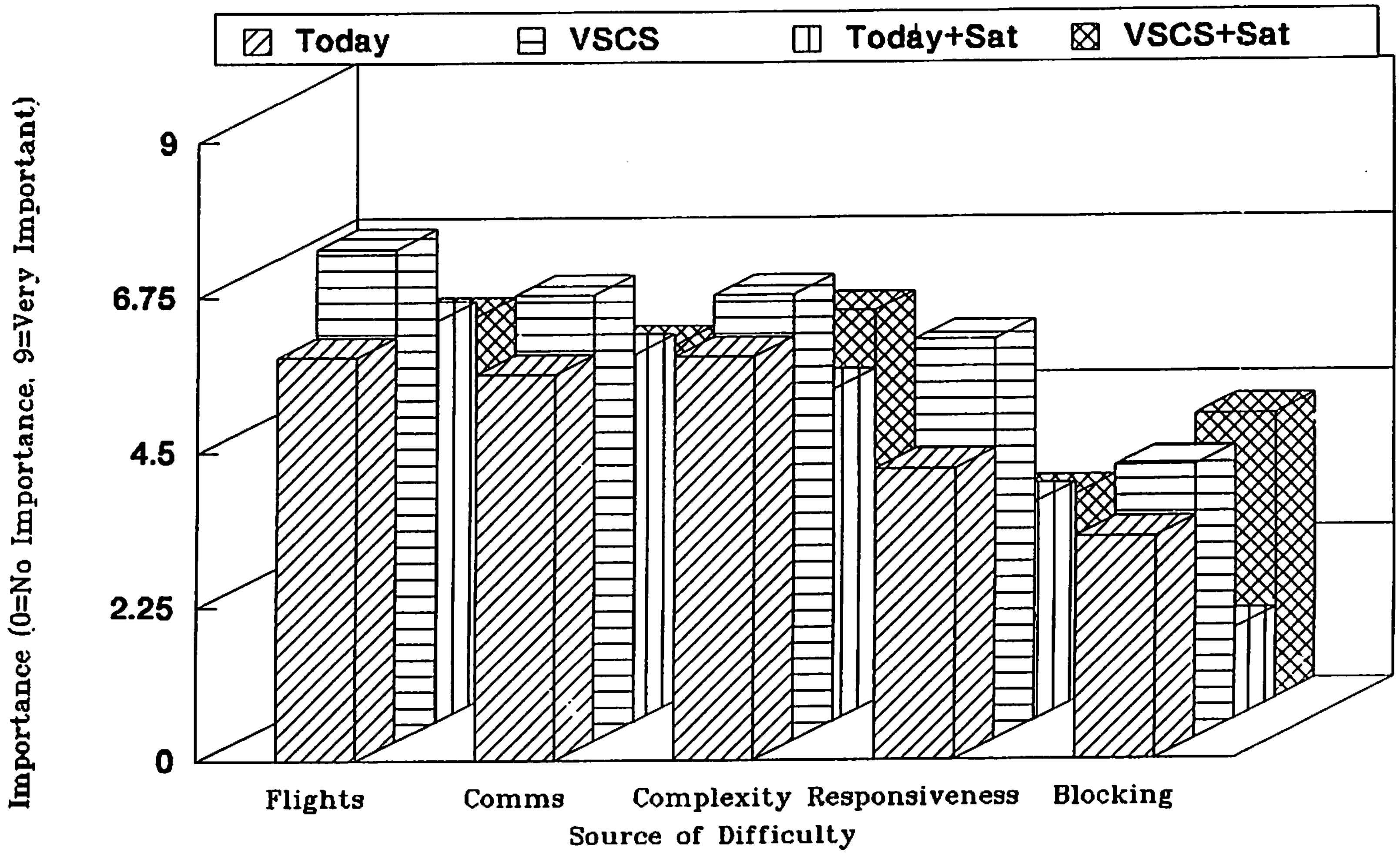


Figure 21.Mean Response to "Sources of Difficulty" Question: High Load

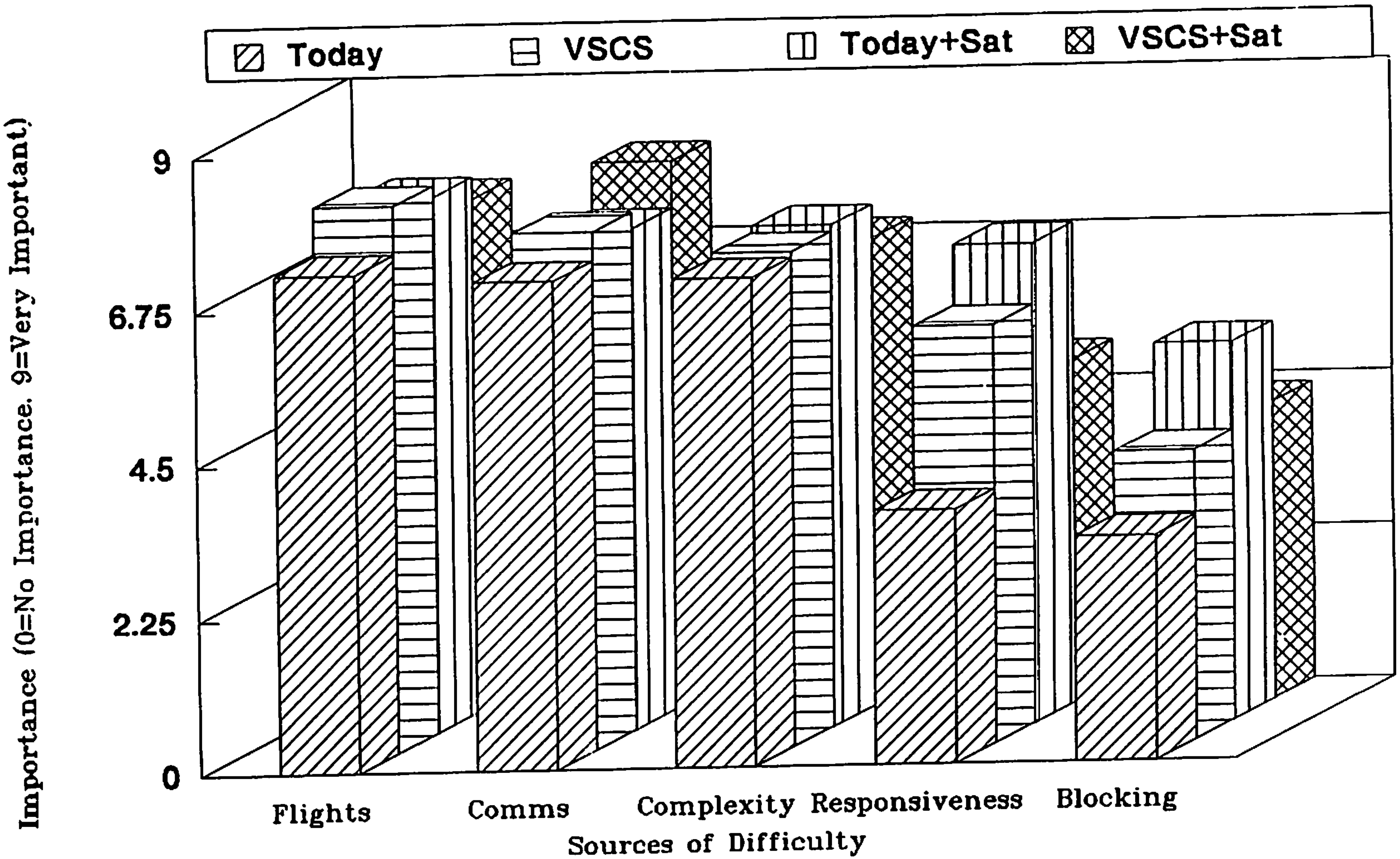


Figure 22. Mean Response to "Sources of Difficulty" Question: Very High Load

No systematic effects of delay are evident in these figures. The corresponding values are provided in Table 17.

Overcontrol - The operations observers reported little tendency to overcontrol (act too far ahead of the aircraft) among the R-controllers. No cases of extensive overcontrol were reported. Three observations of "some overcontrol" were recorded following sessions with Today, VSCS, and VSCS + Sat delays. The remaining 78 observations indicated no tendency to overcontrol.

3.5. System Performance

Indications of system performance included separation infringements, number of aircraft handled and rated smoothness of the flow of air traffic. Separation infringements were said to occur when two aircraft violated the separation requirements used for this study. (A precise definition can be found in Section 2.10.3). Figure 23 depicts the number of separation infringements per session for each delay and communication workload condition. The values for this figure are provided in Table 18. No trend due to delay is evident in this data. The number of infringements during each session and in each sector is found in Appendix G.

The infringements at the two very high communication workloads were higher than under any other conditions. Because there were only 38 infringements recorded during the entire study the data were aggregated into satellite and non-satellite delay conditions (see Figure 24). This more clearly reveals the lack of effect of delay on infringements found in this study. A regression analysis confirms the lack of statistically significant effects due to delay. Communications workload produced a marginally significant effect on separation infringements ($p = .013$).

Statistically significant effects would have required a striking increase in the number of infringements recorded because the small number of infringements observed reduced the power of the statistical test. Even with the most aggregate analysis, detection of a significant difference between satellite and non-satellite conditions would require twice as many in one condition as in the other. For example, if 26 separation infringements occurred in the satellite conditions and twelve in the non-satellite conditions, the difference would be just significant at the .05 level.

The 38 separation infringements was much higher than expected on the basis of Atlanta Center records (zero or one in the entire simulation, as noted in Section 1.0). Irregularities in the simulation, including pilot "miskeying," caused most or all of these infringements. For example, if a pilot transferred an aircraft to an incorrect sector "frequency" the aircraft would move erratically across a test sector and could not be removed from the PVD until it entered a different test sector. Problems with pilot scripting were responsible for other irregularities.

Table 17. Mean Response to "Sources of Difficulty" Question by Communications Workload and Delay

Communication Workload	Delay	Number of Flights	Number of Communications	Complexity	Pilot Response	Call Blocking
Medium	*Today*	4.33	3.56	3.33	3.33	2.11
	VSCS	3.67	3.33	2.33	1.83	1.00
	Today+Sat	3.83	3.67	3.17	2.67	1.83
	VSCS+Sat	3.83	3.33	4.00	3.33	2.83
High	*Today*	5.88	5.63	5.88	4.25	3.25
	VSCS	7.17	6.50	6.50	5.83	4.00
	Today+Sat	5.83	5.33	4.83	3.17	1.33
	VSCS+Sat	5.60	5.17	5.67	3.00	4.17
Very High	*Today*	7.29	7.14	7.14	3.71	3.29
	VSCS	8.00	7.56	7.22	6.11	4.22
	Today+Sat	7.83	7.33	7.33	7.00	5.50
	VSCS+Sat	7.50	8.00	6.83	5.00	4.33

Rating of importance on 0-9 scale: 0 = Not Important; 9 = Very Important.

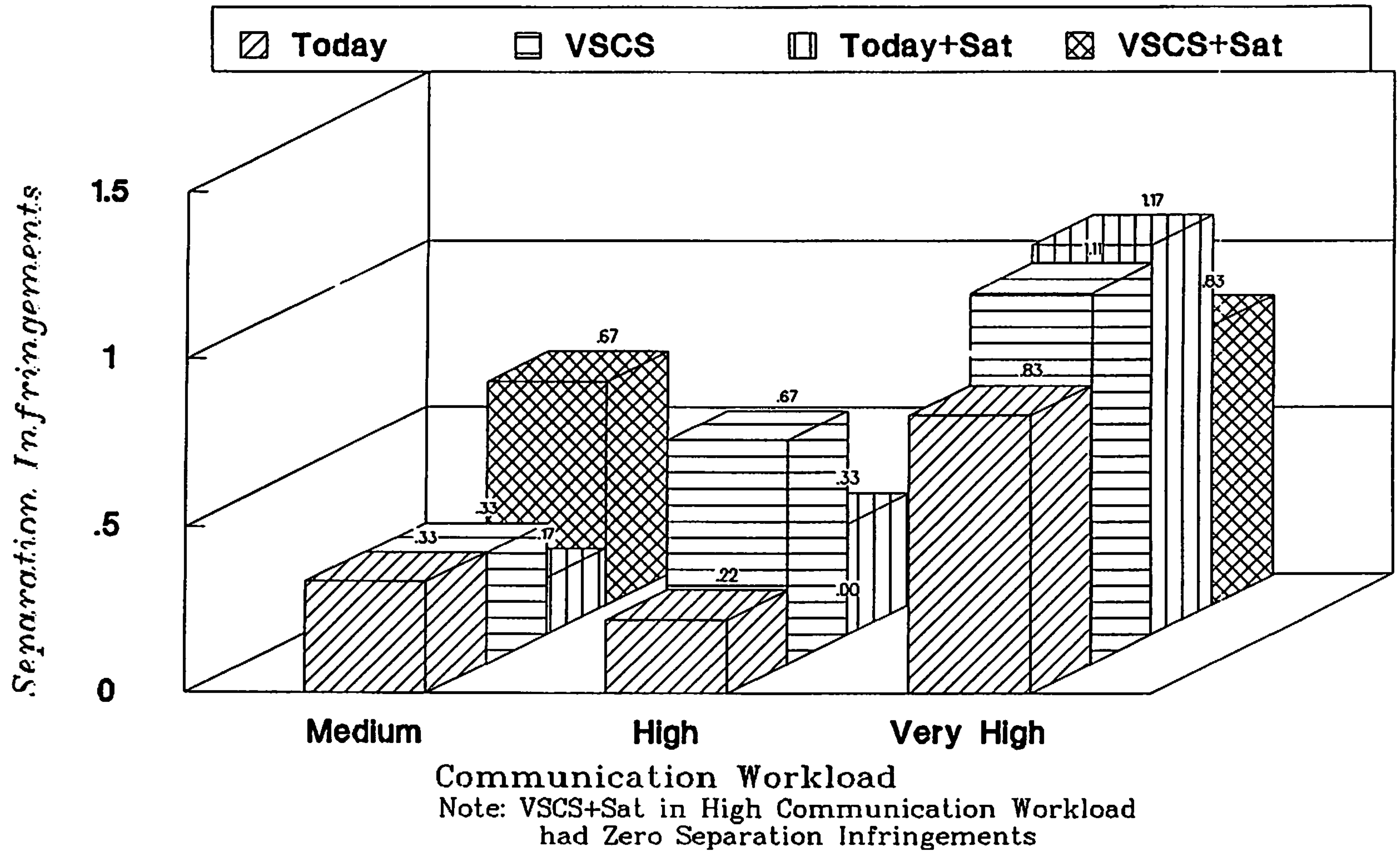


Figure 23. Mean Separation Infringements vs. Delay and Communications Workload

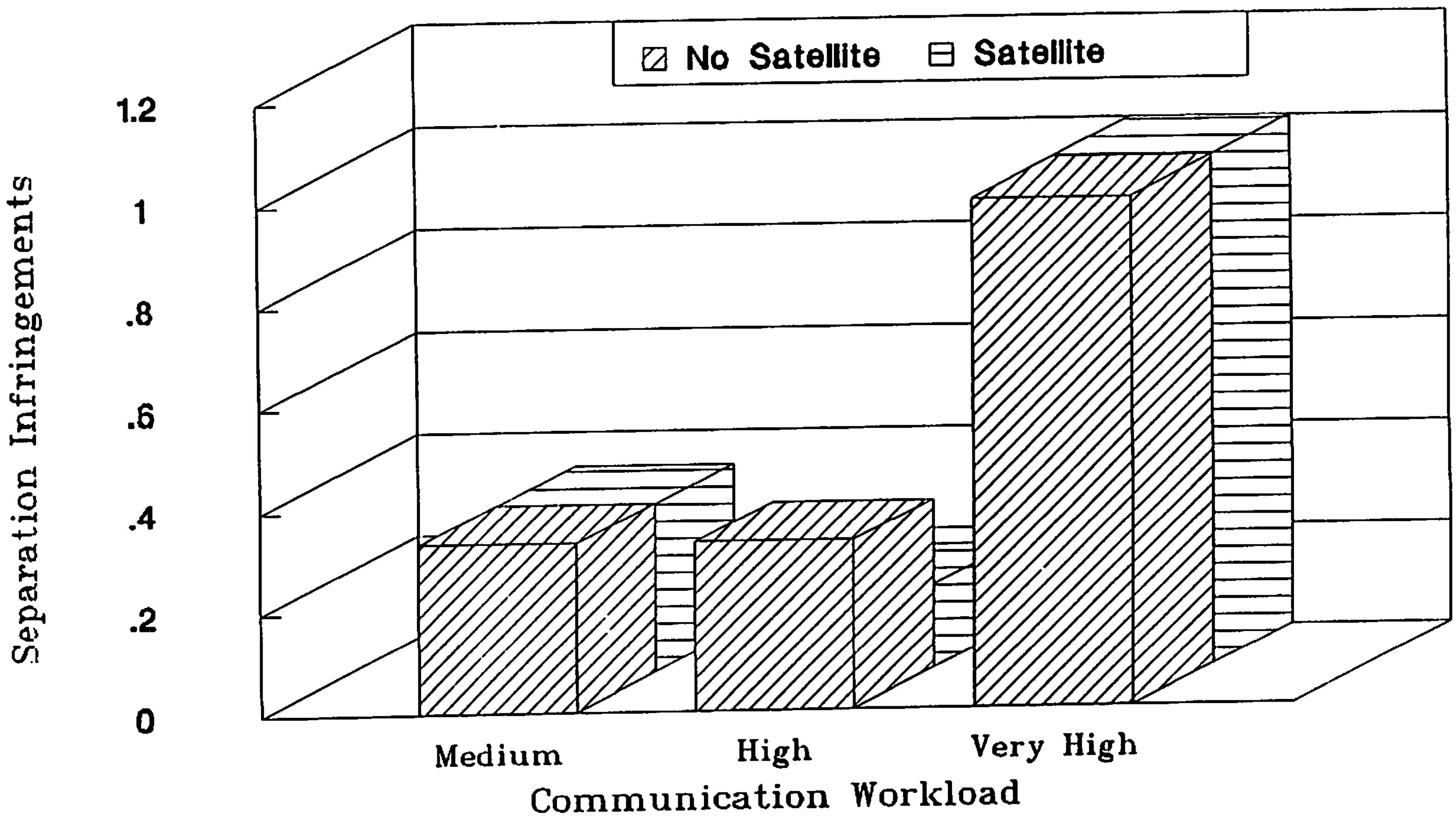


Figure 24. Mean Separation Infringements: Satellite vs. Non-Satellite

Table 18. Mean Separation Infringements (per Session)

	DELAY			
LOAD	Today	VSCS	Today+Sat	VSCS+Sat
Medium	1.00	1.00	0.50	2.00
High	0.67	2.00	1.00	0.00
Very High	2.50	3.33	3.50	2.50

Aircraft Handled - Figure 25 depicts the mean number of aircraft handled for each delay and workload condition. Table 19 provides the corresponding values. A regression was conducted on the number of aircraft handled each session in each test sector. Variation due to communications workload and sector were statistically significant. No significant differences due to delay nor interactions with delay were found, although the interaction of delay and communication workload was nearly significant ($p = .026$).

Table 19. Aircraft Handled (Mean Aircraft per Session)

	DELAY			
LOAD	Today	VSCS	Today+Sat	VSCS+Sat
Medium	34.67	35.17	33.67	32.33
High	45.56	45.67	47.33	45.00
Very High	48.17	55.00	53.50	56.50

Smoothness of Traffic Flow - The operations observers were asked to rate the extent of any disruption in air traffic flow in the preceding session. None indicated severe disruption in any session. Four cases of "moderate disruption" were recorded, one in each delay condition. The remaining 77 observations indicated no disruption.

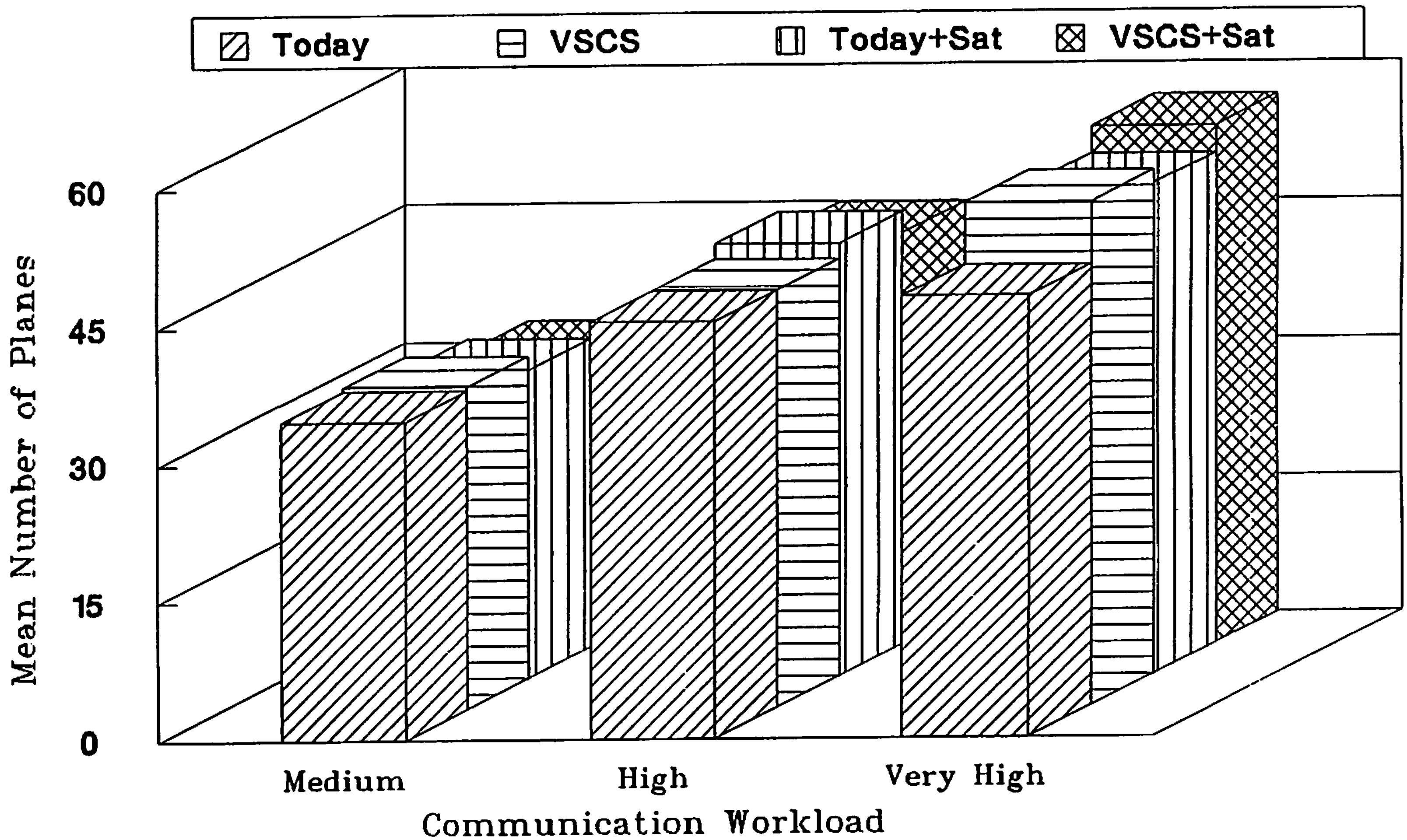


Figure 25. Aircraft Handled (Mean Aircraft per Session)

4. Discussion

The study was designed to test three hypotheses:

- System performance is degraded with increased delay.
- Controller stress increases with delay.
- Step-ons increase with delay.

Delay was not found to affect measures of stress or of system performance. The measures of stress and performance were found to vary with communications workload (except in cases where there were too few events recorded to permit a satisfactory statistical analysis). Only step-ons were found to increase with delay and then only for the long delays characteristic of satellites at the highest communications workload level.

In the real world step-ons may be distractions and are arguably a cause of controller stress, which can in turn affect system performance, i.e., step-ons potentially increase workload and could be detrimental to system performance. Loss of information due to step-ons can also degrade system performance. In the simulation the absolute number of step-ons was limited by the exclusion of emergencies and weather, which would have increased communications workload and thus increased step-ons.

Therefore under all delay and communications workload conditions fewer step-ons would be expected than in real world operations. Because of this limitation in the number of step-ons (no sector ever had more than 0.42 step-ons per minute) the impact of step-ons on controller stress and system performance may have been limited.

Limitations in the electronic aspects of the simulation (lack of a squeal) reduced loss of information due to pilot-pilot step-ons, and thus reduced the number of call-backs and irritation to the controller. This also may have the obscured the relationship between step-ons and the stress and system performance measures.

5. Conclusions

System Performance

- No statistically significant differences were found in measures of separation infringements or numbers of aircraft handled between any of the delay conditions.

Communications Disruptions

- No statistically significant increases in communications disruptions were found which could be attributed to simulated VSCS delays.
- Statistically significantly more pilot-controller/controller-pilot step-ons were recorded for satellite conditions than non-satellite conditions at very high workload.
- In Macon High (a sector which had much lower communications rates at all workload levels than Sinca Low and Dublin High) there were no apparent differences in step-on rate between satellite and non-satellite conditions.
- No statistically significant differences in verbal mistakes were found between satellite and non-satellite conditions.

Controller Stress

- No statistically significant differences were found in measures of stress, effort, or attention between any of the delay conditions.

Even though increased step-ons were found to be associated with satellite delay conditions, this study did not demonstrate that, in and of itself, delay will cause significant negative impacts on system performance. Evidence obtained from analysis of ATC operations suggests that voice communication difficulties and distractions can lead to operational errors, particularly when the controller is handling large numbers of aircraft. [1] However the fact that satellite systems appear to be operating successfully in a limited number of areas suggests that strategies have evolved which ameliorate the effects of increased step-ons.

The question remains: Will the observed increase in step-ons, under satellite delay conditions, particularly at very high communication workload conditions translate into decreased real world system performance? This matter can best be resolved through a separate field study of systems which include sectors with high communications activity and use satellite communications.

1 Golaszewski, R. An Analysis of Pilot-Controller Read-Back Errors. *Journal of ATC*, December, 1989

Appendix A

ATC Voice Communications Delay Test Plan

Draft Coordination/Approval Version 10-17-89
Gerard Spanier ACN-140

1. Object

The object of these tests is to determine if communication delays in Air Traffic voice transmissions adversely impact voice communications performance beyond baseline (today's) performance under specific conditions. The specific conditions include

- Type: enroute sectors
- Air-to-round voice communications
- Compliance to worst case VSCS specification delay values
- Inclusion of end-to-end set-up delays that exist today or that will exist in the VSCS time frame
- Delays due to the use of satellite links
- Communications under realistically high load conditions. Significant differences between the controller performances under the tests will be analyzed and reported.

2. Background

As part of the modernization of the National Airspace System Air Traffic Control (sub)system, the NAS plan requires a new Air Traffic Control voice communications system, the Voice Switching and Control System (VSCS), specifically for use in the enroute Area Control Facilities (ACF). This system is under development, and may result in different delay characteristics due to design. Other improvements to the NAS may depend upon the use of satellite communications, to improve accessibility, reliability, cost-benefit, and expandability. Communication delays could possibly result in reduced numbers of voice communications, loss of communications due to multiple transmitters in use at the same time on the same frequency (step-ons), lost transmissions or excessive repetitions due to uncertainties or hesitations from repeated transmissions. Willful transmission by a pilot while that same pilot knows someone else is transmitting is not part of these tests. The pertinent performance of current equipment which will be utilized by the NAS with the VSCS in the VSCS time frame (RCE, etc.) is simulated in the tests to assure accuracy and realism.

By agreement between all involved organizations, interphone and intercom communications will not be analyzed in this set of tests. As per the NAS Plan, ATCT and FSS environments are not utilizing the VSCS as a communication system, therefore those environments are not part of this set of tests. The terminal environment (TRACONS) will not be utilizing the VSCS, primarily due to size incomparability. These three environments are not expected to require the use of satellite communications, so they are not included in the tests. The VSCS will be used for voice communications in terminal sectors within an ACF, in accordance with the current NAS System Design calling for TRACON consolidation. This environment will not be a part of this set of tests, due to scenario and simulation limitations. The use of alternate communications paths, including satellite paths, as part of the back-up and contingency requirements of the NAS, is not a question to be answered by the tests, since the acceptable performance level for communications under known reduced ATC performance during contingencies is not established nor within the scope of the tests.

3. Test Categories

This plan covers the following categories:

- Air/ground and ground/air voice communications
- Three pertinent and representative enroute sector types
  - Low altitude high density feeder sector for a major terminal facility (approach/departure sector)
  - High altitude sequencing sector for a low altitude sector and adjacent to other high altitude sectors
  - High altitude sector in the same ARTCC, and adjacent to high altitude sequencing sector
- Non-satellite transmission link in the communication path
- One satellite transmission link (round trip) in the path
- Three levels of communications load
  - Communication load based on a 70%-of-peak sector traffic load
  - Communication load based on a 90%-of-peak sector traffic load
  - Communication load based on a 110%-of-peak sector traffic load
- Transmitter set-up, voice propagation, and other maximum delays as found in today's system
- Transmitter set-up, voice propagation, and other maximum delays as specified for the system to be in use during the VSCS time frame (99.9 percentile)

4. Test Parameters

The test parameters represent those items within the scope of testing that will be varied for each of the categories, for tests to be run. The term 'dead' time is used below, and is defined as the time, for someone listening on a channel, between the end of a pilot's transmission and the reception of a carrier from an enabled FAA VHF/UHF transmitter. This is the time a listener on channel should and would believe that a channel is not in use after the end of a pilot's transmission. Contention between a controller and pilots for the channel during this time is a primary cause of 'step-ons.' The shorter the time, the less opportunity for 'step-ons.' Step-ons due to willful transmission while the pilot knows someone else is speaking are not a part of these tests.

4.1 Delays

4.1.1 Baseline Delay

The baseline delay includes the set-up time delay that exists in the present system and is represented by the delay that occurs between the time that a controller presses the push-to-talk (PTT) switch and the time when pilots are aware that a PTT switch has been depressed. This time is a 'dead' time as defined above, and, for the Baseline delay, consists of 190 milliseconds (ms) from PTT to transmitter and 35 ms for transmitter enable. The baseline delay also includes any propagation or other delay through the audio channel from the microphone of the person speaking to the earpiece of the person listening, with the appropriate timing relationship. 'Today's' system, which is used as the basis for the delay values, contains essentially no propagation delay. Thus, the total delay to be used as the baseline delay is 225 ms, all due to the set-up delay.

4.1.2 VSCS-Time-Frame Delay

The VSCS delay has been identified as follows:

- PTT to VSCS output is 30 ms
- VSCS output through the local Radio Control Equipment (RCE) is 50 ms
- Local RCE through the transmission equipment (TE) is 4 ms
- TE output through the remote RCE to transmitter is 50 ms
- Transmitter enable is 35 ms

for a total of 169 ms. The VSCS voice circuit has a 70 ms. delay in voice transmission, which means that the controller can begin talking as early as 99 ms after PTT without losing or clipping any part of the beginning of the message. As a result, the VSCS delay without a satellite link could be as little as 169 ms, including both the 169 ms set-up delay and the 70 ms voice delay, since these two delays are not serial (not additive) in the situation described above. However, this value does not represent the (worst case) minimum VSCS-time-frame delay. The same 70 ms. voice delay exists in the reception of pilot communications by the controller, but not in the reception by other pilots. This utterance delay at the end of the pilot's communication (called pilot termination delay in this document), which chronologically occurs before the PTT event, must be added to the VSCS set-up delay, giving a total delay of 239 ms. This represents the total 'dead' time as defined above, which makes it the effective VSCS-time-frame delay. For the tests, voice delay between pilots and controllers is 70 ms, and the simulated set-up delay is 99 ms.

4.1.3 TODAY'S System With Satellite Delay

The satellite delay is nominally 260 ms, which is the effective round trip delay encountered by voice signals and control signals travelling from a ground station to a stationary orbiting satellite approximately 22,000 above the earth. This delay exists in voice transmissions in both directions between pilots and controllers, and in set-up control signals initiated by the controller's PTT action. Adding 260 ms to the 225 ms set-up delay of TODAY results in 485 ms. However, the controller who wants to PTT at the end of a pilot's transmission must wait 260 ms after the pilot is finished before the controller is aware that the pilot is finished. This time must be added to the 485 ms, to result in 745 ms effective 'dead' time for a listening pilot, during which time the pilot hears no indication that someone is transmitting.

4.1.4 VSCS Time-Frame with Satellite Delay

The satellite delay is 260 ms, which, as above, is the effective round trip delay encountered from a ground station to a stationary orbiting satellite approximately 22,000 miles above the earth. This delay exists in both transmissions from the controller to the pilots and from the pilots to the controller. Adding the satellite delay to the 70 ms pilot termination delay time identified above results in a 330 ms delay in satellite pilot termination, which is not perceived by other pilots, but affects the start of the controller communications sequence. The controller can initiate the PTT sequence only after the satellite/pilot termination delay. Following this PTT is the delay of the controller-initiated set-up, which consists of the 169 ms as above and the 260 ms satellite delay of the set-up signal. This results in a total maximum expected delay of 759 ms(70 + 260 + 169 + 260). The earliest time after the PTT that a controller can talk without any loss of audio (clipping of words) is 99 ms. For the tests, the voice delay in each direction between controllers and pilots is set to 330ms (70 + 260), and the simulated set-up delay is 99 ms.

4.1.5 The following tables consolidate the above information:

Table A1. Real World Maximum Delays (MSECs)

		set-up	voice	'dead ' time
TODAY	pilot	0	0	
	controller	225	0	225
VSCS	pilot	0	70	
	controller	169	70	239
TODAY + SAT	pilot	0	260	
	controller	485	260	745
VSCS + SAT	pilot	0	330	
	controller	169	330	759

Table A2. Test Values to be Used

		set-up	voice	'dead ' time
TODAY	pilot	0	0	
	controller	225*	0	225
VSCS	pilot	0	70	
	controller	99*	70	239
TODAY+SAT	pilot	0	260	
	controller	225*	260	745
VSCS+SAT	pilot	0	330	
	controller	99*	330	759

* Minimum delay to lose no controller audio (clip) (audio cue to controller's ear)

4.2 Operational Environment

The operational environment will consist of the observed test sectors, the support sectors, a ghost sector (not under test) that accept/issue hand-offs to the test sectors, and the simulation facility, with simulator pilots as the aircraft and the communications sources to the controllers. The test configuration will consist of five sectors from the Atlanta Center:

- Dublin High, sector 7
- Sinca Arrival, sector 8
- Macon High, sector 22
- South Departure, sector 21
- Clark Hill Ultrahigh, sector 24

where the first three sectors are the observed test sectors and the other two sectors are the support sectors. The three test sectors will consist of two high altitude sectors and one low altitude sector with one high altitude sector feeding traffic to the other high altitude sector and the second high altitude sector feeding traffic to the low altitude sector. All sectors will be under operation at the same time, and the test sectors will each operate at different load levels consistent with the typical 'busy day' loads for those sectors, as defined within the center. The sectors are considered to be representative types, and the particular Atlanta sectors used are considered by the Southern Regional Office representatives as good examples of busy sectors.

4.3 Traffic Load

The traffic loads to be used during the tests are defined as medium, high and high density, where medium density is 70%, high density is 90%, and very high density is 110% of the peak traffic density as measured at the Atlanta Center. Each observed test sector will be subject to all three traffic loads at all delays. The communications loads that come about as a result of the above traffic loads will be reviewed during the shakedown tests and the scripts will be adjusted if necessary to assure the required communications traffic loads, up to the specification limits of the VSCS.

4.3.1.

In the test sectors, each simulator pilot will control only a single aircraft at any time, to ensure no simulator pilot limitation for contention on the voice channels. Up to 10 pilots per controller will be provided for, and exercised, in the scripts.

4.4 Scenarios

Scenarios have been prepared for the three traffic loads indicated in paragraph 3 and will be evaluated during the shakedown tests with changes to be made, if needed before starting the actual tests. In addition, some changes may be made in the scripts for each test in order to eliminate the potential for controllers and pilots to become too familiar with the script and reduce the validity of the tests.

4.5 Human Factors

Three types of personnel will be involved directly in the performance of these tests. They are the simulator pilots, the controllers, and the observers, with the following duties assigned to each group.

4.5.1 Simulator Pilots.

There will be approximately 37 simulator pilots available for the tests with as many as ten individual pilots in the same sector on the same frequency at the same time, thus providing the necessary environment for communications contention. All of the simulator pilots will receive training to achieve the desired communications loading effect by learning how and when to access the voice channel as soon as it appears to be unused.

4.5.2 Controllers

Each test will require the services of three types of controllers. There will be a test subject R controller at each observed test sector, who will be a radar controller experienced in operating the selected sector at Atlanta ARTCC. There will be a D controller at each observed test sector performing the D position functions, who will be an experienced Atlanta ARTCC data controller, but will not be a test subject. There will be an R controller at each of the other two sector positions, also an experienced Atlanta ARTCC radar controller, who will not be a test subject while at those positions. Based upon the qualifications of all the controllers involved in the testing, the controllers will be at different sectors and will perform different functions during the set of tests that are run.

4.5.3 Observers

One observer will be required for each of the three test sectors. These people should be the same for all of the tests. They will be experienced, senior radar controllers, ideally Atlanta controllers currently serving as training instructors, and will observe, monitor, and record the performance within the test sector assigned, in accordance with the evaluation process in the test plan. The same observers should be used during the entire test period. They will also be serving as the R controllers during the shakedown tests. In one of the shakedown tests, they will perform their duties as observers to further verify the observer procedures. Observers will use headsets to listen to the pilot and R controller audio at each sector.

5. Test Bed Development

All of the tests will be conducted at the FAA Technical Center using the facilities described below.

5.1 Test Bed Description

The test bed will consist of the following elements:

- NAS Enroute Lab with the Host Computer, the 9020E, and five sectors configured as part of the Atlanta Center.
- Digital Simulation Facility with up to 37 simulator operators providing aircraft targets and communications with the controllers.
- Amecom voice switching system modified with adjustable delay circuits to provide the desired delay times and communications between the simulator operators and the controllers. The set-up delays and the utterance delays will be independently controlled. Capabilities added to the Amecom are:
  - 0 to 1024 ms voice delay in 1 ms steps
  - 0 to 500ms simulated set-up delay by delaying the effect of the PTT signal for a/g communication
  - short audio cue to controller's ear at end of simulated set-up time, corresponding to time after which no audio is lost (clipped).

5.2 Test Implementation

Each test will be of approximately one hour duration with a gradual buildup of the traffic to the desired level. The desired traffic level will be maintained for sufficient time to collect adequate data for analysis. The three observed test sectors will be staffed with both an R and D controller, while the other two sectors will have the staffing needed to support the operation of the test sectors . An observer will be assigned to each observed test sector and data will be collected for all three test sectors during each test run. There will be three test runs on each day of testing with three days of testing per week for a total of nine tests a week. This sequence of testing will be performed for three weeks with a new group of Atlanta controllers being the test subjects each week.

5.2.1

Shakedown testing of the software, scenarios, pilots, communication hardware, procedures, etc. will take place for three days to assure that all aspects of the testing are proper and can go ahead as planned. A review of communication loading during the shakedown tests will determine whether the scripts need modification. Controllers from Atlanta sectors will be utilized as D controllers for the observed test sectors and R controllers for the other two test sectors; the training instructors will serve as the R controllers for the three observed test sectors. In addition, the shakedown tests will include some tests with the training instructors performing as observers.

5.3 Test Procedure

Table A3. depicts the experimental conditions to be experienced by three ATCS teams. Each team is made up of 3 R controllers and 3 D controllers. These 6 individuals will operate three of the five sectors provided in the simulation; the remaining two sectors will be manned, and will operate, communicate and control targets, accept handoffs, and give handoffs, but will not be test sectors nor sectors observed by the test observers. A ghost communication position will also handle the ground-ground communications outside of the test sectors.

Communications workload levels are set in the simulations scenarios. The communications workload levels, driven by the traffic load levels in the scenarios, are considered medium (M), high (H), and very high (VH) relative to the Atlanta ARTCC operations values.

The test delay conditions as shown in the Table A3 correspond to (0) for Baseline (TODAY), (1) for VSCS time frame, (2) for TODAY with Satellite, and (3) for the VSCS time-frame with Satellite, and are the current worst case delay, and the three other delays, which correspond to the conditions of paragraphs 4.1.1, 4.1.2, 4.1.3, and 4.1.4 respectively.

Table A4 shows the balanced run sequence of delays combined with load conditions for controller teams. There is a balance of load conditions over controller teams, and there is even a partial balance over sector assignments within the team. Each team are test subjects in three sector assignments identified as a, b, and c. Each team also experiences the baseline delay once at each sector. This layout achieves nearly the maximum balance for three teams each experiencing 9 conditions. With few exceptions, there is no load condition, delay condition or sector assignment that is immediately repeated. With one exception, the delay and load conditions are well-distributed over each sequence of conditions. In order to satisfy a constraint that each team be tested at a base-line or VSCS delay value before they are tested at the longer (satellite) delay values, a small adjustment to the order is included, and potential balance weakening is acknowledged.

This design balances all major variables and partially balances the minor variables, which results in an experiment with a minimum of 'confounding,' and a maximum of 'analyzability.'

Each R controller test subject will participate in one baseline delay test at all three traffic density levels, and three other delay tests also at all three traffic density levels. In order to improve the validity of the tests, controllers will be rotated through all three test sectors and, if possible, will not be a test subject in the same sector on consecutive tests . See Table A5.

Table A3. Test Assignments

Team and Week	Communication Workload			Sector Assignment
	Medium	High	Very High	
1	0	1	2	a
	3	0	1	b
	2	3	0	c
2	0	2	3	a
	1	0	2	b
	3	1	0	c
3	2	0	3	a
	0	3	1	b
	1	2	0	c

Table A4. Sequence of Test Conditions

Team and Week	Session Number								
	1	2	3	4	5	6	7	8	9
1	0VH c	1H a	3M b	2VH a	0H b	0M a	3H c	1VH b	2M c
2	1H c	0M a	2VH b	3M c	0H b	0VH c	2H a	1M b	3VH a
3	1M c	3VH a	2H c	0M b	3H b	0VH c	2M a	1VH b	0H a

Table A5. Assignment of Controllers to Sectors

Assignment	R Controller No.	Sector
a	1	1
	2	2
	3	3
b	4	2
	5	3
	6	1
c	7	3
	8	1
	9	2

5.4 Test Management

A Test Manager will be responsible for the coordination of the Technical Center's preparation of the test facilities, test scenarios, hardware and software changes to equipment, schedules, personnel availability, and for the content of the Test Plan and its approval. The Test Manager will provide for the Test Directors and other Technical Center personnel to assure the conducting of the tests.

Test Director(s) from the Technical Center, under the direction of the Test Manager, will be responsible for conducting the tests. They will assure that all test personnel have been briefed, all positions are staffed, and the test bed is fully operational before the start of each test.

Furthermore, test scripts, questionaires, observer reporting forms, and all other reporting forms will be explained and distributed prior to the start of each test run. Test directors will provide day to day supervision of the activities and coordinate the starting, running, and ending of the tests, as well as the distribution and collection of questionaires, and the collection and processing of the daily digital and analog tapes. Representatives of the sponsoring organizations, ATR, AAP, and ASM will assist to ensure conformance to the test plan and to maintain an appropriate test environment.

6.0 Test Design/Description

All of the tests have the same basic objective, as stated in paragraph 1.0, to determine the impact of voice transmission delays, within a realistic operational environment, on controller workload and performance. Each test run will produce specific performance data from two primary sources, controller and observer answers to questionaires after each run and observer notes and records after each run. Secondary sources of performance data, recorded digital control and analog voice recordings, and pilot's records, will provide information to corroborate and complement the primary sources.

6.1 Test Type

(to be provided)

6.2 Objective Of Test

(to be provided)

6.3 Test Description

(to be provided)

6.4 Questionaire Development

Two questionaires will be developed, one for use by the observers and one for use by the controllers. The observer questionaire will record subjective and objective answers to questions and include observations that are made during the actual running of the tests. The controller questionaire will include questions about peformance and perceived performance relative to the just-completed test. These questionaires will be used initially during the test bed shakedown, with changes made, if necessary, prior to the start of the formal tests.

6.4.1 Pilot's Records
Pilots will keep a record of the number of calls they each make to a controller which are not answered.

7. Test Evaluation

7.1 Evaluation Criteria
(See Addenda)

7.2 Data Reduction and Analysis
(See Addenda)

7.3 Test Result Evaluation
(See Addenda)

8. Responsibilities

The organizational responsibilities for each area of the testing are listed below. Specific organizational units and/or persons will be identified in the test procedures.

8.1 Specification of Test Parameters
ATR at Headquarters will coordinate with AAP and ASM and provide leadership in the specification of test requirements, in reviewing test plans and materials, in monitoring test conduct, and in reviewing test products.

8.2 Development of Test Bed
ACN will be responsible for the set-up, use and overall development of the simulated Air Traffic Control test bed at the Technical Center, and for the technical correctness and performance of the test bed.

8.3 Test Design/Description
TSC will be responsible for the test design/description and test data collection documents for use by the test subjects and observers, in support of AAP and ASM.

8.4 Test Management
ACN will be responsible for the overall test management at the FAA Technical Center.

8.5 Test Evaluation
ACN/ATS/TSC will be responsible for quantitative and qualitative evaluation of the tests, with TSC as the lead organization.

8.6 Report/Test Plan Preparation
ACN will be responsible for preparing the test plan and for the preparation of the report of the result in conjunction with TSC. ATR will approve the test plan.

8.7 Coordination

ACN will coordinate all of the activities.

9. Resource Requirements

9.1 Funding

AAP/ASM will provide all of the funding necessary to accomplish this task.

Cost of field controllers, etc (Travel, Per Diem, Salary)	______________
Operation of Simulation Facility	______________
Operation of the ATC Lab	______________
All project people	______________
Equipment, supplies	______________
Total	______________

9.2 Staffing

The required staffing for this program is:

Shakedown Tests (one week)

Atlanta training instructors 3

Atlanta R controllers 3 + 2 = 5

Atlanta D controllers 3

Ghost position 1

Simulator pilots 26-30 est.

Full Tests (each week for three weeks)

Atlanta training instructors 3

Atlanta R controllers (sector specific) 3

Atlanta R controllers 2

Atlanta D controllers 3

Ghost position 1

Simulator pilots 26-30 est.

Test management and support 12 est.

10. Schedule

Test Plan Development October 6, 1989

Test Bed Shakedown November 6-8, 1989

Test Schedule November 28.29.30 daily schedule TBD

Test Report (Draft) January 19, 1990

Errata and Corrections

1.0 (additions for information and clarification)

4.2 (last sentence changed to clarify)

Addenda

7.1 Evaluation Criteria

Evaluation will be based upon items that will appear on the observers' computer checklists for use during test runs, questionaires for use by observers after each run, questionaires for use by test R-controllers after each run, as well as the limited data collected by the simulation pilots and secondary data derived from Simulation Analysis Review, digital Amacom controller PTT, and pilot and controller voice tapes. In general, the data will be diagnostic of communications problems, workload, and reduced levels of performance due to the experimental conditions. Computer or paper (backup) checklists will consist of tallies for step-ons, requests for repeated pilot transmissions, conflict alerts, and mistakes. Observers' questionaires will consist of items concerning realism of the simulation, difficulty, attention, stress, disruption of traffic flow, time spent in various sub-tasks, and safety. In addition, items on controllers' questionaires will address simulated air traffic load and complexity, difficulty in completing communications, frustration, misunderstandings in communicating with simulation pilots, and satisfaction with their (the test controllers') performance.

7.2 Data Reduction and Analysis

Multiple regression techniques will be employed in the analysis of the data. It is anticipated that dependent variable data will be uploaded into the SAS statistical analysis system and analyzed using the GLM (General Linear Model) procedure. This will provide statistical estimates of the contributions of delay and communications load to the obtained results. Data reduction and summary statistics from all tape sources will be provided by ACN for analysis by TSC. Data reduction from all other sources will be provided by TSC.

7.3 Test Result Evaluation

Where appropriate, tests of statistical significance will be used to assess the probability that differences in results due to delay and communications load are due to chance.

Test Plan Approvals

The Test plan attached satisfies the requirements of the sponsoring organizations to the extent specified in the document. TBDs will be separately approved.

______________	for ATR
______________	for AAP
______________	for ASM
______________	for TSC
______________	for ACN

Appendix B

Analysis and Determination of Communication Delays for Test Purposes

G. Spanier

This analysis includes a description, in textual form, of the actions and related delays that exist or will exist. They are followed by a tabulation of the delays, for additional clarity. This is followed by an explanation of the basis for the selection of the specific delay quantities that are (were) used in the tests in order to simulate the delay conditions. The actual values used in the tests produce EFFECTIVE DELAYS which, as far as the human user of the system is concerned, replicate the real-time, chronological delays of an actual system.

The tests incorporate four different combinations of delays that simulate delay conditions that are expected to exist: the VSCS time frame (abbreviated to 'VSCS'), the real world today (indicated as 'Today'), and both with and without satellite links.

Additional discussion of delays is found in section 4.1, DELAYS, in the ATC Voice Communications Delay Test Plan, 10-17-89, in the Appendix of this report.

The criteria for the communication of a voice message in the context of this analysis are:

a. the utterances by a controller are not clipped or missing from the beginning of a message because the transmitter is not yet ready to transmit at the time that the utterance reaches it.

b. a listener on the frequency hears an indication such as lack of noise level or audio which indicates that the frequency is NOT in use, and such a time period is called 'dead time.'

c. the controller is the effective 'controller' of the frequency, and will not attempt to communicate (transmit) until a pilot who is talking finishes, and the controller actually knows this by message context and noise level.

d. Inadvertent or otherwise malicious transmission by a pilot while the frequency is in use is beyond the control of the controller, and is not taken into account.

e. for purposes of analysis, the shortest times for waiting to transmit after a channel is available are counted, i.e. a PTT action will occur immediately after a frequency is free to use, and a controller is considered to be talking as soon as the transmitter is capable of transmitting.

f. the starting point for all chronological analysis of communications is the end of the voice transmission by a pilot, and the simultaneous turn-off of his transmitter.

g. a squeal is usually considered a positive indication to a listener on a frequency that two or more transmitters in the range of the receiver are turned on.

A. Description

In the present system, the delay from the press of the push-to-talk (PTT) switch by a controller until the controller receives a side tone noise level change (audio cue) from his local communication position equipment indicating that his local equipment is no longer in the receive mode, this delay, is just a few milliseconds. It is actually the local electronics responding to the PTT action, and does not correspond to any pertinent event in time. The PTT action also forces the generation of a signal in the local comm equipment which is called 'transmitter enable' which, when it gets to the transmitter, will instruct the transmitter to turn itself on in a full-power RF transmitting mode. The transmitter 'ON' status is communicated back to the controller's position and turns on an indicator light. There is no audible signal which directly corresponds to that indicator light. The time between PTT and the light turning on, the only positive indication to the controller that the transmitter is in the transmission mode, is 423 milliseconds (ms), comprised of 194 ms from PTT to transmitter, 35 ms for transmitter to enable, and 194 ms for the return signal to reach the local comm equipment to turn on the controller's light. Waiting for the light to turn on before speaking is not and will not be normal practice.

However, all pilots listening on the frequency know that someone has depressed a PTT switch, since they would immediately hear a background noise level change from their receiver due to a received RF signal (audio is not necessary), but they do not know who has initiated the communication. If it is a controller (the important case), then the controller would have initiated the PTT action 229 ms (194 + 35) earlier. During this time interval a communications type of interference called a 'step-on' (see full definition elsewhere in this report) can occur if a PTT switch is depressed by a pilot, and, as a result, the controller will not be aware of that pilot's action, nor of the step-on condition, and the pilot will not be aware of the controller's action. The comm channels are used in a simplex mode; there is no received audio during the time a PTT switch is held on.

Pilot-initiated communications are not subject to any delay in either transmission or controller reception. Step-ons can also occur if pilots simultaneously depress their PTT switches or are not aware of another pilot's transmission. Depending on the locations of the aircraft transmitting simultaneously, others listening on the frequency, including the controller, may hear an audio squeal caused by two RF signals interfering with and affecting the normal operation of the receiver's local oscillator. When a controller hears this, it is a clear indication that all or a portion of a pilot's communication will not be intelligible.

For the case of the use of a ground-to-satellite-to-ground link, 260 ms (see derivation and references) must be added to the worst case Today condition, 229 ms, which results in a total delay of 489 ms before a pilot is aware that the frequency is in use.

For the VSCS time frame system, the delays have different sources, and are identified as follows: The PTT to VSCS output is 30 ms, the local RCE to transmission equipment is 50 ms, the transmission equipment is 4 ms, the transmission equipment to remote RCE output is 50 ms, and the transmitter enable is 35 ms for a total of 169 ms, with an additional 134 ms for the controller to receive the transmitter 'on' status indication.

Once the controller starts to talk, there can be up to a 70 ms utterance delay from local comm equipment, from microphone to aircraft speaker. This delay is also present in communications from pilot's microphone to controller's speaker. The corresponding delay time interval, for a potential step-on of a controller, is 169 ms from transmitter set-up plus 70 ms, or 239 ms, after set-up for the voice utterance to get to the transmitter. The time for receipt of the controller's first utterance is 373 ms if he waits for the transmit enable light - waiting for the light to turn on is not the standard or normal process today, nor will it be in the future.

When a pilot completes his transmission, there is no delay before other pilots know this, but there is that 70 ms delay before the controller knows. This delay must be added to the time that another pilot is not aware that anyone else is transmitting, as explained in the previous paragraph, which changes the pertinent value to 239 ms (169 + 70).

The other delay that can exist is the earth-to-satellite-to-earth link delay, which is a approximately 260 ms (see derivation and references). This value should be added to the worst case VSCS condition (239 ms), which in that case results in a total delay of 499 ms before a pilot is aware that the frequency is in use.

B. Tabulation

The following tabulation of voice communication delays in Today's system, the VSCS system, and with and without satellite link, is based on numbers provided by the SEIC to the VSCS program, by specification values, and confirmed by the program personnel, and uses worst case, 99.9%ile response times, and other values based on measured and specification values and engineering practice. The figures and analysis are specifically directed towards enroute sector air/ground communications.

1. Set Up Time

Real World Today

70	ms	from PTT to output of 4-channel ARTCC comm equipment
60	ms	from comm equip output to tone control equip output
4	ms	transmission equipment input to tone control input
60	ms	from tone control equipment input to xmitter input
35	ms	xmitter turn-on to full power
229	ms	total setup time (line is enabled for controller speech)

Return path controller

60	ms	xmitter enable to output of tone control equip
4	ms	transmission equip input to output
60	ms	tone control input to comm equip input
70	ms	comm equip input to side-tone cue to controller's ear
194	ms	total enable cue return time (controller knows xmitter is enabled)

*****Controllers do not normally wait for any transmitter 'on' signal, either audible or visual, before talking.*****

VSCS

30	ms	from PTT to output of VSCS
50	ms	from VSCS output to RCE output
4	ms	from RCE output to TE out
50	ms	from TE output to RCE output
35	ms	from xmitter input to full power output
169	ms	total setup time

From xmitter enable back to controller's ear

50	ms	xmitter enable to RCE output
4	ms	from RCE output to TE output
50	ms	from TE output to RCE output
30	ms	from VSCS input to side-tone cue to controller's ear
134	ms	total enable cue return time

*****Controllers do not normally wait for any transmitter 'on' signal, either audible or visual, before talking.*****

2. Voice Propagation Delay - Controller/Pilot

Real world today

0.0	ms	from microphone input to speaker output

VSCS Time Frame

70	ms	maximum from microphone to speaker

3. Satellite Link Delay

For a synchronous satellite orbiting the earth at 22,400 NM, with no significant (less than 1.0 ms) delay of retransmission in the satellite, the propagation delay due to distance in air from the earth station to the satellite and then back to an earth station is nominally 262.927 ms. 260 ms is used in this analysis. (See derivation)

Set-up delay with satellite - Today

229	ms	set-up delay w/o satellite
260	ms	transmitter enable signal delay through satellite
489	ms	total

VSCS

70	ms	delay before controller is aware pilot has completed his transmission
169	ms	set-up delay w/o satellite
260	ms	transmitter enable signal delay through satellite
489	ms	total

4. Delay Overlap

For the Today system, both transmitter control signal and audio travel on the same path to the transmitter, which means that the actual delay between a controller PTT action and starting to speak must take into account the 229 ms delay before the transmitter is ready to transmit (to prevent the first part of an utterance from being clipped). Conversely, if a controller speaks at the same time that he presses the PTT switch, approximately 229 ms of audio at the start of a message will not be transmitted (the transmitter may be transmitting a few milliseconds before it gets up to full power output). This applies at all times of start of transmission.

For the VSCS system, the transmitter enable control signal travels through the local comm equipment on one path with delay independent of the path and the delay that audio experiences passing through the local comm equipment. The effect is that in order to avoid clipping audio, a controller need only wait 169 ms (the set-up time) minus 70 ms (the audio delay time), or only 99 ms after PTT before speaking. With this amount of delay, the audio will arrive at the transmitter at just the exact time that the transmitter will be up to transmitting power. Conversely, if a controller speaks at the same time as PTT, only 99 ms of audio will be lost. This number is a worst case number, greatly affected by local communication system voice loading.

This delay overlap requires a careful set-up during the testing, to insure that effective delay is utilized in the simulation laboratory.

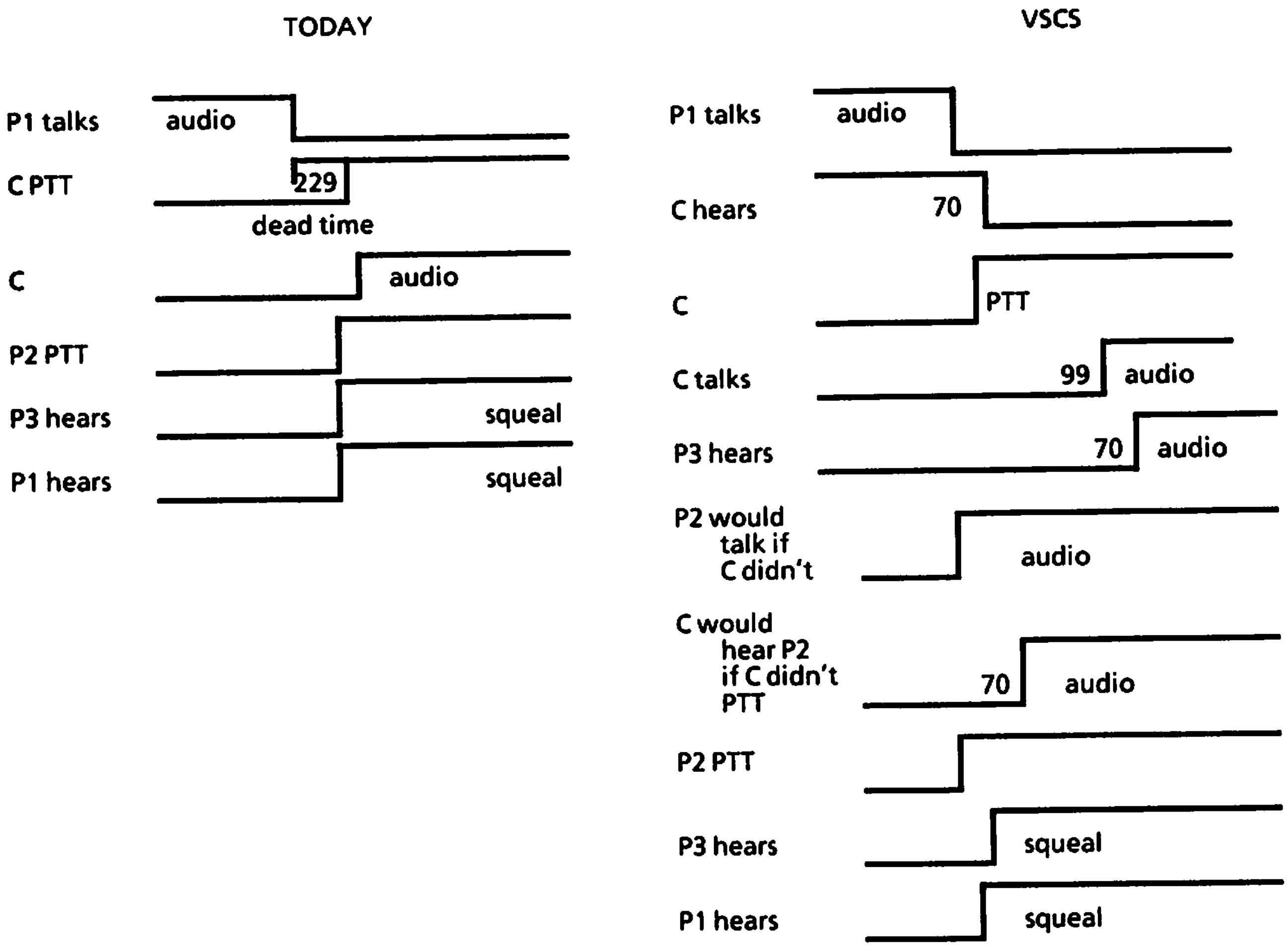
5. Example

Example of critical communication problem, with all delays shown in proper time relationship:

Pilot P1 is talking.

Pilot P2 wants to call, and is waiting for P1 to finish.

Controller C listens to P1, and then wants to talk to a Pilot P3 (or even to P1 again).



The potential for step-ons at the end of a pilot's communication is directly related to the opportunity for step-ons, the effective dead time.

All pilots hear the controller finish an utterance at the same time, today and VSCS, so there is no delay difference effect.

C. Delay Values Chosen

Real World Maximum Delays

	Set -up	Voice	Dead Time
Today	pilot 0 ms ATCS 229 ms	0 ms 0 ms	0+0+229+0 = 229 ms
VSCS	pilot 0 ms ATCS 169 ms	70 ms 70 ms	0+70+169+70-70 = 239 ms
Today/Sat	pilot 0 ms ATCS 229 + 260 ms	260 ms 260 ms	260+229+260 = 749 ms
VSCS/Sat	pilot 0 ms ATCS 169 + 260ms	70+260 ms 70+260 ms	330+169+330-70 = 759 ms

In order to allocate the proper delay values to the simulation equipment, to produce the effective delays experienced, the test values are chosen as:

Simulation Test Values

	Delay Before No Clipping of Audio	Audio Delay	Effective Dead Time
Today	pilot 0 ms ATCS 225 ms *	0 ms 0 ms	0+0+229+0 = 225 ms
VSCS	pilot 0 ms ATCS 99 ms	70 ms 70 ms	70+99+70 = 239 ms
Today/Sat	pilot 0 ms ATCS 225 ms *	260 ms 260 ms	260+225+260 = 745 ms
VSCS/Sat	pilot 0 ms ATCS 99 ms	330 ms 330 ms	339+99+330 = 759 ms

* Rounded to 225 to indicate variability of this measured value.

Appendix C

Simulation Validity

Checks on the validity of the simulation consisted of automatically recorded data and questionnaire items. Automatic counts were made of air traffic density and communication activity. The latter was indicated by the frequency with which the R-controllers keyed their microphones. Tables 1 and 2 show the traffic density and communication activity achieved in the simulation. The intended air traffic density of the simulated sectors was presented in Section 2.4.2. The traffic density values from the simulation show good agreement with the intended traffic levels, the greatest discrepancy being only 1.49 aircraft less than intended in the Macon High high communications load condition.

Three R-controller questionnaire items addressed the realism of the simulation pilots' communications and simulated air traffic. An item concerning the realism of the air traffic in the simulation showed a mean rating of 3.30 on a four-point scale, where 1.0 was "many major differences," 2.0 was "some major differences," 3.0 was "some minor differences," and 4.0 was "almost no differences." Items concerning the R-controllers' subjective impressions of simulation pilot realism indicated that the simulation pilots were perceived to have made as many requests of the controllers as real pilots, as indicated by a mean rating of 3.32 on a five-point scale, where 1.0 was "many fewer," 3.0 was "the same," and 5.0 was "many more." They were also perceived to speak at the same rate as real pilots. Here the mean was again 3.32 on a five-point scale, where 1.0 was "much more slowly," 3.0 was "no difference," and 5.0 was "much more rapidly."

Appendix D

Questionnaires

This appendix contains the questionnaires as well as all the data collected from the questionnaires given to both the operations observers and to the R-controllers. The first four columns of both tables present a row number (one for each respondent), then the level of load (ld), delay (dy), and sector (sc), in that order. The remaining columns are labelled with the question number from the questionnaire. The letter "y" is used to represent missing data for a question with numeric responses and the letter "x" is used to represent missing data for a question with character responses.

Study of the Effect of Equipment Delays on Simulated Air Traffic Operations

Tracking Code _______ Date _______ Time _______ Sector _______

Post-run Questionaire for Test Radar Controllers

The following items pertain to the BUSIEST POINT of the test run that you just completed. Your answers will be kept confidential.

1. At its busiest point, how would you rate the traffic load as compared to actual peak traffic for this sector?

   a. 50% of actual traffic
   b. 60% of actual traffic
   c. 70% of actual traffic
   d. 80% of actual traffic
   e. 90% of actual traffic
   f. 100% of actual traffic
   g. 110% of actual traffic
   h. 120% of actual traffic
   i. 130% of actual traffic
   j. 140% of actual traffic
   k. 150% of actual traffic

2. How realistic was the simulated air traffic compared to actual traffic for this sector?
   a. almost no difference between simulation and real air traffic
   b. some minor differences
   c. some major differences
   d. many major differences between simulation and real air traffic

2a. If you answered c or d in item 1, did these differences affect your work?
   a. yes, they made it easier.
   b. yes, they made it more difficult.
   c. no, the differences did not affect the difficulty of my work.

2b. Please describe the difference(s):

3. Please compare the performance of the simulation pilots with that of actual pilots:

3a. Actual pilots speak:

1	2	3	4	5
much more slowly		no difference		much more rapidly

3b. Actual pilots make:

1	2	3	4	5
many fewer requests		the same number of requests		many more requests

3c. Actual pilots make:
a. the same types of requests
b. different types of requests
If you answered b, please list some examples:

3d. Please describe any other differences between the performance of the simulation pilots and real pilots that may have affected your work:

3e. Indicate any difficulties you experienced in communicating with simulation pilots:

1	2	3	4	5
no difficulties		some difficulties		many difficulties

3f. If any difficulties occurred, please describe the nature of the difficulties.

4. How does the intercom system used in this test run compare to the communications equipment that you are used to? You may skip this item after having answered it after the first run.

4a. Voice Clarity: The intercom system was

1	2	3	4	5
much clearer		the same		much less clear

4b. Amount of Static: The intercom system has

1	2	3	4	5
much less static		the same		much more static

4c. Amount of Crosstalk: The intercom system has

1	2	3	4	5
much less crosstalk		the same		much more crosstalk

5. Please describe any problems with the equipment used in the preceeding test run:

6. Indicate how the D-Controller affected your workload.

1	2	3	4	5
greatly decreased my workload		my workload not affected		greatly increased my workload

7. If you have been assigned to this simulated sector before, in this study, please rate the similarity of the scenario (flights, flight plans, traffic patterns, etc.) to the earlier run(s).

1	2	3	4	5
completely different		some similarity		identical

7a. If there was some similarity to that run (answers 2,3,4 or 5), what was similar? Please describe any similarities in the space below:

8. The amount and complexity of traffic in the simulation was:

1	2	3	4	5
very low		moderate		very high

9. Indicate the amount of attention or concentration required to control the simulated air traffic:
   a. little: my full attention was needed only part of the time.
   b. moderate: my full attention was needed most of the time.
   c. high: my full attention was needed all of the time.
   d. too high: impossible to pay sufficient attention to some aspects of the task.

10. Rate the cause(s) of the scenarios' difficulty (even if it was easy and required little attention) by placing a number from 0-9 in each blank, where 9 indicates a very important cause and 0 indicates no importance.
   a. Number of flights:_______.
   b. Number of voice communications:_______.
   c. Complexity of air traffic:_______.
   d. Simulation pilots' responsiveness to your calls:_______.
   e. Call blocking, hesitations, step-ons:_______.
   f. Other communications problems:_______.
   g. Nonroutine events:_______.
   h. Other:_______.

10a. If you chose a number other than zero for h, please describe the other cause of difficulty:

11. Please rate the overall level of stress that you experienced.

1	2	3	4	5
no stress		moderate stress		excessive stress

12. Were you satisfied with your performance on this test run?
   a. very satisfied
   b. somewhat satisfied
   c. somewhat dissatisfied
   d. very dissatisfied

12a. If you were dissatisfied (c or d), why was this the case?
   Place a number from 0-9 in each blank, where 9 indicates a very important reason and 0 indicates no importance.
   a. Number of flights:_______.
   b. Number of voice communications:_______.
   c. Complexity of air traffic:_______.
   d. Simulation pilots' responsiveness to your calls:_______.
   e. Call blocking, hesitations, step-ons:_______.
   f. Other communications problems:_______.
   g. Nonroutine events:_______.
   h. Other:_______.

Please use the space below for any other comments:

Study of the Effect of Equipment Delays on Simulated Air Traffic Operations

Tracking Number_______ Date _______ Time _______ Sector _______

CONTROLLER OBSERVER'S END OF RUN OBSERVATIONS

All of the following items pertain to the effects of experimental conditions upon participating air traffic controllers. These conditions are arranged to test the impact of new equipment by finding the conditions under which a lower standard of performance occurs. Therefore, a lower standard of performance due to these experimental conditions is anticipated. No conclusions regarding the proficiency of these research participants are warrented by their performance during these tests. Any use of the data or conclusions of this study as indications of the operational performance of the participating controllers would constitute a misinterpretation of the data and the conclusions of the study.

Please describe any uncorrected mistakes that you listed during the preceeding test run. It is assumed that any and all of these mistakes are due to the experimental conditions imposed upon the controller, and are not indicators of controllers' operational performance.

Uncorrected Mistakes (Mis-Speaking):

The following items pertain to the BUSIEST POINT of the test run that you just observed.

1. Please compare the performance of the simulation pilots at the busiest point in the test run with that of real pilots:

1a. Actual pilots speak:
  a. more slowly
  b. more rapidly
  c. no difference

1b. Actual pilots make:
  a. fewer requests
  b. more requests
  c. as many requests

1c. Actual pilots make:
  a. the same types of requests
  b. different types of requests
  If you answered b, please list some examples:

1d. Please describe any other differences between the performance of the simulation pilots and real pilots that may have affected the controller's work:

2. Were all of the simulation pilots' initial calls answered?

1	2	3	4	5
all were answered		some were not answered		many were not answered

3. About how long did the controller spend at various activities?
   a. Talking with pilots: _______%
   b. Talking with D-controller: _______%
   c. Writing on flight strips: _______%
   d. Ground communications: _______%
   e. No observable activity: _______%
   f. Other: _______%
   = 100%

3a. If you placed a number other than zero in f, please describe the other activity:

4. Indicate how the D-Controller affected the R-Controller's workload.

1	2	3	4	5
greatly decreased R's workload		R's workload not affected		greatly increased R's workload

5. Please rate the overall level of the controller's stress as indicated by any signs of stress that you noticed.

1	2	3	4	5
no stress		moderate stress		excessive stress

6. Indicate the amount of attention or concentration required to control the simulated air traffic:
   a. little: controller's full attention was needed only part of the time.
   b. moderate: controller's full attention was needed most of the time.
   c. high: controller's attention was needed all of the time.
   d. too high: impossible to pay sufficient attention to some aspects of the task.

7. Rate the cause(s) of the scenarios' difficulty (even if it was easy and required little attention) by placing a number from 0-9 in each blank, where 9 indicates a very important cause and 0 indicates no importance.
   a. Number of flights:_______.
   b. Number of voice communications:_______.
   c. Complexity of air traffic:_______.
   d. Simulation pilots' responsiveness to calls:_______.
   e. Call blocking, hesitations, step-ons:_______.
   f. Other communications problems:_______.
   g. Nonroutine events:_______.
   h. Other:_______.

7a. If you chose a number other than zero for h, please describe the other cause of difficulty:

8. Did the experimental conditions cause the controller to overcontrol the air traffic?
   a. No overcontrol was apparent.
   b. Some overcontrol was apparent.
   c. Extensive overcontrol was apparent.

9. How smooth was the flow of simulated air traffic?
   a. not disrupted
   b. moderately disrupted
   c. severely disrupted

10. Please discuss anything that you observed in this run that might affect safety in actual operations:

Please use the space below for any other comments.

																Controller Questionnaire Responses																			
row	id	dy	sc	1	2	2a	3a	3b	3c	3e	4a	4b	4c	6	7	8	9	10a	10b	10c	10d	10e	10f	10g	10h	11	12	12a	12b	12c	12d	12e	12f	12g	12h
1	1	0	1	F	B	X	4	4	X	2	Y	Y	Y	3	3	3	B	5	5	4	4	5	4	1	Y	2	A	Y	Y	Y	Y	Y	Y	Y	Y
2	1	0	1	B	B	X	3	3	A	1	Y	Y	Y	3	Y	2	A	3	3	3	3	1	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
3	1	0	1	B	A	X	3	5	B	1	2	2	3	2	Y	2	B	3	2	3	0	1	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
4	1	0	2	D	A	X	5	4	A	1	Y	Y	Y	3	3	3	B	7	7	6	6	5	4	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
5	1	0	2	B	A	X	3	3	A	1	Y	Y	Y	1	Y	2	A	9	3	2	1	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
6	1	0	2	C	B	X	3	4	A	1	Y	Y	1	3	Y	2	A	3	3	3	4	4	0	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
7	1	0	3	C	B	X	4	4	A	3	3	3	3	3	3	2	B	0	0	0	2	0	0	0	Y	1	B	Y	Y	Y	Y	Y	Y	Y	Y
8	1	0	3	C	B	X	3	4	A	4	Y	Y	Y	3	Y	3	B	5	6	4	4	1	1	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
9	1	0	3	B	A	X	3	4	A	1	Y	Y	Y	1	Y	2	A	4	3	5	6	2	0	0	5	2	A	Y	Y	Y	Y	Y	Y	Y	Y
10	1	1	1	B	B	X	3	3	A	1	Y	Y	Y	3	2	2	A	5	6	4	2	2	4	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
11	1	1	1	A	A	X	3	2	X	1	3	3	1	2	Y	2	A	5	5	1	1	1	0	0	3	1	A	0	0	0	0	0	0	0	0
12	1	1	2	A	A	X	3	4	X	3	Y	Y	Y	3	5	1	A	2	2	2	1	0	1	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
13	1	1	2	A	C	A	5	5	B	1	2	2	3	2	Y	1	A	2	1	2	1	0	0	0	0	1	B	Y	Y	Y	Y	Y	Y	Y	Y
14	1	1	3	A	A	X	3	3	A	1	Y	Y	5	1	2	1	A	3	2	1	2	0	0	3	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
15	1	1	3	C	B	X	3	2	X	1	2	2	4	3	Y	3	B	5	4	4	4	3	2	2	0	2	B	0	0	0	0	0	0	0	4
16	1	2	1	F	A	X	4	3	A	2	Y	Y	Y	3	3	3	B	9	8	7	6	5	3	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
17	1	2	1	C	B	X	3	4	B	1	Y	Y	1	3	3	2	A	2	2	2	2	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
18	1	2	2	B	B	X	4	5	B	1	3	3	1	2	2	2	A	0	0	0	0	0	0	0	Y	1	A	Y	Y	Y	Y	Y	Y	Y	Y
19	1	2	2	B	A	X	2	4	A	3	Y	Y	Y	2	4	1	A	2	2	2	2	0	4	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
20	1	2	3	G	B	X	4	3	A	2	Y	Y	Y	4	3	3	B	7	7	6	6	5	4	0	2	3	A	Y	Y	Y	Y	Y	Y	Y	Y
21	1	2	3	C	B	X	3	5	B	1	2	2	3	2	3	2	B	3	3	2	0	1	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
22	1	3	1	D	B	X	1	1	B	1	2	1	1	1	Y	3	B	0	0	4	0	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
23	1	3	1	B	A	X	3	1	A	1	Y	Y	1	1	3	1	A	3	0	3	0	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
24	1	3	2	F	B	X	5	4	A	5	Y	Y	Y	3	Y	3	B	5	7	5	9	7	5	5	7	2	A	Y	Y	Y	Y	Y	Y	Y	Y
25	1	3	2	B	B	C	3	2	B	3	Y	Y	Y	3	5	2	A	4	4	3	3	2	4	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
26	1	3	3	D	A	X	3	3	A	1	Y	Y	Y	3	Y	1	B	9	6	6	6	7	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
27	1	3	3	B	B	X	4	5	X	1	2	1	1	3	4	2	A	2	3	3	2	1	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
28	2	0	1	G	A	X	4	5	A	3	3	1	2	2	5	3	B	1	0	0	0	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
29	2	0	1	D	C	B	3	2	B	4	Y	Y	Y	5	3	4	C	7	7	7	9	1	9	0	9	4	B	Y	Y	Y	Y	Y	Y	Y	Y
30	2	0	2	D	B	X	4	3	B	3	Y	Y	Y	3	3	2	B	4	5	5	6	6	5	3	4	2	A	Y	Y	Y	Y	Y	Y	Y	Y
31	2	0	2	D	B	X	4	3	A	4	Y	Y	Y	3	3	4	B	6	7	6	7	1	9	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
32	2	0	2	D	A	X	3	3	A	3	Y	Y	Y	1	5	2	A	5	4	5	6	6	7	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
33	2	0	3	F	A	X	4	2	A	3	3	3	2	3	3	4	C	9	8	8	6	7	5	3	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y

													Controller Questionnaire Responses																						
row	ld	dy	sc	1	2	2a	3a	3b	3c	3e	4a	4b	4c	6	7	8	9	10a	10b	10c	10d	10e	10f	10g	10h	11	12	12a	12b	12c	12d	12e	12f	12g	12h
34	2	0	3	D	A	X	3	3	A	1	Y	Y	1	1	3	3	B	6	6	7	0	2	0	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
35	2	0	3	F	A	X	3	5	B	1	2	2	3	2	1	4	C	9	8	9	0	3	0	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
36	2	1	1	H	B	X	4	3	A	3	3	4	1	3	Y	4	C	7	6	7	9	8	7	7	Y	3	A	Y	Y	Y	Y	Y	Y	Y	Y
37	2	1	1	D	B	X	3	3	A	2	1	1	1	3	Y	3	B	9	7	6	3	1	8	0	0	3	B	Y	Y	Y	Y	Y	Y	Y	Y
38	2	1	2	E	A	X	3	3	A	3	Y	Y	Y	3	Y	2	B	5	4	7	6	6	3	2	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
39	2	1	2	B	B	X	3	4	A	4	3	3	3	3	Y	2	A	5	5	3	2	1	6	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
40	2	1	3	H	D	B	5	1	X	5	3	3	4	3	Y	5	C	9	9	9	9	5	Y	Y	Y	3	D	9	9	9	9	4	0	0	0
41	2	1	3	F	B	X	4	4	A	1	2	2	2	4	Y	4	C	8	8	7	6	3	0	0	0	2	B	Y	Y	Y	Y	Y	Y	Y	Y
42	2	2	1	E	B	X	3	3	A	3	Y	Y	Y	3	4	4	C	8	8	7	4	4	5	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
43	2	2	1	D	A	X	3	3	A	1	Y	Y	Y	2	3	3	B	5	3	5	2	2	0	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
44	2	2	2	D	A	X	3	2	A	3	Y	Y	2	1	3	2	A	5	5	2	3	2	8	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
45	2	2	2	A	B	X	3	5	B	1	2	2	3	2	4	2	A	3	3	2	0	0	0	0	0	1	C	0	0	0	0	0	0	0	9
46	2	2	3	F	A	X	3	3	A	1	3	Y	Y	2	3	4	C	9	9	7	4	0	3	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
47	2	2	3	D	B	X	3	4	A	1	Y	Y	Y	2	3	3	B	5	4	6	6	0	0	0	0	3	B	Y	Y	Y	Y	Y	Y	Y	Y
48	2	3	1	G	A	X	5	3	A	2	2	2	2	3	4	5	C	9	8	8	5	5	4	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
49	2	3	1	F	A	X	3	5	B	1	2	2	3	2	3	5	C	9	6	9	0	3	0	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
50	2	3	2	C	B	X	1	4	B	3	3	3	1	3	1	2	B	0	0	0	0	9	9	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
51	2	3	2	D	A	X	3	3	A	1	Y	Y	3	3	3	2	A	2	2	2	2	0	0	0	0	2	B	Y	Y	Y	Y	Y	Y	Y	Y
52	2	3	3	H	B	X	4	3	B	3	Y	Y	4	4	3	4	C	8	7	8	6	5	4	4	3	3	A	Y	Y	Y	Y	Y	Y	Y	Y
53	2	3	3	F	A	X	3	3	A	2	Y	Y	Y	1	4	5	C	Y	8	7	5	3	3	0	4	4	B	Y	Y	Y	Y	Y	Y	Y	Y
54	3	0	1	H	B	X	3	1	A	3	Y	Y	2	1	3	4	C	9	8	8	2	4	6	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
55	3	0	1	D	A	X	3	3	A	1	Y	Y	Y	3	Y	4	B	7	7	7	2	5	0	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
56	3	0	1	D	A	X	3	3	A	1	Y	Y	1	3	3	3	B	6	7	6	6	0	0	0	Y	2	A	Y	Y	Y	Y	Y	Y	Y	Y
57	3	0	2	F	B	X	3	2	B	4	Y	Y	Y	5	3	4	D	8	8	9	4	2	5	5	7	4	B	Y	Y	Y	Y	Y	Y	Y	Y
58	3	0	2	D	B	X	3	5	B	1	2	2	3	2	3	3	B	5	4	4	0	2	0	0	0	2	B	Y	Y	Y	Y	Y	Y	Y	Y
59	3	0	3	H	B	X	3	3	X	1	Y	Y	Y	2	2	5	D	9	9	9	5	7	0	0	0	3	B	Y	Y	Y	Y	Y	Y	Y	Y
60	3	0	3	G	A	X	3	3	A	1	Y	Y	2	3	3	5	C	7	7	7	7	3	0	0	0	3	B	Y	Y	Y	Y	Y	Y	Y	Y
61	3	1	1	H	C	X	1	3	A	3	3	3	1	3	1	4	C	8	7	8	9	5	5	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
62	3	1	1	G	C	B	3	Y	B	3	Y	Y	3	3	3	5	C	8	8	8	8	0	0	0	0	4	B	Y	Y	Y	Y	Y	Y	Y	Y
63	3	1	1	G	B	X	3	5	B	3	2	2	3	2	1	5	C	9	8	9	2	5	2	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
64	3	1	2	G	B	X	4	4	B	3	Y	Y	Y	4	3	4	C	6	6	5	8	5	5	7	3	3	A	Y	Y	Y	Y	Y	Y	Y	Y
65	3	1	2	C	A	X	3	3	A	1	Y	Y	Y	2	4	3	B	7	7	4	2	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
66	3	1	2	F	A	X	3	4	A	1	Y	Y	3	3	4	4	B	7	7	5	4	3	0	0	Y	3	A	Y	Y	Y	Y	Y	Y	Y	Y

Controller Questionnaire Responses

row	Id	dy	sc	1	2	2a	3a	3b	3c	3e	4a	4b	4c	6	7	8	9	10a	10b	10c	10d	10e	10f	10g	10h	11	12	12a	12b	12c	12d	12e	12f	12g	12h
67	3	1	3	G	A	X	4	3	A	3	Y	Y	Y	3	3	5	C	9	8	8	7	5	4	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
68	3	1	3	H	B	X	3	5	B	1	2	2	3	2	2	5	D	9	9	9	6	8	0	0	0	4	B	Y	Y	Y	Y	Y	Y	Y	Y
69	3	1	3	G	A	X	4	3	A	1	Y	Y	Y	4	3	5	C	9	8	9	9	7	7	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
70	3	2	1	K	C	B	5	3	A	4	Y	Y	Y	1	4	5	D	9	9	9	8	6	5	9	9	5	B	Y	Y	Y	Y	Y	Y	Y	Y
71	3	2	1	G	B	X	3	4	A	5	Y	Y	Y	4	Y	5	D	9	9	9	2	2	9	0	0	4	B	Y	Y	Y	Y	Y	Y	Y	Y
72	3	2	2	E	A	X	5	4	A	3	3	2	2	3	4	3	B	9	8	7	8	6	7	0	0	2	A	Y	Y	Y	Y	Y	Y	Y	Y
73	3	2	2	G	B	X	3	3	A	3	Y	Y	Y	5	Y	5	C	9	9	9	8	7	8	0	8	3	A	Y	Y	Y	Y	Y	Y	Y	Y
74	3	2	3	G	B	X	4	2	A	3	3	3	5	3	2	3	B	2	0	2	9	5	1	0	0	2	C	0	0	0	9	0	0	0	0
75	3	2	3	I	C	B	3	3	A	2	Y	Y	Y	4	Y	5	C	9	9	8	7	7	6	0	0	4	A	Y	Y	Y	Y	Y	Y	Y	Y
76	3	3	1	H	B	X	4	3	A	3	Y	Y	Y	4	4	5	D	9	9	8	8	8	0	0	0	3	B	Y	Y	Y	Y	Y	Y	Y	Y
77	3	3	1	H	C	A	3	4	B	1	Y	Y	Y	2	Y	5	C	9	8	9	0	5	0	0	0	3	A	Y	Y	Y	Y	Y	Y	Y	Y
78	3	3	2	F	A	X	3	4	A	1	Y	Y	1	1	3	3	B	7	7	5	2	0	0	0	0	1	A	Y	Y	Y	Y	Y	Y	Y	Y
79	3	3	2	E	A	X	4	3	A	5	Y	Y	Y	1	Y	3	C	5	9	5	9	4	9	0	7	3	B	Y	Y	Y	Y	Y	Y	Y	Y
80	3	3	3	G	B	X	3	3	A	4	Y	Y	Y	5	4	5	D	9	9	7	4	9	9	2	0	4	A	Y	Y	Y	Y	Y	Y	Y	Y
81	3	3	3	H	C	B	3	4	B	3	Y	Y	3	3	3	4	C	6	6	7	7	0	0	0	0	4	X	Y	Y	Y	Y	Y	Y	Y	Y

Operations Observer Questionnaire Responses

row	id	dy	sc	1a	1b	1c	2	3a	3b	3c	3d	3e	3f	4	5	6	7a	7b	7c	7d	7e	7f	7g	7h	8	9
1	1	0	1	C	B	A	1	40	5	5	0	50	0	3	1	A	1	1	2	2	1	0	0	0	A	A
2	1	0	1	C	B	A	1	50	5	5	0	40	0	3	1	A	3	3	3	1	1	5	0	0	A	A
3	1	0	1	C	B	A	1	50	10	5	5	30	y	3	1	A	5	4	5	2	1	0	0	0	A	A
4	1	0	2	B	C	A	1	35	10	19	1	20	15	3	1	A	1	1	1	1	1	1	1	0	A	A
5	1	0	2	C	C	A	2	40	40	5	10	0	5	3	1	A	1	1	1	1	1	0	0	0	A	A
6	1	0	2	C	C	A	1	45	15	10	5	20	5	3	1	A	1	1	1	1	0	0	0	0	A	A
7	1	0	3	C	C	A	2	50	5	5	2	38	0	3	1	A	2	1	0	2	2	0	0	0	A	A
8	1	0	3	C	B	A	2	40	20	5	0	35	0	3	1	A	3	2	1	0	0	0	0	0	A	A
9	1	0	3	C	B	B	1	50	10	10	0	30	y	3	1	A	2	2	2	0	0	0	0	0	A	A
10	1	1	1	C	C	A	1	40	10	5	0	45	0	3	1	A	3	1	3	0	0	0	0	0	A	A
11	1	1	2	C	C	A	1	35	20	10	5	20	10	3	1	A	1	1	1	1	0	0	0	0	A	A
12	1	1	2	C	C	A	1	30	25	5	5	30	5	2	1	A	1	1	1	1	0	0	0	0	A	A
13	1	1	3	C	B	B	1	30	5	15	2	43	0	3	1	A	2	1	2	0	0	0	0	0	A	A
14	1	1	3	C	B	B	2	50	15	10	2	23	8	3	1	A	3	3	2	2	1	0	0	0	A	A
15	1	2	1	B	B	A	1	50	0	5	0	45	0	3	1	A	4	1	3	2	1	0	0	0	A	A
16	1	2	1	C	B	A	1	50	10	5	10	25	y	3	1	A	5	4	4	1	0	0	0	0	A	A
17	1	2	2	B	C	A	1	40	10	10	5	35	0	3	1	A	2	2	2	2	2	2	0	0	A	A
18	1	2	2	C	C	A	1	35	20	10	2	23	10	3	1	A	1	1	1	1	0	0	0	0	A	A
19	1	2	3	B	B	B	2	40	10	5	0	45	0	3	1	A	2	1	1	2	3	0	0	0	A	A
20	1	2	3	C	B	A	2	40	15	5	0	40	0	3	1	A	2	1	2	0	1	0	0	0	A	A
21	1	3	1	B	B	A	1	35	5	5	0	55	0	3	1	A	3	2	2	4	0	0	0	0	A	A
22	1	3	1	C	B	A	1	55	5	5	10	25	0	3	1	A	3	2	3	1	1	0	0	0	A	A
23	1	3	2	B	C	A	2	35	24	10	1	20	10	3	1	A	2	2	2	2	2	0	0	0	A	A
24	1	3	2	C	C	A	1	40	5	10	10	30	5	3	1	A	1	1	1	1	0	0	0	0	A	A
25	1	3	3	C	B	B	1	40	20	5	1	34	0	3	1	A	2	2	2	2	0	0	0	0	A	A
26	1	3	3	C	B	B	1	40	5	10	2	43	0	3	1	A	3	2	0	0	1	0	0	0	A	A
27	2	0	1	B	B	A	1	50	5	5	0	40	0	3	1	A	4	3	3	3	0	0	0	0	A	A
28	2	0	1	B	B	A	1	60	5	5	5	25	0	3	1	B	3	1	3	1	1	0	0	0	A	A
29	2	0	1	C	B	A	1	50	10	10	5	25	0	3	1	A	6	5	5	2	1	0	0	0	A	A
30	2	0	2	B	C	A	2	44	30	10	1	5	10	3	2	B	2	2	2	2	2	2	2	0	A	A
31	2	0	2	C	C	A	1	40	25	20	5	0	10	3	1	B	2	2	2	3	0	0	0	0	A	A
32	2	0	2	C	C	A	1	50	25	10	5	5	5	3	1	B	3	2	2	1	0	0	0	0	A	A
33	2	0	3	C	B	A	2	75	5	5	0	15	0	4	2	C	7	6	5	4	5	0	0	0	A	A

									Operations Observer Questionnaire Responses																
row	ld	dy	sc	1a	1b	1c	2	3a	3b	3c	3d	3e	3f	4	5	6	7a	7b	7c	7d	7e	7f	7g	7h	8	9
34	2	0	3	C	B	A	1	60	3	15	1	21	0	3	1	B	4	3	4	2	1	0	0	0	A	A
35	2	0	3	C	B	A	2	60	10	15	2	13	0	3	1	C	6	5	5	4	2	0	0	0	A	A
36	2	1	1	B	B	A	3	75	10	15	0	0	0	3	2	B	8	5	8	7	4	2	0	0	A	A
37	2	1	1	C	B	A	2	80	5	5	0	10	0	3	2	B	8	7	8	4	2	5	0	0	A	A
38	2	1	1	C	B	A	1	65	5	5	5	20	y	3	1	A	4	2	4	0	0	0	0	0	A	A
39	2	1	2	A	C	A	2	40	15	15	0	30	0	4	1	B	2	2	2	4	2	1	0	0	A	A
40	2	1	2	B	C	A	1	45	20	13	2	10	10	3	1	B	1	1	1	1	1	3	0	0	A	A
41	2	1	3	B	B	B	2	60	10	10	0	20	0	3	2	B	4	6	4	7	5	2	3	3	A	A
42	2	1	3	C	B	A	1	75	10	10	1	4	0	3	2	C	6	5	4	2	1	0	0	0	A	A
43	2	2	1	C	C	A	2	75	5	5	0	15	0	3	2	B	6	4	7	1	1	0	0	0	A	A
44	2	2	1	C	C	A	2	80	10	5	5	0	0	3	2	B	6	5	7	3	2	0	0	0	A	A
45	2	2	2	C	C	A	2	30	20	10	5	20	15	3	1	A	1	1	1	1	1	0	0	0	A	A
46	2	2	2	C	C	A	1	40	15	5	5	25	10	2	2	B	2	2	2	1	1	0	0	0	A	A
47	2	2	3	C	B	A	2	55	10	15	0	20	y	3	1	B	2	3	1	0	1	0	0	0	A	A
48	2	2	3	C	B	A	2	60	5	15	0	20	0	3	2	B	6	5	4	2	2	0	0	0	A	A
49	2	3	1	B	B	A	2	65	5	5	0	25	0	3	2	B	8	4	8	3	2	2	0	0	A	A
50	2	3	1	B	B	A	2	80	5	5	10	0	0	3	3	B	8	7	8	4	2	0	0	0	A	A
51	2	3	2	B	C	A	1	30	20	10	0	30	10	2	1	B	1	1	1	2	1	2	3	0	A	A
52	2	3	2	C	C	A	1	40	10	10	2	28	10	3	1	A	1	1	1	1	1	0	0	0	A	A
53	2	3	3	C	C	A	2	60	7	10	0	23	0	4	1	C	5	6	5	4	3	0	0	0	A	A
54	2	3	3	C	B	A	1	60	10	15	0	15	0	3	2	C	6	5	7	2	1	0	0	0	A	A
55	3	0	1	C	B	A	2	80	5	10	5	0	0	3	2	C	7	6	8	4	2	0	0	0	A	A
56	3	0	1	C	C	A	2	85	0	10	0	5	0	3	2	C	8	6	8	3	4	0	0	0	A	A
57	3	0	2	C	C	A	2	60	5	10	10	0	15	4	3	C	5	4	3	2	2	2	0	0	A	A
58	3	0	2	C	C	A	2	60	10	10	2	8	10	2	3	C	5	4	5	4	2	0	0	0	A	A
59	3	0	3	C	C	A	2	80	5	10	0	5	0	3	3	C	8	6	8	2	4	0	0	0	A	A
60	3	0	3	C	C	A	2	80	0	15	0	5	0	3	3	C	9	7	8	2	4	0	0	0	B	B
61	3	1	1	B	B	A	2	80	5	5	0	10	0	3	3	B	8	7	8	6	3	0	0	0	A	A
62	3	1	1	C	B	A	3	90	5	5	0	0	0	3	3	C	8	7	9	6	5	0	0	0	B	B
63	3	1	1	C	B	A	2	90	5	5	0	0	0	3	3	C	8	7	9	5	0	0	0	0	A	A
64	3	1	2	B	C	A	2	40	20	14	1	5	20	4	3	B	4	1	3	4	1	1	3	0	A	A
65	3	1	2	C	C	A	1	65	10	10	5	2	8	3	3	C	4	4	2	1	0	0	0	0	A	A
66	3	1	2	C	C	A	2	60	20	10	5	0	5	4	3	B	6	5	2	3	2	0	0	0	A	A

									Operations Observer Questionnaire Responses																	
row	Id	dy	sc	1a	1b	1c	2	3a	3b	3c	3d	3e	3f	4	5	6	7a	7b	7c	7d	7e	7f	7g	7h	8	9
67	3	1	3	B	C	A	2	80	10	15	0	5	0	3	2	C	7	6	6	4	4	0	0	0	A	A
68	3	1	3	C	C	A	2	85	0	15	0	0	0	3	4	C	9	9	7	8	4	0	0	0	A	A
69	3	1	3	C	B	A	2	80	5	10	0	5	0	3	2	C	6	5	4	3	2	0	0	0	A	A
70	3	2	1	B	B	A	2	80	5	5	0	0	10	3	4	D	8	8	9	7	6	y	6	0	A	B
71	3	2	1	C	C	A	1	85	5	10	0	0	0	4	2	C	5	5	5	3	3	0	0	0	A	A
72	3	2	2	A	C	A	1	30	30	10	0	0	30	4	1	B	2	2	2	2	2	2	2	0	A	A
73	3	2	2	C	C	A	2	50	20	10	10	0	10	3	2	C	5	1	2	1	1	1	0	0	A	A
74	3	2	3	C	C	A	1	50	10	5	0	35	0	2	2	B	2	3	3	5	2	3	0	0	A	A
75	3	2	3	B	B	A	2	80	5	10	1	4	0	4	2	C	8	6	5	5	3	4	0	0	A	A
76	3	3	1	C	C	A	2	80	10	5	0	5	0	3	3	C	8	8	9	3	6	1	0	0	A	A
77	3	3	1	C	C	A	2	90	5	5	0	0	y	3	3	D	9	7	8	4	7	0	0	0	B	B
78	3	3	2	C	C	A	2	40	20	10	10	0	20	4	3	C	5	4	5	3	1	1	0	0	A	A
79	3	3	2	C	C	A	1	65	10	10	5	5	5	4	2	B	4	3	2	5	1	2	1	0	A	A
80	3	3	3	C	B	A	2	80	0	2	0	18	y	4	2	C	8	7	7	4	5	0	3	0	A	A
81	3	3	3	C	C	A	3	80	5	10	0	0	5	3	3	C	7	8	7	4	5	0	0	0	A	A

Appendix E

Analysis Procedures

In order to develop unbiased and accurate comparisons between the various categories of delay it was desired that the sessions incorporate each level of delay with other independent variables (experimental conditions) in a balanced manner, i.e., if delay 1 appears X percent of the time under medium communication workload then delay 2 also appears X percent of the time under medium communication workload. The experimental design achieved a maximum degree of balance for the size of the experiment, but perfect balance was not achieved. Even with an imperfectly balanced design the analysis can, to an extent, correct for imbalance. This assumes that the design is analyzable - roughly that there is a representative mixture of combinations of conditions in the design. Although the design was not completely balanced, it was analyzable, and corrections for lack of balance were made.

Before describing the regression model that was used, it is necessary to consider the data set on which it operated. The regression was performed using the Statistical Analysis System (SAS). The data set consisted of 81 records; 27 experimental trials (or sessions) and three test sectors in each session. Each record included data on a number of variables including communication workload, delay, and subject. The communication workload and delay values were the same for all three records pertaining to a given session (i.e. the records from the three test sectors). The subject variable indicated which of the R-controllers worked in the session/sector combination that created that record. In addition to the four independent variables, each of the 81 records included several dependent variables. These were counts of various events which occurred during the session. For example, one was the count of controller-pilot step-ons.

The regression model that was used (Model 1 in Appendix G) specified the above four independent variables and also the interactions of delay with communication workload and sector. The SAS GLM (General Linear Model) program partitions the sum of the squares in each dependent variable among the specified factors and interactions and uses the residual sum of the squares to estimate a mean square error to form a basis for deciding statistical significance for all comparisons to be made in the analysis. Each factor, interaction, and even comparisons of specific levels of the independent variables is tested for significance using the mean square error. The comparisons of various conditions may be made using the least square (LS) means generated by SAS. The LS means are estimates of the average values of dependent variables under various conditions specified by combinations of independent variables. These estimates are corrected for unbalance in the experimental design. For example, LS means for step-ons were computed at each level of the delay. These estimate the mean number of step-ons at each level of delay and are corrected for the fact that a given delay was not necessarily tested equally often under each communication workload condition nor with each subject.

The output of the SAS GLM procedure gives information for deciding on the statistical significance of the individual factors and interactions based on their "partial" sums-of-squares. The LS means can also be obtained as well as "p-diffs". The latter are for assessing the significance of differences in LS means. The SAS GLM output also includes an R2 value and a probability value for the model. The R2 value indicates the extent to which the dependent variable is affected by all of the independent variables in the regression. The model probability value gives information for determining the significance of the independent variables considered together.

When the LS means of all levels of a factor are to be compared then a correction for multiple testing is required. In SAS, means and simple factors (e.g., differences in step-ons due to different categories of delay) are corrected, but not compound factors (e.g., interactions). The correction of interactions requires a separate analysis, using Tukey's HSD (Honestly Significant Difference). Consequently, compound factors are constructed first and then the regression (GLM) for constructing the Tukey HSDs is run. This regression uses essentially the same model but the variables are coded differently (using the compound variables). Tukey's HSDs permit significance statements which are controlled to limit the total Type 1 Error even if all possible differences are of potential interest. Without the Tukey HSD, there would be a possibility that some effects noted in the study which might appear to be statistically significant were really not. Since the HSD analysis corrects for multiple testing we use a significance level of .05 for it. However, in general we attempt to limit the cumulative error using .01 as the level of significance.

All data from the first session was lost due to a procedural error in the simulation. Also, automatically recorded data from three sessions was lost due to problems with magnetic tape storage. The effect of the missing data was negligible; sufficient data was obtained for the estimation of the parameters needed to make all of the planned comparisons.

Appendix F

SAS Output

This appendix contains the SAS output from the regressions used for the study. The dependent variables analyzed are: Corrected Mistakes (CM), Uncorrected Mistakes (UM), Step-ons recorded in the controller lab (S0 + S1 + S2), Step-ons recorded in the pilot lab (STEPS), Pilot-Pilot Step-ons (PP), Stress reported by the operations observers, Stress reported by the controllers, Attention and Concentration reported by the operations observers, Attention and Concentration reported by the controllers.

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJ	9	1 2 3 4 5 6 7 8 9
LOAD	3	1 2 3
DELAY	4	0 1 2 3
SECTOR	3	1 2 3

NUMBER OF OBSERVATIONS IN DATA SET = 81

DEPENDENT VARIABLE: CM

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	547.17611374	20.26578199
ERROR	53	209.51524428	3.95311782
CORRECTED TOTAL	80	756.69135802	

MODEL F = 5.13 PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	CM MEAN
0.723117	64.9386	1.98824491	3.06172840

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	201.53580247	6.37	0.0001
LOAD	2	164.31142498	20.78	0.0001
DELAY	3	2.10907822	0.18	0.9110
SECTOR	2	157.74235917	19.95	0.0001
DELAY*SECTOR	6	10.53710641	0.44	0.8458
LOAD*DELAY	6	10.94034250	0.46	0.8338

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	171.30618429	5.42	0.0001
LOAD	2	150.25528223	19.00	0.0001
DELAY	3	1.37785309	0.12	0.9502
SECTOR	2	158.31943825	20.02	0.0001
DELAY*SECTOR	6	10.53710641	0.44	0.8458
LOAD*DELAY	6	10.94034250	0.46	0.8338

DEPENDENT VARIABLE: UM

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	49.37805217	1.82881675
ERROR	53	46.62194783	0.87965939
CORRECTED TOTAL	80	96.00000000	

MODEL F = 2.08 PR > F = 0.0114

R-SQUARE	C.V.	ROOT MSE	UM MEAN
0.514355	211.0279	0.93790159	0.44444444

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	19.93888889	2.83	0.0108
LOAD	2	6.80759573	3.87	0.0270
DELAY	3	2.80484371	1.06	0.3727
SECTOR	2	4.67829132	2.66	0.0793
DELAY*SECTOR	6	1.60433921	0.30	0.9321
LOAD*DELAY	6	13.54409331	2.57	0.0295

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	14.93757598	2.12	0.0496
LOAD	2	6.96947066	3.96	0.0249
DELAY	3	3.32085860	1.26	0.2981
SECTOR	2	5.18954075	2.95	0.0610
DELAY*SECTOR	6	1.60433921	0.30	0.9321
LOAD*DELAY	6	13.54409331	2.57	0.0295

DEPENDENT VARIABLE: S0+S1+S2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	564.89653837	20.92209401
ERROR	53	190.83185669	3.60060107
CORRECTED TOTAL	80	755.72839506	

MODEL F = 5.81 PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	S0+S1+S2 MEAN
0.747486	55.4872	1.89752499	3.41975309

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	67.01728395	2.33	0.0321
LOAD	2	209.95204018	29.16	0.0001
DELAY	3	40.41697061	3.74	0.0164
SECTOR	2	164.42427638	22.83	0.0001
DELAY*SECTOR	6	22.28764182	1.03	0.4153
LOAD*DELAY	6	60.79832545	2.81	0.0188

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	68.46576236	2.38	0.0288
LOAD	2	227.33850000	31.57	0.0001
DELAY	3	36.16478473	3.35	0.0258
SECTOR	2	170.10625031	23.62	0.0001
DELAY*SECTOR	6	22.28764182	1.03	0.4153
LOAD*DELAY	6	60.79832545	2.81	0.0188

LEAST SQUARES MEANS

DELAY	CM LSMEAN	PROB |T| H0: LSMEAN(I)=LSMEAN(J) I/J	1	2	3	4
0	2.94417300	1	.	0.5803	0.9295	0.7913
1	3.28130655	2	0.5803	.	0.6645	0.7929
2	3.00000000	3	0.9295	0.6645	.	0.8675
3	3.11111111	4	0.7913	0.7929	0.8675	.

DELAY	UM LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3	4
0	0.26583424	1	.	0.2480	0.0897	0.8206
1	0.59971046	2	0.2480	.	0.5608	0.3852
2	0.77777778	3	0.0897	0.5608	.	0.1610
3	0.33333333	4	0.8206	0.3852	0.1610	.

DELAY	S0+S1+S2 LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3	4
0	3.14214622	1	.	0.7151	0.0109	0.5528
1	2.92987695	2	0.7151	.	0.0052	0.3585
2	4.72222222	3	0.0109	0.0052	.	0.0587
3	3.50000000	4	0.5528	0.3585	0.0587	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

LOAD	CM LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3
1	1.31944444	1	.	0.0012	0.0001
2	3.20833333	2	0.0012	.	0.0084
3	4.72466522	3	0.0001	0.0084	.

LOAD	UM LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3
1	0.08333333	1	.	0.0468	0.0093
2	0.61111111	2	0.0468	.	0.5011
3	0.78804741	3	0.0093	0.5011	.

LEAST SQUARES MEANS

LOAD	S0+S1+S2 LSMEAN	PROB |T| H0: LSMEAN(I)=LSMEAN(J) I/J	1	2	3
1	1.55555556	1	.	0.0008	0.0001
2	3.41666667	2	0.0008	.	0.0001
3	5.74846182	3	0.0001	0.0001	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

LOAD	DELAY	CM LSMEAN	LSMEAN NUMBER
1	0	0.77777778	1
1	1	1.88807456	2
1	2	1.25560984	3
1	3	1.35631560	4
2	0	3.00000000	5
2	1	2.68964893	6
2	2	3.38807456	7
2	3	3.75560984	8
3	0	5.05474122	9
3	1	5.26619616	10
3	2	4.35631560	11
3	3	4.22140789	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.3011	0.6547	0.5881	0.0214	0.0775	0.0174	0.0071
2	0.3011	.	0.5971	0.6562	0.3004	0.5027	0.1970	0.1223
3	0.6547	0.5971	.	0.9326	0.1065	0.2317	0.0787	0.0339
4	0.5881	0.6562	0.9326	.	0.1276	0.2506	0.0930	0.0480
5	0.0214	0.3004	0.1065	0.1276	.	0.7712	0.7166	0.4800
6	0.0775	0.5027	0.2317	0.2506	0.7712	.	0.5591	0.3725
7	0.0174	0.1970	0.0787	0.0930	0.7166	0.5591	.	0.7585
8	0.0071	0.1223	0.0339	0.0480	0.4800	0.3725	0.7585	.
9	0.0002	0.0079	0.0024	0.0030	0.0587	0.0516	0.1524	0.2796
10	0.0001	0.0029	0.0004	0.0009	0.0216	0.0237	0.0884	0.1572
11	0.0014	0.0426	0.0116	0.0116	0.2070	0.1524	0.4187	0.6144
12	0.0021	0.0471	0.0158	0.0194	0.2558	0.2028	0.4711	0.6969

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.0002	0.0001	0.0014	0.0021
2	0.0079	0.0029	0.0426	0.0471
3	0.0024	0.0004	0.0116	0.0158
4	0.0030	0.0009	0.0116	0.0194
5	0.0587	0.0216	0.2070	0.2558
6	0.0516	0.0237	0.1524	0.2028
7	0.1524	0.0884	0.4187	0.4711

LEAST SQUARES MEANS FOR EFFECT LOAD*DELAY

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

DEPENDENT VARIABLE: CM

I/J	9	10	11	12
8	0.2796	0.1572	0.6144	0.6969
9	.	0.8458	0.5591	0.4711
10	0.8458	.	0.4144	0.3386
11	0.5591	0.4144	.	0.9100
12	0.4711	0.3386	0.9100	.

LEAST SQUARES MEANS

LOAD	DELAY	UM LSMEAN	LSMEAN NUMBER
1	0	-0.00000000	1
1	1	0.18639160	2
1	2	0.02461093	3
1	3	0.12233080	4
2	0	0.44444444	5
2	1	1.45566413	6
2	2	0.35305827	7
2	3	0.19127760	8
3	0	0.35305827	9
3	1	0.15707564	10
3	2	1.95566413	11
3	3	0.68639160	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.7117	0.9610	0.8080	0.3194	0.0053	0.4846	0.7042
2	0.7117	.	0.7742	0.9094	0.6091	0.0276	0.7594	0.9931
3	0.9610	0.7742	.	0.8619	0.4059	0.0134	0.5607	0.7594
4	0.8080	0.9094	0.8619	.	0.5229	0.0171	0.6822	0.9023
5	0.3194	0.6091	0.4059	0.5229	.	0.0486	0.8561	0.6155
6	0.0053	0.0276	0.0134	0.0171	0.0486	.	0.0543	0.0279
7	0.4846	0.7594	0.5607	0.6822	0.8561	0.0543	.	0.7742
8	0.7042	0.9931	0.7594	0.9023	0.6155	0.0279	0.7742	.
9	0.4846	0.7594	0.5607	0.6822	0.8561	0.0543	1.0000	0.7742
10	0.7294	0.9544	0.7907	0.9472	0.5274	0.0160	0.7025	0.9454
11	0.0003	0.0026	0.0011	0.0013	0.0039	0.3600	0.0060	0.0026
12	0.1770	0.3600	0.2434	0.3187	0.6315	0.1756	0.5408	0.3815

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.4846	0.7294	0.0003	0.1770
2	0.7594	0.9544	0.0026	0.3600
3	0.5607	0.7907	0.0011	0.2434
4	0.6822	0.9472	0.0013	0.3187
5	0.8561	0.5274	0.0039	0.6315
6	0.0543	0.0160	0.3600	0.1756
7	1.0000	0.7025	0.0060	0.5408
8	0.7742	0.9454	0.0026	0.3815
9	.	0.7025	0.0060	0.5408
10	0.7025	.	0.0011	0.3044
11	0.0060	0.0011	.	0.0276
12	0.5408	0.3044	0.0276	.

LEAST SQUARES MEANS

LOAD	DELAY	S0+S1+S2 LSMEAN	LSMEAN NUMBER
1	0	1.88888889	1
1	1	1.03754976	2
1	2	1.96045965	3
1	3	1.33532392	4
2	0	2.66666667	5
2	1	4.33532392	6
2	2	3.87088310	7
2	3	2.79379298	8
3	0	4.87088310	9
3	1	3.41675715	10
3	2	8.33532392	11
3	3	6.37088310	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.4053	0.9440	0.5872	0.3885	0.0193	0.0561	0.3761
2	0.4053	.	0.4198	0.7938	0.1144	0.0053	0.0125	0.1277
3	0.9440	0.4198	.	0.5828	0.4891	0.0405	0.0982	0.4502
4	0.5872	0.7938	0.5828	.	0.1946	0.0084	0.0295	0.2028
5	0.3885	0.1144	0.4891	0.1946	.	0.1055	0.2407	0.9007
6	0.0193	0.0053	0.0405	0.0084	0.1055	.	0.6837	0.1787
7	0.0561	0.0125	0.0982	0.0295	0.2407	0.6837	.	0.3469
8	0.3761	0.1277	0.4502	0.2028	0.9007	0.1787	0.3469	.
9	0.0049	0.0010	0.0132	0.0029	0.0343	0.6386	0.3655	0.0729
10	0.1005	0.0252	0.1531	0.0539	0.4155	0.3881	0.6619	0.5379
11	0.0001	0.0001	0.0001	0.0001	0.0001	0.0006	0.0002	0.0001
12	0.0001	0.0001	0.0003	0.0001	0.0006	0.0783	0.0265	0.0027

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.0049	0.1005	0.0001	0.0001
2	0.0010	0.0252	0.0001	0.0001
3	0.0132	0.1531	0.0001	0.0003
4	0.0029	0.0539	0.0001	0.0001
5	0.0343	0.4155	0.0001	0.0006
6	0.6386	0.3881	0.0006	0.0783
7	0.3655	0.6619	0.0002	0.0265
8	0.0729	0.5379	0.0001	0.0027
9	.	0.1649	0.0035	0.1767
10	0.1649	.	0.0001	0.0060
11	0.0035	0.0001	.	0.0889
12	0.1767	0.0060	0.0889	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJ	9	1 2 3 4 5 6 7 8 9
LOAD	3	1 2 3
DELAY	4	0 1 2 3
SECTOR	3	1 2 3

NUMBER OF OBSERVATIONS IN DATA SET = 72

DEPENDENT VARIABLE: PROX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	25.54802184	0.94622303
ERROR	44	30.72975594	0.69840354
CORRECTED TOTAL	71	56.27777778	

MODEL F = 1.35 PR > F = 0.1817

R-SQUARE	C.V.	ROOT MSE	PROX MEAN
0.453963	150.4270	0.83570542	0.55555556

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	5.66666667	1.01	0.4395
LOAD	2	8.64193098	6.19	0.0043
DELAY	3	0.26962300	0.13	0.9426
SECTOR	2	4.78169014	3.42	0.0415
DELAY*SECTOR	6	3.66142626	0.87	0.5219
LOAD*DELAY	6	2.52668479	0.60	0.7264

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	3.65278374	0.65	0.7284
LOAD	2	6.68073801	4.78	0.0132
DELAY	3	0.10189931	0.05	0.9856
SECTOR	2	4.48813801	3.21	0.0498
DELAY*SECTOR	6	3.66142626	0.87	0.5219
LOAD*DELAY	6	2.52668479	0.60	0.7264

LEAST SQUARES MEANS

DELAY	PROX LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3	4
0	0.53161939	1	.	0.9749	0.9303	0.7668
1	0.52245863	2	0.9749	.	0.9127	0.8036
2	0.55555556	3	0.9303	0.9127	.	0.7155
3	0.44355792	4	0.7668	0.8036	0.7155	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

DELAY	SECTOR	PROX LSMEAN	LSMEAN NUMBER
0	1	0.80577295	1
0	2	0.15288851	2
0	3	0.63619670	3
1	1	1.00575743	4
1	2	0.03334169	5
1	3	0.52827677	6
2	1	0.32842281	7
2	2	0.08257020	8
2	3	1.25567365	9
3	1	0.53716871	10
3	2	0.35594783	11
3	3	0.43755721	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.1598	0.7121	0.6806	0.1167	0.5738	0.3211	0.1392
2	0.1598	.	0.2956	0.0885	0.8055	0.4409	0.7123	0.8831
3	0.7121	0.2956	.	0.4480	0.2248	0.8241	0.5249	0.2481
4	0.6806	0.0885	0.4480	.	0.0560	0.3405	0.1926	0.0740
5	0.1167	0.8055	0.2248	0.0560	.	0.3233	0.5575	0.9238
6	0.5738	0.4409	0.8241	0.3405	0.3233	.	0.6939	0.3768
7	0.3211	0.7123	0.5249	0.1926	0.5575	0.6939	.	0.6252
8	0.1392	0.8831	0.2481	0.0740	0.9238	0.3768	0.6252	.
9	0.3467	0.0265	0.1996	0.6191	0.0196	0.1623	0.0703	0.0235
10	0.6046	0.4526	0.8446	0.3872	0.3530	0.9865	0.6947	0.3885
11	0.3752	0.6953	0.5833	0.2198	0.5507	0.7497	0.9589	0.6074
12	0.4716	0.5736	0.7016	0.2956	0.4429	0.8665	0.8354	0.5078

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.3467	0.6046	0.3752	0.4716
2	0.0265	0.4526	0.6953	0.5736
3	0.1996	0.8446	0.5833	0.7016
4	0.6191	0.3872	0.2198	0.2956
5	0.0196	0.3530	0.5507	0.4429
6	0.1623	0.9865	0.7497	0.8665

LEAST SQUARES MEANS FOR EFFECT DELAY*SECTOR

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

DEPENDENT VARIABLE: PROX

I/J	9	10	11	12
7	0.0703	0.6947	0.9589	0.8354
8	0.0235	0.3885	0.6074	0.5078
9	.	0.1834	0.0918	0.1287
10	0.1834	.	0.7443	0.8576
11	0.0918	0.7443	.	0.8831
12	0.1287	0.8576	0.8831	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

LEAST SQUARES MEANS

LOAD	DELAY	PROX LSMEAN	LSMEAN NUMBER
1	0	0.52570922	1
1	1	-0.09751773	2
1	2	0.23847518	3
1	3	0.52304965	4
2	0	0.33333333	5
2	1	0.52304965	6
2	2	0.23581560	7
2	3	0.07180851	8
3	0	0.73581560	9
3	1	1.14184397	10
3	2	1.19237589	11
3	3	0.73581560	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.2221	0.5696	0.9965	0.6692	0.9965	0.5675	0.3702
2	0.2221	.	0.5109	0.3118	0.3428	0.3118	0.4933	0.7399
3	0.5696	0.5109	.	0.6605	0.8335	0.6605	0.9958	0.7314
4	0.9965	0.3118	0.6605	.	0.7462	1.0000	0.6381	0.4869
5	0.6692	0.3428	0.8335	0.7462	.	0.7462	0.8292	0.5629
6	0.9965	0.3118	0.6605	1.0000	0.7462	.	0.6381	0.4869
7	0.5675	0.4933	0.9958	0.6381	0.8292	0.6381	.	0.7478
8	0.3702	0.7399	0.7314	0.4869	0.5629	0.4869	0.7478	.
9	0.6783	0.0912	0.3319	0.7274	0.3752	0.7274	0.3057	0.1970
10	0.1956	0.0100	0.0475	0.3171	0.0517	0.3171	0.0553	0.0199
11	0.1740	0.0139	0.0637	0.2793	0.0612	0.2793	0.0639	0.0305
12	0.6783	0.0912	0.3319	0.7274	0.3752	0.7274	0.3057	0.1970

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.6783	0.1956	0.1740	0.6783
2	0.0912	0.0100	0.0139	0.0912
3	0.3319	0.0475	0.0637	0.3319
4	0.7274	0.3171	0.2793	0.7274
5	0.3752	0.0517	0.0612	0.3752
6	0.7274	0.3171	0.2793	0.7274
7	0.3057	0.0553	0.0639	0.3057
8	0.1970	0.0199	0.0305	0.1970
9	.	0.3824	0.3692	1.0000
10	0.3824	.	0.9147	0.3824
11	0.3692	0.9147	.	0.3692
12	1.0000	0.3824	0.3692	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJ	9	1 2 3 4 5 6 7 8 9
LOAD	3	1 2 3
DELAY	4	0 1 2 3
SECTOR	3	1 2 3

NUMBER OF OBSERVATIONS IN DATA SET = 81

DEPENDENT VARIABLE: PP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	69.49846110	2.57401708
ERROR	53	95.85956359	1.80867101
CORRECTED TOTAL	80	165.35802469	

MODEL F = 1.42 PR > F = 0.1351

R-SQUARE	C.V.	ROOT MSE	PP MEAN
0.420291	96.4021	1.34486840	1.39506173

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	20.59135802	1.42	0.2087
LOAD	2	22.62994350	6.26	0.0036
DELAY	3	2.33348828	0.43	0.7323
SECTOR	2	5.96601307	1.65	0.2019
DELAY*SECTOR	6	11.44443781	1.05	0.4014
LOAD*DELAY	6	6.53322040	0.60	0.7274

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	23.50154752	1.62	0.1401
LOAD	2	22.38491911	6.19	0.0038
DELAY	3	2.29705793	0.42	0.7370
SECTOR	2	5.15200021	1.42	0.2497
DELAY*SECTOR	6	11.44443781	1.05	0.4014
LOAD*DELAY	6	6.53322040	0.60	0.7274

DEPENDENT VARIABLE: STEPS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	772.37823547	28.60660131
ERROR	53	382.75756700	7.22184089
CORRECTED TOTAL	80	1155.13580247	

MODEL F =	3.96	PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	STEPS MEAN
0.668647	79.4435	2.68734830	3.38271605

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	75.91635802	1.31	0.2570
LOAD	2	317.19285938	21.96	0.0001
DELAY	3	138.33701638	6.39	0.0009
SECTOR	2	64.79375973	4.49	0.0159
DELAY*SECTOR	6	75.23837046	1.74	0.1307
LOAD*DELAY	6	100.89987149	2.33	0.0454

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	56.20671871	0.97	0.4672
LOAD	2	334.47995495	23.16	0.0001
DELAY	3	133.56629272	6.16	0.0011
SECTOR	2	76.23502541	5.28	0.0081
DELAY*SECTOR	6	75.23837046	1.74	0.1307
LOAD*DELAY	6	100.89987149	2.33	0.0454

LEAST SQUARES MEANS

DELAY	PP LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3	4
0	1.41250452	1	.	0.8875	0.5520	0.5651
1	1.47077452	2	0.8875	.	0.6552	0.4888
2	1.66666667	3	0.5520	0.6552	.	0.2697
3	1.16666667	4	0.5651	0.4888	0.2697	.

DELAY	STEPS LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3	4
0	2.18955845	1	.	0.8274	0.0020	0.0030
1	2.36907347	2	0.8274	.	0.0047	0.0066
2	4.94444444	3	0.0020	0.0047	.	0.9018
3	4.83333333	4	0.0030	0.0066	0.9018	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

DELAY	SECTOR	PP LSMEAN	LSMEAN NUMBER
0	1	1.49101363	1
0	2	0.83745837	2
0	3	1.90904157	3
1	1	2.24218292	4
1	2	0.71472324	5
1	3	1.45541740	6
2	1	2.28491575	7
2	2	1.27403779	8
2	3	1.44104646	9
3	1	0.85648669	10
3	2	1.56695204	11
3	3	1.07656127	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.3395	0.5402	0.2900	0.2788	0.9602	0.2895	0.7712
2	0.3395	.	0.1200	0.0529	0.8620	0.3876	0.0541	0.5588
3	0.5402	0.1200	.	0.6406	0.0981	0.5214	0.6147	0.3914
4	0.2900	0.0529	0.6406	.	0.0419	0.2877	0.9559	0.2133
5	0.2788	0.8620	0.0981	0.0419	.	0.3165	0.0419	0.4699
6	0.9602	0.3876	0.5214	0.2877	0.3165	.	0.2854	0.8106
7	0.2895	0.0541	0.6147	0.9559	0.0419	0.2854	.	0.2122
8	0.7712	0.5588	0.3914	0.2133	0.4699	0.8106	0.2122	.
9	0.9460	0.4197	0.5310	0.2923	0.3490	0.9851	0.2966	0.8355
10	0.3964	0.9796	0.1579	0.0770	0.8544	0.4300	0.0802	0.5961
11	0.9181	0.3301	0.6468	0.3740	0.2724	0.8852	0.3698	0.7160
12	0.5789	0.7462	0.2670	0.1353	0.6329	0.6240	0.1288	0.8045

LEAST SQUARES MEANS FOR EFFECT DELAY*SECTOR

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

DEPENDENT VARIABLE: PP

I/J	9	10	11	12
1	0.9460	0.3964	0.9181	0.5789
2	0.4197	0.9796	0.3301	0.7462
3	0.5310	0.1579	0.6468	0.2670
4	0.2923	0.0770	0.3740	0.1353
5	0.3490	0.8544	0.2724	0.6329
6	0.9851	0.4300	0.8852	0.6240
7	0.2966	0.0802	0.3698	0.1288
8	0.8355	0.5961	0.7160	0.8045
9	.	0.4647	0.8729	0.6508
10	0.4647	.	0.3788	0.7844
11	0.8729	0.3788	.	0.5427
12	0.6508	0.7844	0.5427	.

LEAST SQUARES MEANS

DELAY	SECTOR	STEPS LSMEAN	LSMEAN NUMBER
0	1	2.24316372	1
0	2	1.91634687	2
0	3	2.40916477	3
1	1	2.27759270	4
1	2	2.33917563	5
1	3	2.49045208	6
2	1	6.09007230	7
2	2	3.34842935	8
2	3	5.39483168	9
3	1	6.47650096	10
3	2	1.18489221	11
3	3	6.83860683	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.8103	0.9030	0.9805	0.9463	0.8622	0.0122	0.4594
2	0.8103	.	0.7175	0.7998	0.7645	0.6871	0.0063	0.3386
3	0.9030	0.7175	.	0.9264	0.9608	0.9541	0.0163	0.5251
4	0.9805	0.7998	0.9264	.	0.9666	0.8849	0.0162	0.4887
5	0.9463	0.7645	0.9608	0.9666	.	0.9181	0.0158	0.5138
6	0.8622	0.6871	0.9541	0.8849	0.9181	.	0.0229	0.5710
7	0.0122	0.0063	0.0163	0.0162	0.0158	0.0229	.	0.0924
8	0.4594	0.3386	0.5251	0.4887	0.5138	0.5710	0.0924	.
9	0.0364	0.0228	0.0492	0.0432	0.0518	0.0640	0.6656	0.2063
10	0.0061	0.0033	0.0077	0.0085	0.0094	0.0106	0.8101	0.0508
11	0.4742	0.6239	0.4128	0.4710	0.4555	0.3991	0.0032	0.1821
12	0.0031	0.0015	0.0043	0.0045	0.0042	0.0065	0.6344	0.0321

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.0364	0.0061	0.4742	0.0031
2	0.0228	0.0033	0.6239	0.0015
3	0.0492	0.0077	0.4128	0.0043
4	0.0432	0.0085	0.4710	0.0045
5	0.0518	0.0094	0.4555	0.0042
6	0.0640	0.0106	0.3991	0.0065
7	0.6656	0.8101	0.0032	0.6344
8	0.2063	0.0508	0.1821	0.0321
9	.	0.4982	0.0095	0.3710
10	0.4982	.	0.0017	0.8218
11	0.0095	0.0017	.	0.0009
12	0.3710	0.8218	0.0009	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

LEAST SQUARES MEANS

LOAD	DELAY	PP LSMEAN	LSMEAN NUMBER
1	0	0.88888889	1
1	1	0.51529135	2
1	2	1.37305465	3
1	3	0.11165400	4
2	0	1.33333333	5
2	1	1.61165400	6
2	2	2.01529135	7
2	3	1.20638798	8
3	0	2.01529135	9
3	1	2.28537821	10
3	2	1.61165400	11
3	3	2.18195802	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.6056	0.5034	0.2841	0.4863	0.3188	0.1233	0.6604
2	0.6056	.	0.2911	0.6175	0.2605	0.1782	0.0587	0.3941
3	0.5034	0.2911	.	0.1216	0.9561	0.7671	0.4282	0.8309
4	0.2841	0.6175	0.1216	.	0.0948	0.0587	0.0215	0.1778
5	0.4863	0.2605	0.9561	0.0948	.	0.6999	0.3473	0.8604
6	0.3188	0.1782	0.7671	0.0587	0.6999	.	0.6175	0.6153
7	0.1233	0.0587	0.4282	0.0215	0.3473	0.6175	.	0.3192
8	0.6604	0.3941	0.8309	0.1778	0.8604	0.6153	0.3192	.
9	0.1233	0.0587	0.4282	0.0215	0.3473	0.6175	1.0000	0.3192
10	0.0357	0.0190	0.2057	0.0053	0.1475	0.3719	0.7136	0.1357
11	0.3188	0.1782	0.7671	0.0587	0.6999	1.0000	0.6175	0.6153
12	0.0779	0.0364	0.3192	0.0128	0.2433	0.4810	0.8309	0.2306

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.1233	0.0357	0.3188	0.0779
2	0.0587	0.0190	0.1782	0.0364
3	0.4282	0.2057	0.7671	0.3192
4	0.0215	0.0053	0.0587	0.0128
5	0.3473	0.1475	0.6999	0.2433
6	0.6175	0.3719	1.0000	0.4810
7	1.0000	0.7136	0.6175	0.8309
8	0.3192	0.1357	0.6153	0.2306
9	.	0.7136	0.6175	0.8309
10	0.7136	.	0.3719	0.8882
11	0.6175	0.3719	.	0.4810
12	0.8309	0.8882	0.4810	.

LEAST SQUARES MEANS

LOAD	DELAY	STEPS LSMEAN	LSMEAN NUMBER
1	0	1.22222222	1
1	1	1.06867535	2
1	2	2.01764387	3
1	3	2.74701412	4
2	0	1.44444444	5
2	1	2.74701412	6
2	2	3.06867535	7
2	3	2.68431053	8
3	0	3.90200869	9
3	1	3.29153094	10
3	2	9.74701412	11
3	3	9.06867535	12

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	1	2	3	4	5	6	7	8
1	.	0.9153	0.5819	0.2928	0.8614	0.2928	0.2045	0.3132
2	0.9153	.	0.5574	0.3006	0.7948	0.3006	0.2030	0.3194
3	0.5819	0.5574	.	0.6507	0.6913	0.6507	0.5160	0.6692
4	0.2928	0.3006	0.6507	.	0.3682	1.0000	0.8420	0.9689
5	0.8614	0.7948	0.6913	0.3682	.	0.3682	0.2635	0.3917
6	0.2928	0.3006	0.6507	1.0000	0.3682	.	0.8420	0.9689
7	0.2045	0.2030	0.5160	0.8420	0.2635	0.8420	.	0.8119
8	0.3132	0.3194	0.6692	0.9689	0.3917	0.9689	0.8119	.
9	0.0678	0.0735	0.2463	0.4751	0.0931	0.4751	0.5934	0.4521
10	0.1158	0.1345	0.3747	0.7171	0.1594	0.7171	0.8795	0.6713
11	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
12	0.0001	0.0001	0.0001	0.0002	0.0001	0.0002	0.0003	0.0002

PROB |T| H0: LSMEAN(I)=LSMEAN(J)

I/J	9	10	11	12
1	0.0678	0.1158	0.0001	0.0001
2	0.0735	0.1345	0.0001	0.0001
3	0.2463	0.3747	0.0001	0.0001
4	0.4751	0.7171	0.0001	0.0002
5	0.0931	0.1594	0.0001	0.0001
6	0.4751	0.7171	0.0001	0.0002
7	0.5934	0.8795	0.0001	0.0003
8	0.4521	0.6713	0.0001	0.0002
9	.	0.6780	0.0006	0.0016
10	0.6780	.	0.0001	0.0002
11	0.0006	0.0001	.	0.6744
12	0.0016	0.0002	0.6744	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJ	9	1 2 3 4 5 6 7 8 9
DEL_LOAD	12	D0L1 D0L2 D0L3 D1L1 D1L2 D1L3 D2L1 D2L2 D2L3 D3L1 D3L2 D3L3
DEL_SECT	12	D0S1 D0S2 D0S3 D1S1 D1S2 D1S3 D2S1 D2S2 D2S3 D3S1 D3S2 D3S3

NUMBER OF OBSERVATIONS IN DATA SET = 81

DEPENDENT VARIABLE: STEPS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	772.37823547	28.60660131
ERROR	53	382.75756700	7.22184089
CORRECTED TOTAL	80	1155.13580247	

MODEL F = 3.96 PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	STEPS MEAN
0.668647	79.4435	2.68734830	3.38271605

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	75.91635802	1.31	0.2570
DEL_LOAD	11	556.42974726	7.00	0.0001
DEL_SECT	8	140.03213019	2.42	0.0260

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	56.20671871	0.97	0.4672
DEL_LOAD	8	410.00289540	7.10	0.0001
DEL_SECT	8	140.03213019	2.42	0.0260

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: STEPS

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE

ALPHA=0.05 CONFIDENCE=0.95 DF=53 MSE=7.22184
CRITICAL VALUE OF STUDENTIZED RANGE=4.834

COMPARISONS SIGNIFICANT AT THE 0.05 LEVEL ARE INDICATED BY '***'

DEL_LOAD COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
D2L3 - D3L3	-4.303	1.000	6.303	
D2L3 - D0L3	0.864	6.167	11.470	***
D2L3 - D2L2	1.697	7.000	12.303	***
D2L3 - D3L1	1.697	7.000	12.303	***
D2L3 - D1L3	2.159	7.000	11.841	***
D2L3 - D1L2	1.697	7.000	12.303	***
D2L3 - D3L2	2.197	7.500	12.803	***
D2L3 - D2L1	2.864	8.167	13.470	***
D2L3 - D0L2	3.715	8.556	13.397	***
D2L3 - D0L1	3.937	8.778	13.619	***
D2L3 - D1L1	3.697	9.000	14.303	***
D3L3 - D2L3	-6.303	-1.000	4.303	
D3L3 - D0L3	-0.136	5.167	10.470	
D3L3 - D2L2	0.697	6.000	11.303	***
D3L3 - D3L1	0.697	6.000	11.303	***
D3L3 - D1L3	1.159	6.000	10.841	***
D3L3 - D1L2	0.697	6.000	11.303	***
D3L3 - D3L2	1.197	6.500	11.803	***
D3L3 - D2L1	1.864	7.167	12.470	***
D3L3 - D0L2	2.715	7.556	12.397	***
D3L3 - D0L1	2.937	7.778	12.619	***
D3L3 - D1L1	2.697	8.000	13.303	***
D0L3 - D2L3	-11.470	-6.167	-0.864	***
D0L3 - D3L3	-10.470	-5.167	0.136	
D0L3 - D2L2	-4.470	0.833	6.136	
D0L3 - D3L1	-4.470	0.833	6.136	
D0L3 - D1L3	-4.008	0.833	5.674	
D0L3 - D1L2	-4.470	0.833	6.136	
D0L3 - D3L2	-3.970	1.333	6.636	
D0L3 - D2L1	-3.303	2.000	7.303	
D0L3 - D0L2	-2.452	2.389	7.230	
D0L3 - D0L1	-2.230	2.611	7.452	
D0L3 - D1L1	-2.470	2.833	8.136	

D2L2 - D2L3	-12.303	-7.000	-1.697	***
D2L2 - D3L3	-11.303	-6.000	-0.697	***
D2L2 - D0L3	-6.136	-0.833	4.470	
D2L2 - D3L1	-5.303	0.000	5.303	
D2L2 - D1L3	-4.841	0.000	4.841	
D2L2 - D1L2	-5.303	0.000	5.303	

DEL_LOAD COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
D2L2 - D3L2	-4.803	0.500	5.803	
D2L2 - D2L1	-4.136	1.167	6.470	
D2L2 - D0L2	-3.285	1.556	6.397	
D2L2 - D0L1	-3.063	1.778	6.619	
D2L2 - D1L1	-3.303	2.000	7.303	
D3L1 - D2L3	-12.303	-7.000	-1.697	***
D3L1 - D3L3	-11.303	-6.000	-0.697	***
D3L1 - D0L3	-6.136	-0.833	4.470	
D3L1 - D2L2	-5.303	0.000	5.303	
D3L1 - D1L3	-4.841	0.000	4.841	
D3L1 - D1L2	-5.303	0.000	5.303	
D3L1 - D3L2	-4.803	0.500	5.803	
D3L1 - D2L1	-4.136	1.167	6.470	
D3L1 - D0L2	-3.285	1.556	6.397	
D3L1 - D0L1	-3.063	1.778	6.619	
D3L1 - D1L1	-3.303	2.000	7.303	
D1L3 - D2L3	-11.841	-7.000	-2.159	***
D1L3 - D3L3	-10.841	-6.000	-1.159	***
D1L3 - D0L3	-5.674	-0.833	4.008	
D1L3 - D2L2	-4.841	0.000	4.841	
D1L3 - D3L1	-4.841	0.000	4.841	
D1L3 - D1L2	-4.841	0.000	4.841	
D1L3 - D3L2	-4.341	0.500	5.341	
D1L3 - D2L1	-3.674	1.167	6.008	
D1L3 - D0L2	-2.774	1.556	5.885	
D1L3 - D0L1	-2.552	1.778	6.108	
D1L3 - D1L1	-2.841	2.000	6.841	

D1L2 - D2L3	-12.303	-7.000	-1.697	***
D1L2 - D3L3	-11.303	-6.000	-0.697	***
D1L2 - D0L3	-6.136	-0.833	4.470	
D1L2 - D2L2	-5.303	0.000	5.303	
D1L2 - D3L1	-5.303	0.000	5.303	
D1L2 - D1L3	-4.841	0.000	4.841	
D1L2 - D3L2	-4.803	0.500	5.803	
D1L2 - D2L1	-4.136	1.167	6.470	
D1L2 - D0L2	-3.285	1.556	6.397	
D1L2 - D0L1	-3.063	1.778	6.619	
D1L2 - D1L1	-3.303	2.000	7.303	
D3L2 - D2L3	-12.803	-7.500	-2.197	***
D3L2 - D3L3	-11.803	-6.500	-1.197	***
D3L2 - D0L3	-6.636	-1.333	3.970	
D3L2 - D2L2	-5.803	-0.500	4.803	
D3L2 - D3L1	-5.803	-0.500	4.803	
D3L2 - D1L3	-5.341	-0.500	4.341	
D3L2 - D1L2	-5.803	-0.500	4.803	
D3L2 - D2L1	-4.636	0.667	5.970	
D3L2 - D0L2	-3.785	1.056	5.897	

DEL_LOAD COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT	
D3L2 - D0L1	-3.563	1.278	6.119	
D3L2 - D1L1	-3.803	1.500	6.803	
D2L1 - D2L3	-13.470	-8.167	-2.864	***
D2L1 - D3L3	-12.470	-7.167	-1.864	***
D2L1 - D0L3	-7.303	-2.000	3.303	
D2L1 - D2L2	-6.470	-1.167	4.136	
D2L1 - D3L1	-6.470	-1.167	4.136	
D2L1 - D1L3	-6.008	-1.167	3.674	
D2L1 - D1L2	-6.470	-1.167	4.136	
D2L1 - D3L2	-5.970	-0.667	4.636	
D2L1 - D0L2	-4.452	0.389	5.230	
D2L1 - D0L1	-4.230	0.611	5.452	
D2L1 - D1L1	-4.470	0.833	6.136	

D0L2 - D2L3	-13.397	-8.556	-3.715	***
D0L2 - D3L3	-12.397	-7.556	-2.715	***
D0L2 - D0L3	-7.230	-2.389	2.452	
D0L2 - D2L2	-6.397	-1.556	3.285	
D0L2 - D3L1	-6.397	-1.556	3.285	
D0L2 - D1L3	-5.885	-1.556	2.774	
D0L2 - D1L2	-6.397	-1.556	3.285	
D0L2 - D3L2	-5.897	-1.056	3.785	
D0L2 - D2L1	-5.230	-0.389	4.452	
D0L2 - D0L1	-4.108	0.222	4.552	
D0L2 - D1L1	-4.397	0.444	5.285	
D0L1 - D2L3	-13.619	-8.778	-3.937	***
D0L1 - D3L3	-12.619	-7.778	-2.937	***
D0L1 - D0L3	-7.452	-2.611	2.230	
D0L1 - D2L2	-6.619	-1.778	3.063	
D0L1 - D3L1	-6.619	-1.778	3.063	
D0L1 - D1L3	-6.108	-1.778	2.552	
D0L1 - D1L2	-6.619	-1.778	3.063	
D0L1 - D3L2	-6.119	-1.278	3.563	
D0L1 - D2L1	-5.452	-0.611	4.230	
D0L1 - D0L2	-4.552	-0.222	4.108	
D0L1 - D1L1	-4.619	0.222	5.063	
D1L1 - D2L3	-14.303	-9.000	-3.697	***
D1L1 - D3L3	-13.303	-8.000	-2.697	***
D1L1 - D0L3	-8.136	-2.833	2.470	
D1L1 - D2L2	-7.303	-2.000	3.303	
D1L1 - D3L1	-7.303	-2.000	3.303	
D1L1 - D1L3	-6.841	-2.000	2.841	
D1L1 - D1L2	-7.303	-2.000	3.303	
D1L1 - D3L2	-6.803	-1.500	3.803	
D1L1 - D2L1	-6.136	-0.833	4.470	
D1L1 - D0L2	-5.285	-0.444	4.397	
D1L1 - D0L1	-5.063	-0.222	4.619	

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: STEPS

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE

ALPHA=0.05 CONFIDENCE=0.95 DF=53 MSE=7.22184
CRITICAL VALUE OF STUDENTIZED RANGE=4.834

COMPARISONS SIGNIFICANT AT THE 0.05 LEVEL ARE INDICATED BY '***'

DEL_SECT COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT
D3S3 - D3S1	-4.970	0.333	5.636
D3S3 - D2S1	-4.636	0.667	5.970
D3S3 - D2S3	-4.303	1.000	6.303
D3S3 - D2S2	-1.803	3.500	8.803
D3S3 - D1S1	-1.015	4.095	9.205
D3S3 - D1S3	-0.872	4.238	9.348
D3S3 - D1S2	-0.729	4.381	9.491
D3S3 - D0S1	-0.419	4.542	9.502
D3S3 - D0S3	-0.294	4.667	9.627
D3S3 - D0S2	-0.044	4.917	9.877
D3S3 - D3S2	-0.136	5.167	10.470
D3S1 - D3S3	-5.636	-0.333	4.970
D3S1 - D2S1	-4.970	0.333	5.636
D3S1 - D2S3	-4.636	0.667	5.970
D3S1 - D2S2	-2.136	3.167	8.470
D3S1 - D1S1	-1.348	3.762	8.872
D3S1 - D1S3	-1.205	3.905	9.015
D3S1 - D1S2	-1.062	4.048	9.158
D3S1 - D0S1	-0.752	4.208	9.169
D3S1 - D0S3	-0.627	4.333	9.294
D3S1 - D0S2	-0.377	4.583	9.544
D3S1 - D3S2	-0.470	4.833	10.136
D2S1 - D3S3	-5.970	-0.667	4.636
D2S1 - D3S1	-5.636	-0.333	4.970
D2S1 - D2S3	-4.970	0.333	5.636
D2S1 - D2S2	-2.470	2.833	8.136
D2S1 - D1S1	-1.682	3.429	8.539
D2S1 - D1S3	-1.539	3.571	8.682
D2S1 - D1S2	-1.396	3.714	8.824
D2S1 - D0S1	-1.086	3.875	8.836
D2S1 - D0S3	-0.961	4.000	8.961
D2S1 - D0S2	-0.711	4.250	9.211
D2S1 - D3S2	-0.803	4.500	9.803

D2S3 - D3S3	-6.303	-1.000	4.303
D2S3 - D3S1	-5.970	-0.667	4.636
D2S3 - D2S1	-5.636	-0.333	4.970
D2S3 - D2S2	-2.803	2.500	7.803
D2S3 - D1S1	-2.015	3.095	8.205
D2S3 - D1S3	-1.872	3.238	8.348

DEL_SECT COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT
D2S3 - D1S2	-1.729	3.381	8.491
D2S3 - D0S1	-1.419	3.542	8.502
D2S3 - D0S3	-1.294	3.667	8.627
D2S3 - D0S2	-1.044	3.917	8.877
D2S3 - D3S2	-1.136	4.167	9.470
D2S2 - D3S3	-8.803	-3.500	1.803
D2S2 - D3S1	-8.470	-3.167	2.136
D2S2 - D2S1	-8.136	-2.833	2.470
D2S2 - D2S3	-7.803	-2.500	2.803
D2S2 - D1S1	-4.515	0.595	5.705
D2S2 - D1S3	-4.372	0.738	5.848
D2S2 - D1S2	-4.229	0.881	5.991
D2S2 - D0S1	-3.919	1.042	6.002
D2S2 - D0S3	-3.794	1.167	6.127
D2S2 - D0S2	-3.544	1.417	6.377
D2S2 - D3S2	-3.636	1.667	6.970
D1S1 - D3S3	-9.205	-4.095	1.015
D1S1 - D3S1	-8.872	-3.762	1.348
D1S1 - D2S1	-8.539	-3.429	1.682
D1S1 - D2S3	-8.205	-3.095	2.015
D1S1 - D2S2	-5.705	-0.595	4.515
D1S1 - D1S3	-4.767	0.143	5.052
D1S1 - D1S2	-4.624	0.286	5.195
D1S1 - D0S1	-4.307	0.446	5.200
D1S1 - D0S3	-4.182	0.571	5.325
D1S1 - D0S2	-3.932	0.821	5.575
D1S1 - D3S2	-4.039	1.071	6.182
D1S3 - D3S3	-9.348	-4.238	0.872
D1S3 - D3S1	-9.015	-3.905	1.205
D1S3 - D2S1	-8.682	-3.571	1.539
D1S3 - D2S3	-8.348	-3.238	1.872
D1S3 - D2S2	-5.848	-0.738	4.372
D1S3 - D1S1	-5.052	-0.143	4.767
D1S3 - D1S2	-4.767	0.143	5.052
D1S3 - D0S1	-4.450	0.304	5.057
D1S3 - D0S3	-4.325	0.429	5.182
D1S3 - D0S2	-4.075	0.679	5.432
D1S3 - D3S2	-4.182	0.929	6.039

D1S2 - D3S3	-9.491	-4.381	0.729
D1S2 - D3S1	-9.158	-4.048	1.062
D1S2 - D2S1	-8.824	-3.714	1.396
D1S2 - D2S3	-8.491	-3.381	1.729
D1S2 - D2S2	-5.991	-0.881	4.229
D1S2 - D1S1	-5.195	-0.286	4.624
D1S2 - D1S3	-5.052	-0.143	4.767
D1S2 - D0S1	-4.593	0.161	4.914
D1S2 - D0S3	-4.468	0.286	5.039

DEL_SECT COMPARISON	SIMULTANEOUS LOWER CONFIDENCE LIMIT	DIFFERENCE BETWEEN MEANS	SIMULTANEOUS UPPER CONFIDENCE LIMIT
D1S2 - D0S2	-4.218	0.536	5.289
D1S2 - D3S2	-4.324	0.786	5.896
D0S1 - D3S3	-9.502	-4.542	0.419
D0S1 - D3S1	-9.169	-4.208	0.752
D0S1 - D2S1	-8.836	-3.875	1.086
D0S1 - D2S3	-8.502	-3.542	1.419
D0S1 - D2S2	-6.002	-1.042	3.919
D0S1 - D1S1	-5.200	-0.446	4.307
D0S1 - D1S3	-5.057	-0.304	4.450
D0S1 - D1S2	-4.914	-0.161	4.593
D0S1 - D0S3	-4.468	0.125	4.718
D0S1 - D0S2	-4.218	0.375	4.968
D0S1 - D3S2	-4.336	0.625	5.586
D0S3 - D3S3	-9.627	-4.667	0.294
D0S3 - D3S1	-9.294	-4.333	0.627
D0S3 - D2S1	-8.961	-4.000	0.961
D0S3 - D2S3	-8.627	-3.667	1.294
D0S3 - D2S2	-6.127	-1.167	3.794
D0S3 - D1S1	-5.325	-0.571	4.182
D0S3 - D1S3	-5.182	-0.429	4.325
D0S3 - D1S2	-5.039	-0.286	4.468
D0S3 - D0S1	-4.718	-0.125	4.468
D0S3 - D0S2	-4.343	0.250	4.843
D0S3 - D3S2	-4.461	0.500	5.461
D0S2 - D3S3	-9.877	-4.917	0.044
D0S2 - D3S1	-9.544	-4.583	0.377
D0S2 - D2S1	-9.211	-4.250	0.711
D0S2 - D2S3	-8.877	-3.917	1.044
D0S2 - D2S2	-6.377	-1.417	3.544
D0S2 - D1S1	-5.575	-0.821	3.932
D0S2 - D1S3	-5.432	-0.679	4.075
D0S2 - D1S2	-5.289	-0.536	4.218
D0S2 - D0S1	-4.968	-0.375	4.218
D0S2 - D0S3	-4.843	-0.250	4.343
D0S2 - D3S2	-4.711	0.250	5.211

D3S2 - D3S3	-10.470	-5.167	0.136
D3S2 - D3S1	-10.136	-4.833	0.470
D3S2 - D2S1	-9.803	-4.500	0.803
D3S2 - D2S3	-9.470	-4.167	1.136
D3S2 - D2S2	-6.970	-1.667	3.636
D3S2 - D1S1	-6.182	-1.071	4.039
D3S2 - D1S3	-6.039	-0.929	4.182
D3S2 - D1S2	-5.896	-0.786	4.324
D3S2 - D0S1	-5.586	-0.625	4.336
D3S2 - D0S3	-5.461	-0.500	4.461
D3S2 - D0S2	-5.211	-0.250	4.711

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
SUBJ	9	1 2 3 4 5 6 7 8 9
SAT	2	0 1
LOAD	2	1 2
SECTOR	3	1 2 3

NUMBER OF OBSERVATIONS IN DATA SET = 54

DEPENDENT VARIABLE: STEPS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	15	91.94745990	6.12983066
ERROR	38	133.97846602	3.52574911
CORRECTED TOTAL	53	225.92592593	

MODEL F = 1.74 PR > F = 0.0842

R-SQUARE	C.V.	ROOT MSE	STEPS MEAN
0.406981	92.1779	1.87769782	2.03703704

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	46.92592593	1.66	0.1395
SAT	1	15.80341880	4.48	0.0409
LOAD	1	6.00000000	1.70	0.1999
SECTOR	2	6.03703704	0.86	0.4328
SAT*LOAD	1	0.32432432	0.09	0.7633
SAT*SECTOR	2	16.85675381	2.39	0.1052

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	50.12153398	1.78	0.1124
SAT	1	15.80341880	4.48	0.0409
LOAD	1	5.60432432	1.59	0.2151
SECTOR	2	8.45417732	1.20	0.3127
SAT*LOAD	1	0.32432432	0.09	0.7633
SAT*SECTOR	2	16.85675381	2.39	0.1052

LEAST SQUARES MEANS

SAT	STEPS LSMEAN	PROB |T| H0: LSMEAN1=LSMEAN2
0	1.54700855	0.0409
1	2.64957265	

SAT	LOAD	STEPS LSMEAN	PROB I/J	|T| H0: LSMEAN(I)=LSMEAN(J) 1	2	3	4
0	1	1.14160314	1	.	0.2526	0.0984	0.0218
0	2	1.95241395	2	0.2526	.	0.5389	0.2154
1	1	2.40632941	3	0.0984	0.5389	.	0.5384
1	2	2.89281589	4	0.0218	0.2154	0.5384	.

NOTE: TO ENSURE OVERALL PROTECTION LEVEL, ONLY PROBABILITIES ASSOCIATED WITH PRE-PLANNED COMPARISONS SHOULD BE USED.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Stress reported by Controllers

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	67.17468250	2.48795120
ERROR	53	25.36852737	0.47865146
CORRECTED TOTAL	80	92.54320988	

MODEL F = 5.20 PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	Stress MEAN
0.725874	30.9611	0.69184641	2.23456790

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	13.72351291	3.58	0.0022
DELAY	3	0.46760896	0.33	0.8068
LOAD	2	35.24282608	36.81	0.0001
SECTOR	2	13.40051754	14.00	0.0001
DELAY*LOAD	6	2.65704994	0.93	0.4846
DELAY*SECTOR	6	1.68316708	0.59	0.7398

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	13.38295393	3.49	0.0026
DELAY	3	0.51458362	0.36	0.7833
LOAD	2	35.62196614	37.21	0.0001
SECTOR	2	13.59977015	14.21	0.0001
DELAY*LOAD	6	2.55507194	0.89	0.5092
DELAY*SECTOR	6	1.68316708	0.59	0.7398

SAS 4
11:54 FRIDAY, JUNE 1, 1990

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Attention and Concentration (reported by Controllers)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	54.74329907	2.02752960
ERROR	53	13.79991081	0.26037568
CORRECTED TOTAL	80	68.54320988	

MODEL F =	7.79		PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	Attn. MEAN
0.798668	22.8353	0.51027020	2.23456790

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	6.60911897	3.17	0.0052
DELAY	3	0.57011142	0.73	0.5388
LOAD	2	34.14519835	65.57	0.0001
SECTOR	2	10.02599836	19.25	0.0001
DELAY*LOAD	6	0.79454041	0.51	0.7991
DELAY*SECTOR	6	2.59833156	1.66	0.1484

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	8.86644329	4.26	0.0005
DELAY	3	0.63981277	0.82	0.4891
LOAD	2	34.05185060	65.39	0.0001
SECTOR	2	10.08822210	19.37	0.0001
DELAY*LOAD	6	0.82684016	0.53	0.7836
DELAY*SECTOR	6	2.59833156	1.66	0.1484

SAS 5
11:54 FRIDAY, JUNE 1, 1990

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

DELAY	Stress LSMEAN	Atten. LSMEAN
0	2.18000218	2.25679283
1	2.12326616	2.15747694
2	2.33333333	2.16666667
3	2.27777778	2.38888889

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Stress (reported by operations observers)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	47.59742740	1.76286768
ERROR	53	10.87170841	0.20512657
CORRECTED TOTAL	80	58.46913580	

MODEL F = 8.59 PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	Stress MEAN
0.814061	26.3925	0.45290901	1.71604938

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	5.38580247	3.28	0.0041
DELAY	3	2.98571213	4.85	0.0047
LOAD	2	33.53021532	81.73	0.0001
SECTOR	2	0.74449506	1.81	0.1729
DELAY*LOAD	6	1.58264928	1.29	0.2797
DELAY*SECTOR	6	3.36855314	2.74	0.0217

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	3.65848046	2.23	0.0395
DELAY	3	0.61357510	1.00	0.4014
LOAD	2	33.29689903	81.16	0.0001
SECTOR	2	1.01041205	2.46	0.0949
DELAY*LOAD	6	1.59348765	1.29	0.2757
DELAY*SECTOR	6	3.36855314	2.74	0.0217

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: Attention and Concentration
(reported by operations observers)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	27	52.37633734	1.93986435
ERROR	53	10.51255155	0.19835003
CORRECTED TOTAL	80	62.88888889	

MODEL F = 9.78 PR > F = 0.0001

R-SQUARE	C.V.	ROOT MSE	Attn. MEAN
0.832839	22.6884	0.44536505	1.96296296

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SUBJ	8	3.46944444	2.19	0.0433
DELAY	3	0.68004366	1.14	0.3403
LOAD	2	43.85681328	110.55	0.0001
SECTOR	2	2.02358448	5.10	0.0094
DELAY*LOAD	6	0.53280024	0.45	0.8434
DELAY*SECTOR	6	1.81365123	1.52	0.1884

SOURCE	DF	TYPE III SS	F VALUE	PR > F
SUBJ	8	1.90085010	1.20	0.3182
DELAY	3	0.37121704	0.62	0.6027
LOAD	2	43.45867879	109.55	0.0001
SECTOR	2	1.98381604	5.00	0.0102
DELAY*LOAD	6	0.53222092	0.45	0.8437
DELAY*SECTOR	6	1.81365123	1.52	0.1884

GENERAL LINEAR MODELS PROCEDURE

LEAST SQUARES MEANS

DELAY	Stress LSMEAN	Atten. LSMEAN
0	1.63355438	1.99100669
1	1.81613502	1.89065118
2	1.61111111	1.88888889
3	1.77777778	2.05555556

Appendix G

Separation Infringements (Conflicts)

Row #	Run	Week	Day	Sector	# Conflicts A	B	C
1	1	1	1	1	2	1	1
2	1	1	1	2	2	0	3
3	1	1	1	3	0	1	0
4	2	1	1	1	--	--	--
5	2	1	1	2	--	--	--
6	2	1	1	3	--	--	--
7	3	1	1	1	--	--	--
8	3	1	1	2	--	--	--
9	3	1	1	3	--	--	--
10	1	1	2	1	1	0	0
11	1	1	2	2	0	0	3
12	1	1	2	3	0	0	0
13	2	1	2	1	0	0	0
14	2	1	2	2	0	0	1
15	2	1	2	3	0	0	0
16	3	1	2	1	0	0	0
17	3	1	2	2	1	0	0
18	3	1	2	3	0	0	0
19	1	1	3	1	0	0	0
20	1	1	3	2	0	0	3
21	1	1	3	3	0	0	0
22	2	1	3	1	1	0	0
23	2	1	3	2	2	0	3
24	2	1	3	3	0	0	0
25	3	1	3	1	0	0	0

A = Conflict between two aircraft in same test sector.
B = Conflict between aircraft in different test sectors.
C = Conflict with one aircraft in nontest sector. Not counted.

Sectors:
1 = Dublin High
2 = Sinca Low
3 = Macon High

Row #	Run	Week	Day	Sector	# Conflicts A	B	C
26	3	1	3	2	1	0	0
27	3	1	3	3	0	0	0
28	1	2	1	1	1	0	0
29	1	2	1	2	1	0	0
30	1	2	1	3	0	0	0
31	2	2	1	1	0	0	0
32	2	2	1	2	1	0	1
33	2	2	1	3	0	0	0
34	3	2	1	1	1	0	0
35	3	2	1	2	5	0	1
36	3	2	1	3	0	0	0
37	1	2	2	1	0	0	0
38	1	2	2	2	0	0	0
39	1	2	2	3	2	0	0
40	2	2	2	1	1	1	0
41	2	2	2	2	0	1	4
42	2	2	2	3	0	0	0
43	3	2	2	1	2	0	0
44	3	2	2	2	0	0	3
45	3	2	2	3	1	0	0
46	1	2	3	1	0	0	0
47	1	2	3	2	0	0	3
48	1	2	3	3	0	0	0
49	2	2	3	1	0	0	0
50	2	2	3	2	0	0	1
51	2	2	3	3	0	0	0
52	3	2	3	1	1	0	0
53	3	2	3	2	1	0	2
54	3	2	3	3	0	0	0
55	1	3	1	1	0	0	0
56	1	3	1	2	0	0	0
57	1	3	1	3	0	0	0

Row #	Run	Week	Day	Sector	# Conflicts A	B	C
58	2	3	1	1	2	0	0
59	2	3	1	2	1	0	0
60	2	3	1	3	0	0	0
61	3	3	1	1	0	0	0
62	3	3	1	2	2	0	0
63	3	3	1	3	0	0	0
64	1	3	2	1	--	--	--
65	1	3	2	2	--	--	--
66	1	3	2	3	--	--	--
67	2	3	2	1	0	0	0
68	2	3	2	2	0	0	1
69	2	3	2	3	0	0	0
70	3	3	2	1	1	0	0
71	3	3	2	2	1	0	0
72	3	3	2	3	0	0	0
73	4	3	2	1	3	0	0
74	4	3	2	2	1	0	3
75	4	3	2	3	1	0	0
76	1	3	3	1	0	0	0
77	1	3	3	2	0	0	0
78	1	3	3	3	0	0	0
79	2	3	3	1	2	0	0
80	2	3	3	2	0	0	1
81	2	3	3	3	0	0	0
82	3	3	3	1	0	0	0
83	3	3	3	2	1	0	0
84	3	3	3	3	0	0	0

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