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The Effects of Workload and Decision Support Automation on Enroute R-Side and D-Side Communication Exchanges

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16. Abstract

The Federal Aviation Administration (FAA) is introducing new decision aid technology, called decision support tools (DSTs), into the air traffic control (ATC) workforce. Although considerable research has focused on the effects that DSTs will have on pilot-controller communications, relatively little research has been conducted on how DSTs will affect controller-controller communications. In this study, we examined the effects that aircraft density and different types of DSTs have on the communication exchanges occurring within en route ATC teams. Two hypotheses guided the research. **Hypothesis 1**: More communication exchanges will occur under high workload conditions, as compared with low workload conditions. **Hypothesis 2:** More communication exchanges will occur when using DSTs, as compared with not using DSTs. **Method**. Eight 2-person teams, consisting of certified ATC specialists from an en route center, participated in a decision support automation research experiment. In the experiment communication exchanges of team members were assessed within a 2 (aircraft density) X 3 (type of DST) repeated measures design. Communications were analyzed by an ATC subject matter expert using an FAA ATC communication taxonomy consisting of three categories: the topic of communication, the grammatical form of communication, and the mode of communication. **Results**. A total of 3,194 communication events were coded. Partial support was achieved for hypothesis 1. When communications were analyzed as a composite number, no statistically significant results were observed. However, when the categories were analyzed separately, main effects for aircraft density were observed for two communication topics: general communications about a specific aircraft, $F(1,5) = 11.25$. $p < .05$, and communications involving altitude changes, $F(1,5) = 10.66$, $P < .05$. In both cases, there were more communications associated with the high-aircraft-density condition. No statistical support was achieved for hypothesis 2. However, trend data suggested partial support for the dominant topics of communication while performing under low aircraft density conditions. **Conclusion**. Controller-to-controller communications may be differentially affected by varying levels of aircraft density and technology employed. However, further replications are needed before a more definitive statement can be made.

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THE EFFECTS OF WORKLOAD AND DECISION SUPPORT AUTOMATION ON EN ROUTE R-SIDE AND D-SIDE COMMUNICATION EXCHANGES

Federal Aviation Administration (FAA) forecasts indicate that the number of passengers carried on commercial aircraft will double over the next 15 years reaching one billion by 2015 (FAA Plan to Modernize, 1998). To handle the projected increase in air traffic, the FAA is introducing new technology to aid air traffic control specialists (ATCSs) in their tactical and strategic decision making. Research previously focused on the effects of these decision aids on pilot-to-controller communication; however, relatively little research is available concerning the impact of decision aids on controller-to-controller (CTC) communication (Kanki & Pinzo, 1996). In this study, we examined the effects of aircraft density and automated decision aids on communication exchanges between en route air traffic control teams.

The National Civil Aviation Review Commission states that the expected growth in aviation cannot be safely accommodated without significant breakthroughs in air traffic modernization. The commission also cites air traffic communications as critical components requiring modernization in the aviation system (Aviation Financing, Air Traffic Control, 1999). Several emerging air traffic control systems, including the 21st Voice Switching and Control System (VSCS), Display System Replacement (DSR), and the User Request Evaluation Tool (URET) are in differing stages of implementation. Researchers at the Civil Aerospace Institute (CAMI) and the William J. Hughes Technical Center (WJHTC) are jointly conducting investigations to assess the impact of modernizing ATC communications. This research considers both hardware and software aspects of ATC modernization.

The current joint program of research focuses on CTC communications as they relate to the coordination of job-related tasks. The present study examines communication exchanges between En route Sector Teams (ESTs), also known as R-side and D-side air traffic controller teams, performing under varying levels of workload and using various decision support tools (DSTs). ESTs are composed of two individuals, a radar controller (R-side) and a data controller (D-side). The radar controller's responsibilities include monitoring aircraft, maintaining aircraft separation, and communicating via radio with the aircraft in their airspace (i.e., sector). The data controller's duties include maintaining flight progress strips, entering National Airspace System (NAS) data, coordinating sector activities, and conducting intra-facility and inter-facility communication. The above functions are coordinated through CTC communication.

Operational Error Data Base

Tracking the number of operational errors is one way of evaluating the quality of intra-EST coordination. Broadly speaking, an operational error occurs when a deviation from the standard operational procedures (SOPs) leads to a loss of aircraft separation. For example, in the en route environment, aircraft at the same altitude must be separated by at least five horizontal miles (FAA Order, 2000). Any time a verified loss of separation occurs, an operational error (OE) is recorded in the FAA's Operational Error database, and an investigation is conducted to determine the factors contributing to the loss of separation.

During an operational error investigation, an operational error reporting form is used to help determine the factors contributing to the error. As shown in Table 1, the reporting form is divided into five error categories. These include errors associated with: (1) Data posting, (2) Radar display, (3) Communication (primarily pilot to controller), (4) Coordination, and (5) Position relief briefings.ÐW: Each error category is further divided into varying levels of specificity.

Of interest in this report are the "intra-position" errors associated with "Coordination." In the en route environment, intra-position coordination primarily refers to problems with EST coordination. Since communication is the means by which the R-side and D-side coordinate their respective tasks, errors in coordination include errors in CTC communications. Table 2 shows the number and percentage of coordination related OEs recorded in the FAA's OE database. For the period from January 1998 through October 2000 approximately 126 out of 505 (25%) OEs were associated with problems of coordination. Of the 126 coordination errors (CEs) 45 (36%) occurred in the en route environment. A breakdown in intra-position coordination accounted for 13 out of 45 (30%) en route coordination errors (ECEs).

Table 1.
Structure of FAA ATC Operational Error Reporting Form

1. Data Posting
    a. Computer entry
        (1) Incorrect input
        (2) Incorrect update
        (3) Premature termination of data
        (4) Other
    b. Flight progress strip
        (1) Not prepared
        (2) Not updated
        (3) Posted incorrectly
        (4) Reposted incorrectly
        (5) Updated incorrectly
        (6) Sequenced incorrectly
        (7) Resequenced incorrectly
        (8) Interpreted incorrectly
        (9) Premature removal
        (10) Other

2. Radar display
    a. Misidentification
        (1) Overlapping data blocks
        (2) Acceptance of incomplete or difficult to correlated position info.
        (3) Improper use of identifying turn.
        (4) Failure to reidentify aircraft when accepted target identity becomes questionable.
        (5) Failure to confirm aircraft identity after accepting radar handoff.
        (6) Other
    b. Inappropriate use of displayed data
        (1) Conflict alert
        (2) Quick look
        (3) Mode C
        (4) MSAW/EMSAW
        (5) Other

3. Communication error
    a. Phraseology
    b. Transposition
    c. Misunderstanding
    d. Readback
        (1) Altitude
        (2) Clearance
        (3) Identification
    e. Acknowledgment
    f. Other

4. Coordination
    a. Area of incident
        (1) Inter-position
        (2) Intra-position
        (3) Inter-sector
        (4) Inter-facility
    b. An aircraft penetrated designated airspace of another position of operation or facility without prior approval.
    c. Coordination was effected and controller(s) did not utilize information exchange.
        (1) Aircraft identification
        (2) Altitudes/Flight level
        (3) Route of flight
        (4) Clearance limit
        (5) Speeds
        (6) APREQS
        (7) Special instructions
        (8) Other

5. Position relief briefing deficiencies noted
    a. Employee did not used position relief Checklist
    b. Employee being relieved gave incomplete briefing
    c. Relieving employee did not make use of pertinent data exchanged at briefing
    d. Other

Based on the results of Table 2, it may appear that intra-position coordination problems are not a major factor in the creation of operational errors. However, it should be noted that operational error investigations occur after the fact. Since intra-EST communications are not recorded on tape, an account does not exist of the actual communication exchanges between R-side and D-side positions. Controllers must rely on their memory to reconstruct both the content and timing of the communication exchange being investigated. Thus, intra-EST communications may be a factor in the creation of OEs, but the current reporting system is not sensitive enough to capture the details. Additionally not all intra-position coordination problems produce an operational error. That is, a breakdown in coordination may occur but the problem is resolved in time to prevent an operational error. Although there may be no loss of aircraft separation, from a safety perspective, even a potential loss of separation is a matter of concern. A research initiative revising the OE reporting form to address these and other human factors related to the systematic analysis of OEs is underway at CAMI (Scarborough & Pounds, 2001).

Even if intra-EST communications prove not to be a major factor in the development of OEs, the need to conduct research is not diminished. Empirical knowledge of the daily task-related communication exchanges between R-side and D-side controllers is limited. Considering that the new DSTs are designed to enhance the tactical and strategic decision making capabilities of ESTs, further intra-EST communication research is essential. What effect might these new technologies have on existing patterns of intra-EST communications? Without an understanding of the current baseline patterns of intra-EST communications, there is no empirical way to answer this question.

Field Study

Given the lack of understanding of intra-EST communications, Peterson, Bailey & Willems (in press) conducted a field study to determine the kinds and frequency of intra-EST communication exchanges associated with routine ATC performance. The field study was conducted over a three-day period at one of the FAA's en route centers. Trained ATC specialists using the FAA's Controller-to-Controller Communication/Coordination Taxonomy (C^{4}T) recorded a total of 24 hours of intra-EST communication. Coding occurred in 30-45 minute blocks of time between the hours of 0700 and 1900. Coders chose to observe the most active sectors to ensure a sufficient number of coding events. Thus, rather than obtaining a statistical sample, coders chose a sample of convenience.

The C^{4}T has three communication categories: the topic of communication, the grammatical form of communication (e.g. question, answer), and the mode of communication (e.g. verbal, nonverbal). Thus the C^{4}T captures the "what" (topic) and "how" (form and mode) of communication. Tables 3-5 respectively describe the C^{4}T sub levels within each of the three categories. For further information on the development and operational validation of the C^{4}T, the reader is referred to Peterson, Bailey and Willems (in press).

A frequency analysis of the coding results indicated the following observations. The topic of most intra-EST communications was related to aircraft traffic (40%) and route of flight (15%), with the least communications involving inter-sector coordination approvals (1%). R-side and D-side controllers demonstrated no statistical differences in the topic of their communication. However, they differed in the grammatical form of their communication. Whereas the D-side had a higher percentage of statements and

Table 2.
Breakdown of En route Coordination Errors (1998-2000)

Year	All ATC OEs	All ATC Coordination Errors (CEs)		All En Route Coordination Errors (ECEs)		Inter-Position ECE		Intra-Position ECE		Inter-Sector ECE		Inter-Facility ECE	
		#	%OE	#	%CE	#	%ECE	#	%ECE	#	%ECE	#	%ECE
1998	517	154	30%	47	31%	24	51%	11	23%	0	0	12	26%
1999	627	167	27%	59	35%	30	51%	21	35%	0	0	8	14%
2000*	371	58	16%	29	50%	19	66%	8	27%	0	0	2	7%
Average	505	126	25%	45	36%	24	53%	13	30%	0	0	7	16%

* Through October 1, 2000

Table 3.
Controller-to-Controller Coordination Communications Taxonomy (C^4T):
Coordination-Communication Topic

ATC Coordination-Communication Topic	Definitions
Approval	Communications about intersector control/approval requests (“Get me control for descent on that aircraft.” “APREQ N1234 climbing to FL330.”).
Handoff	Communications relating to the transfer of radar identification of a particular aircraft (“Handoff N1234.” “Did you handoff N1234?”).
Point Out	Communications relating to the transfer of radar identification of a particular aircraft when radio communications will be retained (“Point out N1234 to 22.”).
Traffic	Communications about a traffic situation involving a specific aircraft. Includes conflict, spacing, other protected air space or terrain and the resolution of that situation (“Are you watching that aircraft?”).
Altitude	Communications about altitude not in relation to traffic (“N1234 is requesting flight level 220.”).
Route	Communications regarding headings and/or amendments to route, not in relation to traffic situations (“N1234 is on a 330 heading.” “Next sector, 27, wants N1234 over WEVER.”).
Speed	Communications about speed not in relation to traffic situations (“These three aircraft are slowed to 250 knots.”).
Weather	Communications about weather display or weather updates (Often communicated nonverbally by passing written information: “Sector 22 says continuous moderate turbulence above FL290.”).
Frequency	Communications about an aircraft’s radio communications transfer or frequency assignment (“Have you switched N1234 yet?” “Tell them to switch to N1234.”).
Flow Messages	Communications about traffic flow restrictions not referring to a specific aircraft (“The next sector is requesting 25 miles in trail.”) (due to radar outage).
Flight Strips	Communications about flight progress strips (“Where is that strip?”) Often communicated nonverbally.
Equipment	Communications about any ATC hardware (The radar is out of service.”).
Aircraft ID	Communications involving identifying a specific aircraft (Who was that who called?” “That was N1234 who called.”).

Table 4.
Controller-to-Controller Coordination Communications Taxonomy (C^4T): Coordination-Communication Grammatical Form.

ATC Coordination-Communication Grammatical Form	Definitions
Question	A direct inquiry about the state or status of sector events.
Answer	A response to a direct or implied question
Statement	Providing information, without being asked, about the state or status of sector events.
Command	A direct order to perform a specific act

Table 5.
Controller-to-Controller Coordination Communications Taxonomy (C^4T): Coordination-Communication Expression

ATC Coordination-Communication Form	Definitions
Verbal	Use of voice only communication.
Nonverbal	Use of only body movement communication.
Mixed	Communication that contains both a verbal and non verbal component.
Electronic	Not used. Communication that is electronically transferred.

observations (56% vs. 30%), the R-side had a higher percentage of answers (43% vs. 35%). From this, it appeared that, compared with the R-side, the D-side controller was the initiator of more communication. Finally, there was no intra-EST difference in the method of communication. The most frequent method of intra-EST communication was verbal only (70%). The remaining 30% of communications contained a mixture of verbal and non-verbal expressions. This latter finding suggested that any changes affecting the line of sight between R-side and D-side positions could disrupt the adaptive use of intra-EST nonverbal communication.

Peterson et al. (in press) concluded their report by highlighting the need to conduct controlled experiments to determine how changes in workload and technology affects intra-EST communications. Although field studies preserve operational realism, with a complex task such as air traffic control, many variables come into play, making it difficult to determine which factors affect performance. For example, one might wish to know the effects of more or less CTC communication on sector safety and/or efficiency. However, CTC communication is the result of the interaction between the EST members and the environment (sector complexity and traffic volume) in which they work. Within a laboratory environment, researchers have greater control over the environmental setting (e.g., equipment, sector complexity, traffic volume, work duration) and, thus, can better understand the effects of the experimental manipulation.

Collaborative Research

Although researchers have greater control in a laboratory environment, sometimes the experimental environment does not adequately represent operational reality. When this happens, it is difficult to generalize from experimental outcomes to the operational environment. One way of addressing the artificial nature of a laboratory setting is to ensure that the equipment, participants, and stimulus material reflect real world conditions. This requires significant financial resources. The hardware and software support necessary to simulate a high fidelity en route air traffic control environment costs in excess of $500,000. In addition, the cost for each ATC participant is $2500/week.

Given that research in the area of intra-EST communication is at the descriptive stage of empirical research, large expenditures devoted solely to describing CTC communications are difficult to justify. To help reduce the cost of research, researchers from CAMI and the WJHTC developed a collaborative initiative whereby intra-EST communication data are collected on all experiments related to the WJHTC's Decision Support Automation Research (DSAR) program (Willems, 1999). The research objective of DSAR is to evaluate ATC human performance under varying levels of workload and DSTs. Thus, DSAR experiments provide an ideal setting for the study of intra-EST communications.

Research Hypotheses

During the descriptive phase of research, objectives focus more on systematically collecting and organizing data than it does on hypothesis testing. However, a body of literature exists on controller-to-pilot communication. Using this literature as a starting point, some initial hypotheses can be generated about the effects of workload and technology on communications.

Workload

A consistent finding in controller-to-pilot voice communications research is that workload affects the quality and quantity of communication exchanges (e.g., Prinzo & Britton, 1993). In this literature, workload is primarily measured by the number of aircraft at a given time (i.e., aircraft density) under the control of a R-side ATCS. As aircraft density increases, there is a corresponding trend toward an increasing number of communication errors (Morrison & Wright, 1989; Morrow, Lee, & Rodvold, 1990). Research suggests that, as ATCS and pilots become overburdened the clarity of their communications (e.g., incomplete phraseology, mispronunciation, and rapid speech) begin to suffer. This, in turn, places ATCS and pilots at a higher risk of committing readback/hearback errors (Morrison & Wright, 1989). Standard ATC protocol requires pilots and ATCS to repeat what they heard. The sender then knows that the message was accurately received. A readback/hearback error occurs when an incorrect pilot or ATCS readback of information goes uncorrected.

In addition to communication errors, changes in workload also affect the kinds of communication exchanges that occur. For example, researchers at Human Technology Incorporated (1991) examined the effects that ATC communications had on system performance. They found that high performance teams issued more communication reports to pilots than did lower performance teams. Furthermore, compared to low performance teams, high performance teams issued shorter messages as a means of insuring accuracy. Ratings of team performance were based on over-the-shoulder ratings conducted by ATC subject matter experts. However, it remains to be seen whether these results will generalize to the broader ATC population or are specific to a given experimental manipulation.

Automation

Technology is sometimes considered to be the answer for life's problems. However, technology itself can become a burden. In studies of the use of automation in the cockpit, Hart and Sheridan (1984) found that pilot workload shifted from a physical burden to a more cognitive one. This was evident when the automation required pilots to serve as monitors of a system such as monitoring cockpit flight management system displays (Sarter & Woods, 1994). In studies of the use of automation in commercial airlines, Wiener (1985) noted that pilots found the additional task of monitoring to be troublesome especially during high workload. Not only did monitoring add to the fatigue but there were times when the automation needed to be turned off or ignored during critical portions of a flight (Wiener, 1988).

In addition to the added burden that some technologies create, operators may not use the technology as designed because they simply do not trust it (Riley, 1994). Technology promises much, but the reality is that it sometimes falls short on delivery. For example, as part of its ATC modernization program, the FAA developed new data display terminals and keyboard configurations. It was expected that the new system would help to improve system capacity. However, when the equipment was tested in a field setting, users found that they were having problems making the transition to the new system (Allendoerfer, Galushka, & Mogford, 2000). Compared with performance under the old system, ATCSs were slower and tended to make more data entry errors. Rather than viewing this as simply a matter of adjustment, users attributed the problems that they were having to poor system design.. Although some sort of an adjustment period was expected, problems such as these emphasize the need to switch from technology centered approaches to more human centered approaches to modernization. Whereas the former requires the human to adapt to the technology, the latter requires the technology to adapt to the needs of the user (Billings, 1988).

Although the use of technology is related to workload, its effects on communication are unclear. From the concept of monitoring, an operator has no need to communicate unless an event occurs requiring the actions of another. As far as whether a given technology is used or trusted, one might conjecture that communications would increase during the transition period of adjusting to the new technology. This would be true if there were problems with the technology and team members had to determine the level of trust or confidence in the system. However, once the transition period is completed (and assuming that the system is reliable), one would expect communications to return to a previous baseline.

Considering the above discussion, the following hypotheses were derived.

Hypothesis 1: More intra-EST communication exchanges will occur under high workload conditions, as compared with low workload conditions.

Hypothesis 2: More intra-EST communication exchanges will occur when using DSTs, as compared with not using DSTs. This hypothesis is based on the assumption that there will be insufficient training time for participants to feel fully comfortable with the new system procedures.

Study Limitations

One of the inherent difficulties with conducting applied research is working within limitations. Two limitations that affect this current research are a lack of statistical power and financial resources. Statistical power refers to the minimal sample size necessary for a given effect to reach statistical significance. As cell sizes fall below this minimum, a the ability to adequately test hypotheses is reduced.

Prior to conducting the experiments, researchers conducted a power analysis using software from the Methodologist's Toolchest (Brent & Thompson, 1996). The procedure is derived from Kraemer and Theimann (1987) for related samples balanced designs on pair-wise comparisons with a two-tailed test of significance. Assuming a mean difference of 2, an average standard deviation of 10, an alpha of .10, and a beta of .50, the results produced a minimum sample size of 18 cases (or ESTs) or a total of 36 ATCSs. However, in this study, the available financial resources could only cover the cost of 8 ESTs or a total of 16 ATCSs. As is often the case in applied settings, economic realities become the limiting factor in the quality of the studies conducted.

Given the above limitations, one might ask, is there any real value in studying intra-EST communications in a laboratory setting? The answer, of course, depends on the value that is placed on inferential statistics. There exists the concern among part of the scientific community that, unless results achieve statistical significance, they are not meaningful or are just artifacts of sampling error (e.g., Branch, 1999). What gets lost is that statistical significance does not guarantee that the results will generalize to the broader population. Generalization depends on how the sample was selected to ensure representation (i.e. generalization back to the population). Continuing with the preceding example, let us assume that we have a population of 10,000 enroute ATCSs or 5,000 ESTs. According to sampling theory, we would have to draw a random sample of 357 ESTs to ensure that our sample represents the enroute population. Sample computations were made using the website calculator at
http://ebook.stat.ucla.edu/calculators/sampsize.phtml.

Note that an additional 321 ATCSs are needed to ensure representation as compared to statistical significance. If achieving statistical power is cost prohibitive, representation is even more so.

One way of dealing with the problem of inadequate sample size is evaluating intra-EST communication patterns across numerous studies. Over time, a communication profile develops based on known contextual factors (i.e., experimental conditions). To the extent that similarities in the communication profile are observed, this would suggest a phenomena that is robust and thus indicative of the universal nature of R-side and D-side communication. However, to the extent that the communication profiles are different, this would suggest that situation-specific conditions dictated the nature of intra-EST communications. Thus, regardless of the outcome, the systematic collection of data has the potential to provide insight into the nature of intra-EST communications and to provide guidelines for conducting field studies.

METHOD

The research described in this report is a subset of a broader experiment associated with the WJHTC's DSAR program. Only the methods directly related to the assessment of CTC communications are reported in this study. For additional information on the experimental design, see Willems (1999).

Participants

Eight 2-person teams, consisting of certified ATCSs from an en route center participated in a two-week DSAR experiment. Participants were paid their regular salary and were on government per diem throughout the duration of the experiment. Following training, participants were randomly assigned to an experimental condition.

Equipment

The equipment used in this experiment was functionally equivalent to the workstations used by the R-side and D-side ATCSs in an en route center. An ATC high-fidelity simulator was used to model the airspace used in this study. The experimental environment included full DSR workstations with full operational functionality. A 2,000 by 2,000 pixel, 29" video display unit represented the DSR radarscope. Also included were a DSR flight strip bay, an en route keyboard and trackball, and a DST terminal that included both a conflict avoidance tool (CAT) and a flight path planning tool (FPPT). Prior to the experiment, none of the participants had used the CAT or FPPT.

The CAT used the trajectory of aircraft to predict potential loss of aircraft separation. For example, all things being constant, the CAT determined whether the trajectory of two aircraft would intersect any time within a 20-minute period. Conflict information was presented in several display windows that depicted various flight data and conflict information. One display window presented a list of all aircraft inbound to the sector. The list showed who was the controlling sector of a particular aircraft; flight data such as flight route, aircraft type, speed, altitude and beacon code, and conflict indication. The conflict indication displayed red for predicted violations of less than 5 nautical miles and displayed yellow when less than 12 nautical miles, but more than 5 nautical miles. A graphic-plan-display window graphically depicted aircraft and resembled the DSR display.

By a D-side entering a revised altitude or route change, the FPPT enabled the EST to determine the best flight plan for resolving a potential intra- and/or inter-sector conflict. Thus, instead of resolving conflicts as tactical decisions, the FPPT enabled ATCSs to choose a strategic resolution to a given problem. Within an EST, information from the DSTs was processed by the D-side and communicated to the R-side.

Stimulus Material

An ATC supervisor on detail to the WJHTC developed air traffic control scenarios for use in the training and experimental conditions. Each scenario was 45 minutes long. For the training condition, six scenarios placed participants under a moderate workload defined as the amount of air traffic that could be comfortably handled by a R-side/D-side team, as perceived by a typical ATC supervisor. For the experimental conditions, six low-and seven high-workload scenarios were developed. The low-workload scenarios were defined as the least amount of air traffic in which a typical ATC supervisor added a D-side to assist the R-side controller. The standard for developing high workload scenarios was the greatest amount of air traffic that a typical ATC supervisor allowed a R-side / D-side team to manage.

Measures

All task-related R-side/D-side communications were videotaped and coded by an ATC subject matter expert (SME) using a computerized version of the C^4T. The SME was a retired ATCS who had spent the last five years providing contract support in the area of ATC communications research. This involved providing subject matter expertise in the development of coding taxonomies for both controller- to-pilot communications and controller-to-controller communications.

Training

Prior to participating in the experiment, participants received four days of training on the air space, scenario flow and traffic type, DSR workstations, and DST equipment. After completing the familiarization phase of training, participants performed ATC tasks in response to six 45-minute air traffic scenarios. Each scenario was calibrated by a SME to represent a moderate amount of workload. The decision aids used during training followed the experimental design.

Design and Procedures

Communication exchanges of team members were assessed within a 2 (workload) X 3 (type of DST) doubly repeated measures design. The two levels of workload were low and high, as previously described in the Stimulus Material section. DST levels were: (1) Tech 1- only paper flight strips, (2) Tech 2 - electronic flight strips and a CAT, and (3) Tech 3- electronic flight strips, CAT, and a FPPT.

RESULTS

Field Comparison

Prior to hypothesis testing, the frequency data (collapsed across all trials) were analyzed by topic, grammatical form, and communication mode so that a direct comparison could be made with the field study conducted by Peterson, et al (in press). The purpose of this comparison was to determine if differences existed in the patterns of communication operating within the two settings. Although the experiment was not modeled after a particular en route center, the scenarios were designed to reflect real-world events. Thus, one might expect similarities between intra-EST communications within a field and experimental setting. However, differences are also likely because communications, as a whole, are the product of various person (e.g., personality) and environmental factors (sector/scenario demands).

Table 6 shows the comparisons for the percentage of R-side and D-side communications related to the topic of communication, its grammatical form, and the mode of expression. Although Table 6 shows that field and laboratory settings differed in the percentage of total communications that were attributed to a given topic, both laboratory and field assessments identified the same top three topics. These included communications about "Traffic," "Route," and "Altitude." Compared to the field the most noticeable difference in the experiment was the lack of communications about "Weather (not part of the experiment), "Point-Outs," and "Traffic flow." Additionally, there were only minimal amount of communications concerning "Flight Strips."

The grammatical form of communications also differed between the two environments. The field results show a strong tendency for the D-side to make statements (55.9%) and the R-side (42.8%) to provide

Table 6.
Contrasting percentage comparisons of R-side and D-side communications in field and laboratory settings.

	Enroute Center		Laboratory Setting	
	R-side%	D-side%	R-side%	D-side%
Communication Topic				
Traffic	41.0	37.9	53.7	51.2
Route of flight	14.2	15.6	13.1	11.7
Altitude	7.1	8.0	16.0	21.1
Weather	5.5	6.8	0.0	0.0
Point-out	5.0	6.1	0.0	0.0
Traffic flow	5.2	5.6	0.0	0.0
Frequency	5.9	4.7	3.5	2.7
Flight Strips	5.6	4.5	0.7	1.0
Equipment	3.3	4.0	4.5	4.9
Hand-off	3.6	3.1	2.9	1.8
Speed	2.6	2.8	4.4	2.8
Approval	1.0	0.9	1.0	1.8
Communication Format				
Statement	29.7	55.9	58.0	77.3
Answer	42.8	25.1	18.3	10.4
Question	12.2	16.4	22.9	11.3
Command Answer	5.8	0.3	0.0	0.0
Command	0.5	2.4	0.8	1.0
Communication Mode				
Verbal	77.1	69.3	93.9	69.0
Verbal & Nonverbal	14.7	16.8	5.0	24.7
Nonverbal	13.9	13.9	0.5	2.8
Equipment			0.0	0.1
Equipment & Verbal			0.6	3.4
Equipment & Nonverbal			0.0	0.1

answers. In contrast, the experiment's results show both R-side and D-side predominately making statements (58% vs. 77.3%).

Verbal communication is the method of choice for R-side and D-side controllers. However, as Table 6 shows, the D-side had a stronger tendency to use a mixture of verbal and nonverbal expressions in the experiment than did the R-side (24.7% vs. 5%). For the field setting, the percentage of mixed messages was similar for both the R-side and D-side (14.6% vs. 16.8%). Another difference between the two settings is the percentage of nonverbal communications that were used. In the field, 13.9% of the communications was solely nonverbal for both the R-side and D-side. This is in contrast to the lower percentages recorded during the experiment (R-side 0.5%, D-side 2.8%).

Hypothesis Testing

During the experiment, problems occurred with the computer algorithm used to assign participants to a given condition. This created missing data for three teams in time 1 and three different teams in time 2. Because the communication component of the experiment was primarily descriptive in nature, the decision was reached not to replace missing data with mean substitutions, but instead to drop the cases from further analysis. Furthermore, since time 1 and time 2 data involved missing data for six different teams, the doubly repeated measure design was dropped and changed to a simple 2 x 3 repeated measure design using only time 1 data. From these data, 3,194 communication events were coded. Descriptive statistics for these data are presented in Table 7. These data are also graphically displayed in Figures 1-3.

A 2 x 3 repeated measures analysis of variance (ANOVA) was used to examine the effects that aircraft density (low vs. high) and level of technology (Tech1, Tech2, and Tech3) had on the topic of intra-EST communication, its grammatical form, and the method of expression.

Hypothesis 1 stated that there would be greater amounts of communication under high workload conditions, as compared to low workload conditions. When communications were analyzed as a composite number, no statistically significant results were observed. Each of the C^4T categories was then analyzed separately to determine if the experimental conditions affected any of the subcategories. No significant results were observed for any of the subcategories within the grammatical form of communication or the mode of communication. However, main effects for workload were observed for two communication topics: (1) communications identifying a specific aircraft, $F(1,5) = 11.25$. $p < .05$, and communications involving altitude changes, $F(1,5) = 10.66$, $p < .05$. In both cases the high aircraft density condition was associated with more communication exchanges between the R-side and D-side positions.

Hypothesis 2 stated that more communications would occur in the higher tech condition as compared to the lower tech conditions. Although statistical significance was not attained, Figure 1a shows that under the low workload condition, the highest degree of technology (tech 3) recorded the most communication events about Traffic and Altitude.

CONCLUSION

In this study we examined the effects of aircraft density and different kinds of automated decision aids on communication exchanges between R-side and D-side air traffic controller team members. Collapsing across all technologies, the results showed more total communication exchanges under high aircraft density conditions as compared to low aircraft density conditions. This result was driven by the top two topics of communication: (1) communications about the identification of a specific aircraft, and (2) altitude changes. The effects of automation decision aids on communications, however, were not as clear. There was some evidence that under the low aircraft density condition, more communication exchanges occurred (about the identification of a specific aircraft, altitude changes, and route of flight) using the highest level of automation, as compared with the two lower levels of automation.

The overall trend of the C^4T profile of the experiments (collapsing across all conditions) compared favorably with data collected from the field. In both cases, the top three topics of communication were Traffic, Route, and Altitude. Also, in both cases, verbal communication was the dominant mode. Despite these similarities there were notable differences in the grammatical form of communication between R-side and D-side controllers. Whereas in the field it appeared that the R-side was primarily responding to statements made by the D-side, in the experiment, it appeared that both R-side and D-side controllers were issuing statements. In addition, more nonverbal communications were observed in the field as compared to the laboratory environment. Given that communication is a function of the characteristics of team members and the situations that they face, it is not surprising that differences occurred. It remains for future research

Table 7.
C^{4}T Descriptive Statistics of Experimental Conditions.

Aircraft Density	Measure	Tech 1			Tech 2			Tech 3		
		n	M	SD	n	M	SD	n	M	SD
Low										
	Total Communication	5	63.20	23.27	5	62.60	27.63	5	61.00	27.07
	Topic of Communication									
	Approval	1	1.0		1	1.0		3	1.33	0.58
	Handoff	3	3.33	6.43	2	5.0	5.66	3	5.0	4.58
	Pointout	0			0			0		
	Traffic	5	24.40	6.43	5	26.20	21.71	5	28.60	14.28
	Altitude	5	8.80	6.53	5	8.80	9.26	5	12.40	5.94
	Route of Flight	5	7.4	3.36	5	5.80	4.55	5	9.00	9.80
	Speed	5	3.2	2.68	5	4.8	5.93	2	2.50	.71
	Weather	0			0			0		
	Frequency	5	3.4	1.94	3	2.67	0.58	4	2.75	0.96
	Traffic Flow	0			0			0		
	Flight Strips	2	6.0	4.24	0			0		
	Equipment	2	8.5	10.60	5	5.0	3.87	4	5.0	2.45
	Aircraft ID	0			0			0		
	Grammatical Form of Communication									
	Question	5	9.00	4.36	5	10.20	3.56	5	12.20	7.16
	Answer	5	9.60	8.99	5	8.80	4.18	5	8.80	5.22
	Statement	5	36.20	11.12	5	42.40	19.63	5	39.60	16.85
	Communication Mode									
	Verbal	5	46.40	18.30	5	53.60	24.09	5	51.60	23.55
	Mixed Verbal Nonverbal	5	6.8	7.05	5	6.60	3.51	5	7.80	4.66
High										
	Total Communication	5	69.00	31.63	5	72.60	5.43	5	60.60	23.07
	Topic of Communication									
	Approval	1	5.00		2	3.0	1.41	1	6.00	
	Handoff	2	2.0		3	2.33	1.52	2	1.50	.71
	Pointout	1	1.50		0			0		
	Traffic	5	30.40	10.55	5	35.40	13.18	5	36.40	13.16
	Altitude	5	20.00	10.86	5	13.60	6.19	5	11.40	5.94
	Route of Flight	5	8.20	9.88	5	13.60	10.11	5	5.40	3.78

Table 7. (Continued)
C^4T Descriptive Statistics of Experimental Conditions.

Aircraft Density	Measure	Tech 1			Tech 2			Tech 3		
		n	M	SD	n	M	SD	n	M	SD
High										
	Speed	3	3.67	1.53	4	3.50	1.00	4	4.75	5.56
	Weather	0			0			0		
	Frequency	4	3.75	3.59	4	1.75	0.50	4	3.25	1.26
	Traffic Flow	0			0			0		
	Flight Strips	2	4.0	1.41	0			0		
	Equipment	2	5.5	6.36	3	4.33	1.53	3	6.33	3.51
	Aircraft ID	0			0			0		
	Grammatical Form of Communication									
	Question	5	8.40	2.97	5	13.60	2.88	5	13.40	5.03
	Answer	5	7.60	6.43	5	11.00	4.95	5	9.40	6.91
	Statement	5	51.80	23.99	5	45.80	6.38	5	42.20	13.03
	Communication Mode									
	Verbal	5	52.80	24.10	5	55.20	8.76	5	56.40	17.90
	Mixed Verbal Nonverbal	5	13.80	8.14	5	14.60	7.06	5	8.40	8.14

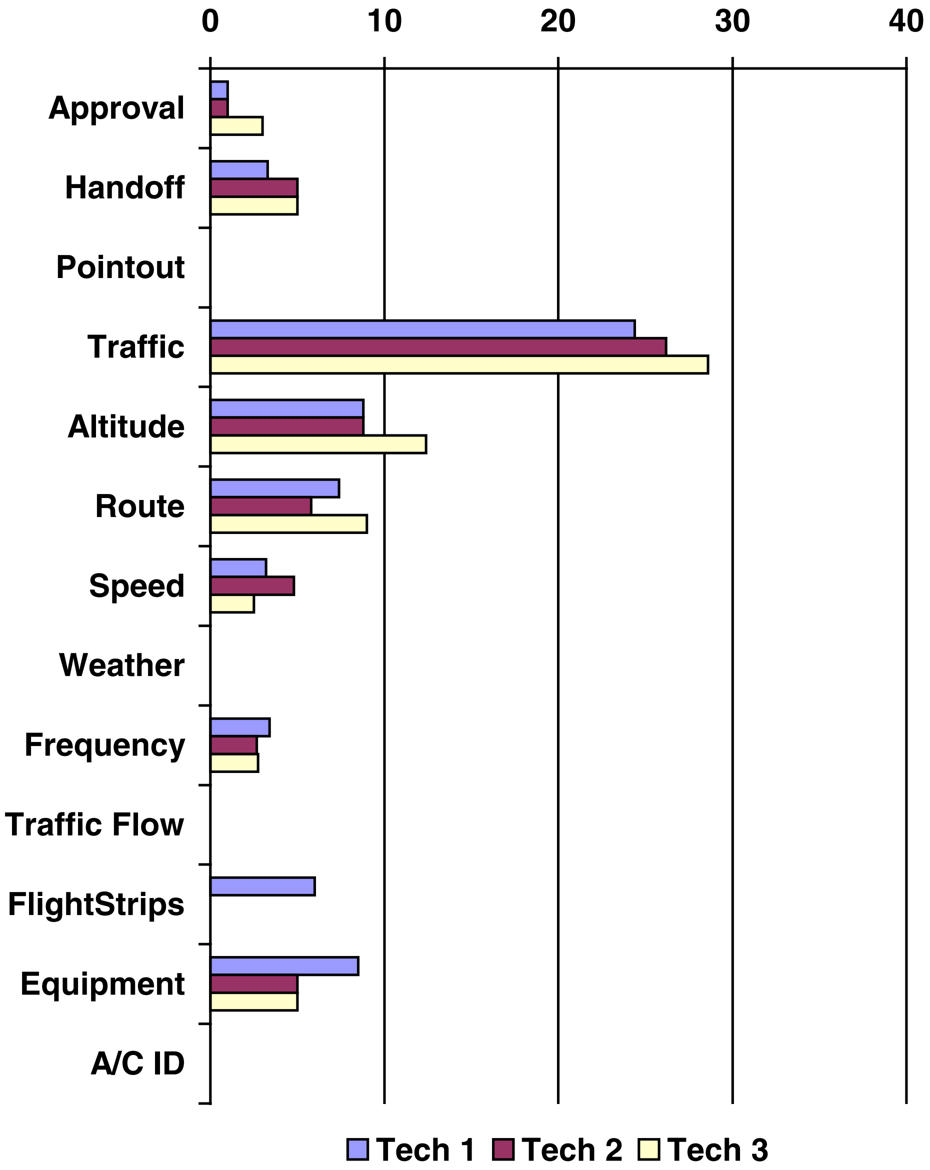

Figure 1a.
Topic of Communication Comparison of Three Decision Support Technologies Under Low Workload Conditions.

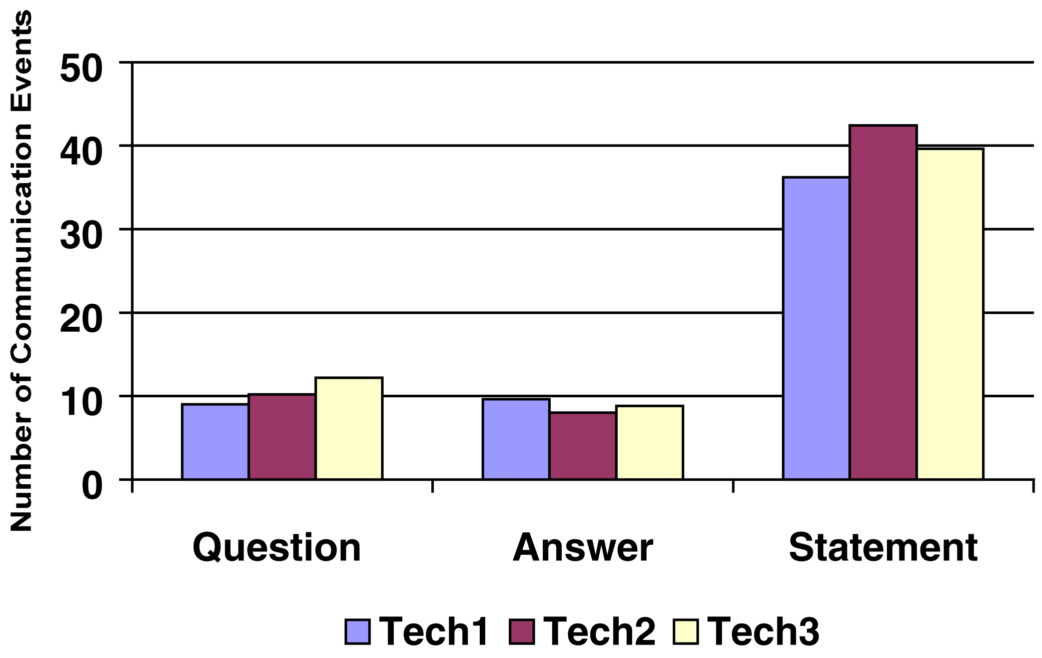

Figure 2a.
Comparison of the Grammatical Form of Communication for Three Decision Support Technologies Under Low Workload Conditions.

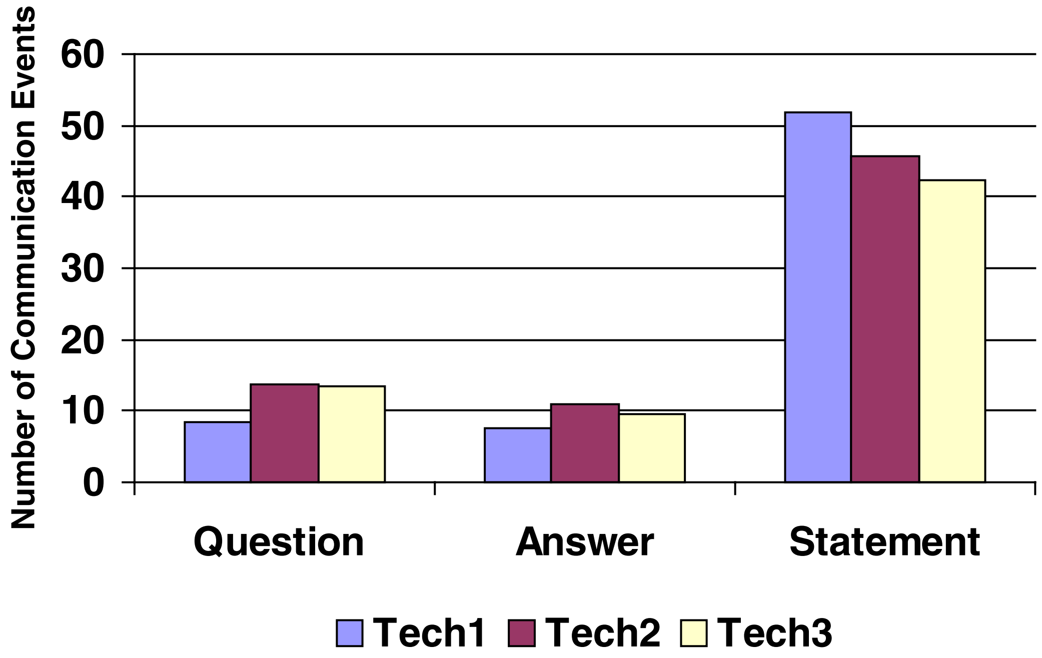

Figure 2b.
Comparison of the Grammatical Form of Communication for Three Decision Support Technologies Under High Workload Conditions.

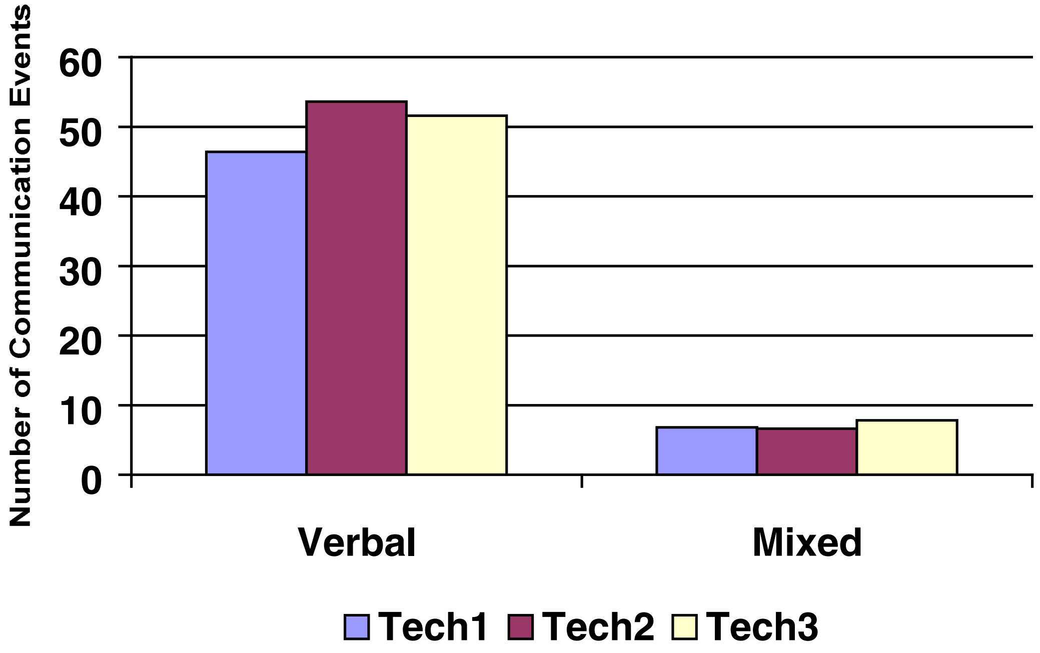

Figure 3a.
Comparison of the Mode of Communication for Three Decision Support Technologies Under Low Workload Conditions.

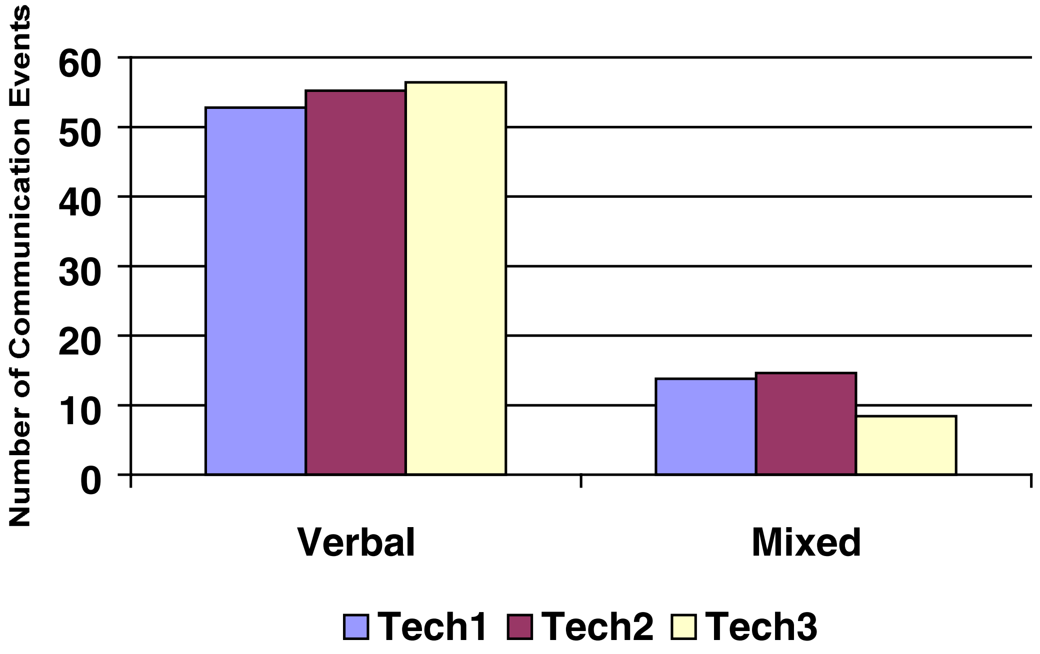

Figure 3b.
Comparison of the Mode of Communication for Three Decision Support Technologies Under High Workload Conditions.

to determine whether and how intra- or inter-team variability affects system outcomes of safety, efficiency, and effectiveness.

Future Directions

Objective measures of ATC intra-team coordination have remained an elusive goal for the FAA. Despite the number of training initiatives targeted at improving ATC team performance, none of them has empirically demonstrated that they lead to improvements in intra-team coordination within the job setting.

Recently, the FAA funded a cooperative research program with Kansas State University to develop a method of identifying expert performance: the Cochran-Weiss-Shanteau statistic (CWS) (Shanteau, 2001; Thomas, 2001; Weiss, 2001). In its current form, CWS is a summative index that differentiates between levels of expertise residing within individuals. However, a dynamic measure of performance expertise is in the developmental stages. By extending this measure to the team level of analysis, researchers will accomplish a number of objectives. These include: (1) objectively classifying teams based on their levels of expertise, (2) determining the role that intra-team communication plays in developing team expertise, and (3) determining how levels of team expertise relate to sector outcome measures such as the average amount of fuel burn or time in sector.

Whether intra-EST communication research takes advantage of advances in the measurement of team expertise, it is important to explore the impact that intra-EST communications has on system safety and efficiency outcomes. To the extent that a relationship exists, researchers will be in a better position to develop more sophisticated models of ATC performance.

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