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Controller-to-Controller Communication and Coordination Taxonomy (C^4T)

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16. Abstract

While previous research in the air traffic control (ATC) communications area has generally concentrated on controller-pilot communications, this program of research focuses on controller-to-controller communications. At the Air Route Traffic Control Center (ARTCC), teams of two controllers, R-side and D-side, are required to communicate on a continuing basis to coordinate the duties of their sector. As modernization of the ATC system progresses, questions arise concerning the effects these changes will have on intra-enroute sector team (EST) communications.

In anticipation of technology changes, the Federal Aviation Administration commissioned a series of studies investigating intra-EST communication. This initial study details the design and subsequent field testing of the Controller-to-Controller Communication and Coordination Taxonomy (C^4T). The taxonomy is designed to capture the following general communication categories: Topic, Format (grammatical form), and Expression. The final taxonomy resulting from this research contains 12 ATC topics (i.e., Traffic, Altitude, etc.). Communication Grammatical Format contained 5 subcategories: Question, Answer, Statement, Command, and Command Answer. Communication Expression consisted of 3 subcategories: Verbal, Nonverbal or a combination of Verbal and Nonverbal, referred to as Both. A field study at an ARTCC was conducted with subject-matter experts coding intra-EST communications using the taxonomy described. Field observations were made at 18 different sectors between the hours of 07:00 and 019:00 based on moderate to high traffic levels. Descriptive statistics detail the results of the taxonomy's use in a field setting.

Testing and further refinement of the taxonomy allows its use in both field and controlled experimental settings, provides a tool for training individuals to code C^4T communications, and enables the establishment of a C^4T baseline to investigate changes in communication patterns as modernization continues in the enroute ATC environment.

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Controller-to-Controller Communication and Coordination Taxonomy (C^4T)

Air traffic has increased about 4% per year, although increases have reached 20% in certain highly competitive locations (Garvey, 1998). The National Civil Aviation Review Commission states that the expected growth in aviation cannot be safely accommodated without significant breakthroughs in air traffic modernization. Air traffic communications are cited as critical components requiring modernization in the Aviation system (Garvey, 1999). The important role that communication plays in maintaining safety and efficiency within the National Airspace is most evident when communications fail and air traffic control (ATC) operational errors, pilot deviations, and runway incursions occur. The tragic accident at Tenerife is perhaps one of the better examples of a communications breakdown between controllers and pilots under conditions of poor visibility, leading to the loss of 583 lives (Stokes & Kite, 1994).

Communications at air traffic control facilities occur at many levels both within and between facilities and between controllers and pilots. Traditionally, analyses of air traffic control communications (ATCC) have focused on the information exchange between pilot and controller and the consequence of breakdowns in communications (Cardosi, 1993; Kanki & Prinzo, 1996a; Prinzo & Maclin, 1996; Prinzo, Lieberman, and Pickett, 1998a; Prinzo, 1998b).

Within enroute air traffic control centers (ARTCCs), controllers often work as an enroute sector team (EST). The EST consists of a radar (R-side) and data (D-side) team whose function is to handle traffic within the sector. The D-side team member assists the R-side when traffic reaches certain levels within the sector. Duties of the R-side and D-side controllers are defined in the ATC position standards (FAA, 1992). Emphasis is placed on the importance of team communications in the following areas: advising other team members of situations requiring attention or immediate action, initiating actions to resolve problems, participating in planning activities, and monitoring the air traffic environment. Thus, the presence of a second controller at the sector facilitates both the strategic planning and operational control of air traffic. Information exchanges between the two team members can either facilitate the safe and efficient flow of traffic across the sector or serve to delay overall traffic flow. To date, little is known about the intra-EST communication process. This study was designed to (a) develop a taxonomy to capture and categorize ATC R-side to D-side communications and (b) to conduct an initial validation of the taxonomy at an en route traffic control center.

Gathering baseline communications data from controllers operating with existing equipment and procedures is critical to both determine the potential affects of new technologies and procedures and to assist in the development of those capabilities. We currently have several emerging air traffic control technologies and systems, including Data Link (DL), the 21st Switching and Control System (VSCS), Display System Replacement (DSR), and the Standard Terminal Automation Replacement System (STARS). In addition, the future will bring advanced decision aids and the possible transfer of control functions between pilots and controllers under certain free flight scenarios. A need to assess the effects of implementation of these technologies and procedures on overall communications was a primary factor in this evaluation of R-side and D-side communications.

METHOD

Taxonomy Development

Prior to observations at the FAA Academy's Radar Training Facility (RTF), subject matter experts (SMEs) and Civil Aerospace Medical Institute (CAMI) researchers met to consider possible categories for the taxonomy. All SMEs had prior ATC experience and contributed to identifying communication content, especially in regard to the topics of communication. Common experience in ATC led to operational definitions of the category ATC Communication Topic.

The observations of intra-EST communication were conducted at the RTF by SMEs, RTF instructors, and CAMI researchers. Information was gathered during four 15-minute air-traffic scenarios, at two levels of traffic workload. The traffic workload chosen was based on position requirements for different levels of air traffic. ATC staffing at enroute centers is routinely modified to accommodate variations in air traffic volume that occur throughout a typical day. During periods of increased volume, controllers work as R-side, D-side teams. This was defined as medium workload. Air traffic may increase to a level where a

third position, called a tracker, is added to the team. The traffic volume just prior to adding a tracker was defined as high workload. RTF observations were made during both medium and high workload scenarios with the EST teams consisting of active R-side and D-side team members.

RTF observations of intra-EST communication resulted in the identification of 12 Communication Topics, five Communication Grammatical Formats, and three types of Communication Expressions. The 12 ATC Communication Topics included: (1) Approval, (2) Handoff, (3) Point-out, (4) Traffic, (5) Altitude, (6) Route, (7) Speed, (8) Weather, (9) Frequency, (10) Flow, (11) Equipment, and (12) Flight Strips. The five Communication Grammatical Formats subcategories were adapted from Bales (1950) and were identified as (1) Question, (2) Answer, (3) Statement, (4) Command, and (5) Command Answer. The three types of Communication Expression were documented as (1) Verbal, (2) Nonverbal, and (3) Both (containing elements of both verbal and nonverbal communication).

Pre-testing Taxonomy Categories

Once the preliminary categories were formulated, a beta test was conducted with the assistance of the SME's, RTF instructors, and CAMI researchers. ESTs participated in simulations of the enroute radar environment during medium and high workloads for 15-minute periods. During these simulations, intra-EST communication was observed and recorded. Following comparison of the recorded observations, the categories were further refined to develop the C^4T taxonomy. With the taxonomy finalized, the selection and training of field coders commenced.

Taxonomy Beta Testing in the Field

Field coders were selected based on their expertise in ATC. All field coders were former air traffic controllers familiar with the intricacies of ATC communication. Three of the field coders were instructors at the FAA Academy RTF. The remaining field coder was an SME with extensive knowledge of ATC communication and experience with field studies.

Field coders were familiarized with the taxonomy during simulated EST scenarios conducted at the FAA Academy. A beta test in the actual enroute field facility was conducted prior to implementation of the taxonomy in the field study. The coders and the principal investigator reached consensus, and the taxonomy was accepted for use in the field study.

Coding Devices: Hardware and Software

CAMI and the William J. Hughes Technical Center (WJHTC) combined resources to acquire four Orasis hand-held computers from Dauphin Technology, Inc., for collection of observational data during field research. These devices provided the coders the mobility necessary to observe both verbal and nonverbal communications. The WJHTC personnel designed software to allow coding of the taxonomy elements in a field setting.

Data Gathering

The Miami ARTCC was the designated field site for taxonomy testing. This site was selected for its variation in traffic density and configuration, and its air space diversity, which includes military and transoceanic air space. The Miami ARTCC also experiences diverse weather conditions with seasonal rain and hurricane conditions. This range of conditions allowed observation of intra-EST communication under a variety of different circumstances. The above mentioned conditions existed during the time of the study, with the exception of hurricane conditions.

Coding was conducted at 18 different sectors at various times between 07:00 and 19:00 based on the amount of air traffic present in a particular sector. Observation of a sector was dependent on moderate-to-high traffic, which allowed the observers to capture the most intra-EST communication per observation period. Initially, observation periods were scheduled for 15-minute intervals. However, beta testing determined that a more optimal time segment for an entire range of intra-EST communication was 30-45 minutes.

Coders observed the intra-EST communication in teams of two observers per intra-EST. One of the coders observed the radar position and coded only the R-side communication of the intra-EST. The other observed the data position and coded only D-side communication. Communication coding was limited to ATC issues. All participants were assured that personal conversations were not included in this study and would not be coded.

Table 1 includes the ATC Communication Topics, and provides an operational definition of each topic, as well as examples of intra-EST communication for each topic. The examples for each topic are derived from actual intra-EST communications and are considered prototypical intra-EST conversations for the topic.

Communication Grammatical Format was coded according to the grammatical presentation of the communications as a Question, Answer, Statement,

Table 1. Controller-to-Controller Coordination Communications Taxonomy (C^4T)

ATC Communication Topic	Definitions and Examples
Approval	Communications about inter-sector 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.")

Command, or Command Answer. Communication Expression included Verbal, Nonverbal and Both. Communication Expression required observation of nonverbal gestures such as head nodding, pointing to the screen, and gesturing thumbs up, among other nonverbal gestures. Communications consisting of only a nonverbal gesture were coded as Nonverbal. Intra-EST communications with verbal and nonverbal elements were coded as Both. A communication with only a voice element was coded as Verbal.

RESULTS

Eighteen different sectors were observed over a three-day period at the Miami ARTCC. Data extraction was completed through coordination with the WJHTC. Following data extraction, the data were merged to create a composite R-side and D-side profile. The profiles are represented in Figure 1, for Communication Topic, Figure 2, for Communication Grammatical Format, and Figure 3, for Communication Expression. More extensive analysis was not conducted on the data from this field study due to the number of confounds associated with the field study environment. Confounds included: sector complexity, workload differential, individual differences among team members, variability across EST teams, and team composition changes during coding.

A primary goal of this study was to determine the practical utility and validity of the communication taxonomy. The coders reported few problems associated with the coding and classifying of R-side and D-side intra-EST communications. Most disparities in coding had been resolved during the beta-testing phase of the study. Coders reported that mobility was essential to viewing nonverbal communication. They also stated that mobility assisted with interpretation of verbal coding by enabling them to view the contextual environment.

Operational relevance was demonstrated by the use of the entire range of potential ATC Communication Topics. The topic of Approval comprised the smallest percentages (R-side 1%, D-side 0.9%) of total intra-EST communication, whereas the topic of Traffic comprised the largest percentages (R-side 41%, D-side 37.9%). Further investigation and discussion concerning operational issues revealed that the majority of inter-sector coordination is handled through memoranda of understanding. The topic of Approval is one example of inter-sector coordination using

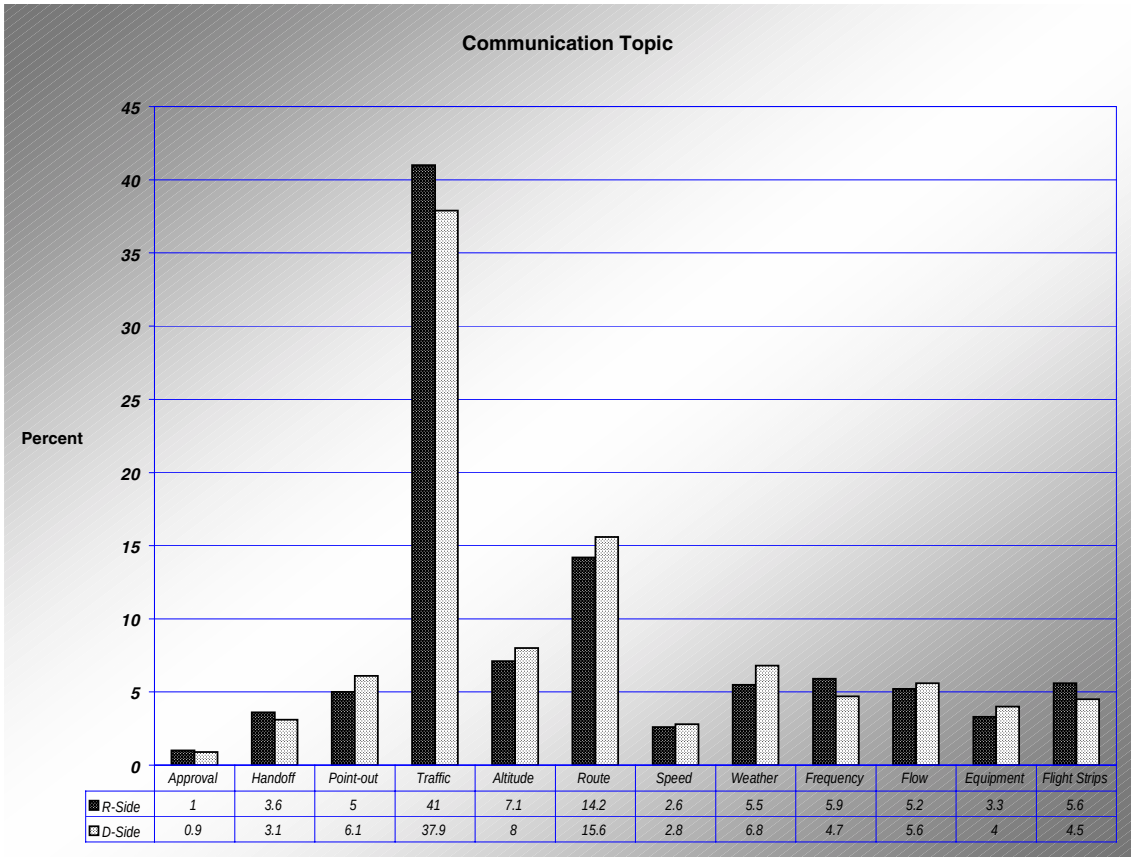

Figure 1: C[4]T Communication Topic

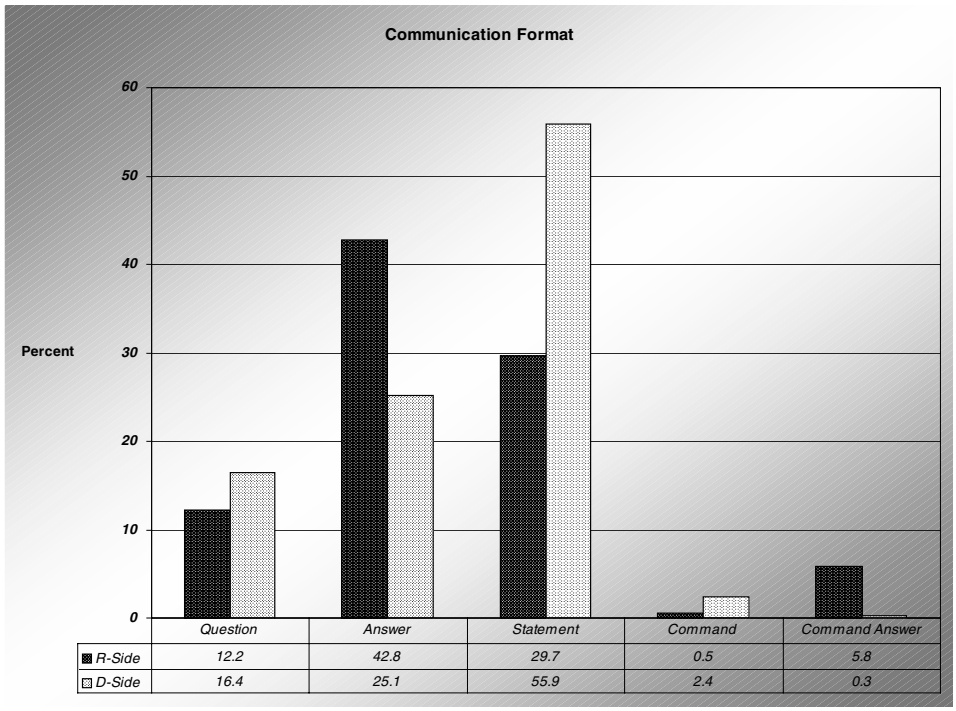

Figure 2: C[4]T Communication Format

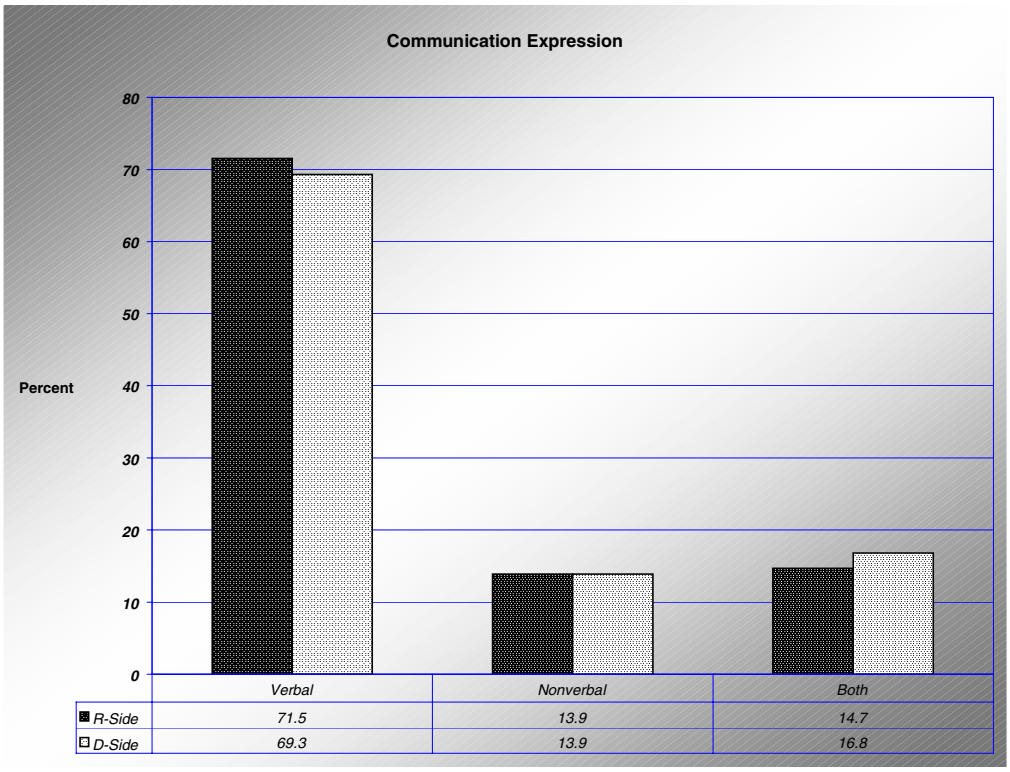

Figure 3: C[4]T Communication Expression

standard operating procedures established through memoranda of understanding; hence, less verbal communication is necessary.

The topic of Traffic, which showed the largest percentage of intra-EST communication, was revised following discussion and a consensus between coders, researchers, and SMEs. The field study definition for Traffic contained a considerable number of intra-EST communications pertaining to the identification of aircraft (i.e., Aircraft ID). Therefore, Aircraft ID was separated from the topic of Traffic and added as an ATC Communication Topic to the C^4T Taxonomy for use in future research (Table 2).

Communication Grammatical Format results revealed that the categories Statement (observations) and Answer comprised the largest percentage of intra-EST communication, accounting for 72.5% of R-side communication and 81.0% of D-side communication. Statements consisted of observations that sometimes contained implied questions. The use of implied questions raises issues as to why intra-ESTs embedded implied questions in their communications. The usage of implied questions embedded in the category, Statement, could be related to task orientation, or it could be a function of individual differences. Further research is necessary to investigate this phenomenon.

Subsequent taxonomy studies will limit the categories of Grammatical Format to three from the original five. Command and Command Answer, as operationally defined, were insufficient to prove useful.

The intra-EST Communication Format differed as a function of EST member. These differences were most apparent in the categories of statements (observations) and answers. The D-side had a larger percentage of statements (D-side 55.9%, R-side 29.7%). Correspondingly, the R-side had a larger percentage of answers (R-side 42.8%, D-side 25.1%).

Table 2. Controller to Controller Coordination Communications Taxonomy (C^4T) Revised.

ATC Communication Topic	Definitions and Examples
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.")
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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 Identification of Aircraft	Communications involving identifying a specific aircraft. ("Who was that calling?" "That was N1234 calling.")

Communication Expression was divided into the categories of Verbal, Nonverbal, and Both (containing components of both nonverbal and verbal expression). The majority of communications by both R-side and D-side were Verbal (71.5% and 69.3% respectively). Combining the categories of Nonverbal and Both (which contains an element of Nonverbal), the data showed that 28.5% of the R-side and 30.7% of the D-side communication had a nonverbal component. This could have implications for configuration of the workplace environment and line of vision for the intra-EST members. Further investigation by researchers determined that written weather update exchanges between the D-side and the R-side may have accounted for some of the nonverbal exchanges between EST members.

DISCUSSION

The results demonstrate that intra-EST communication is an integral part of job related coordination. Controller communication is expressed in various Communication Topics, Communication Grammatical Formats, and Communication Expressions (as shown in Figures 1, 2, and 3, respectively). New technologies designed to enhance the ATC environment may affect intra-EST communications. The development and evaluation of new ATC technologies will require investigation of the technology's effects on the quantity and quality of intra-EST communication. Future studies should focus on the initial impact of planned technological programs, as well as the possible long-term consequences.

Ergonomic studies should take into consideration the consequences of the view or lack of view of ATC displays as well as line of vision and hearing obstructions for the members of the EST. Training and development programs will require structure to assist controllers in devising strategies to adapt intra-EST communication to present and future technological advances. Perhaps future advances in technology will obviate the need for intra-EST communications; however, until such time, intra-EST communications require adequate consideration.

Research in intra-EST communication should be conducted as much as possible in advance of the implementation of new technologies and accompanying procedures. When applicable, C^4T assessment should be conducted prior to implementation, after initial training, and periodically during the useful life of the new technology to ensure there are no decrements in intra-EST communication, and to record and verify possible enhancements to intra-EST communication.

Future studies are scheduled in a controlled laboratory simulation setting using the new technologies being proposed to enhance ATC functions within the NAS. Videotaping allows for an in-depth review of intra-EST communications. Additionally, laboratory ATC simulations allow researchers to address the issues of variability across both sectors and individual team member differences by controlling workload and sector complexity, and by using within-subjects designs.

Future projects can include using the taxonomy to assess the relationship between intra-EST communication and the electronic flight strip environment (Vortac et al., 1996). The taxonomy may also be used as a tool to explore safety-related issues involving intra-EST communications including operational deviations and errors. It also provides an assessment tool for continued research on the relationship between intra-EST communication and ATC efficiency.

RECOMMENDATIONS

The following are recommendations for future research concerning the C^4T Taxonomy:

(1) revise the taxonomy: redefine the Communication Topic, Traffic, and add Aircraft ID as a Communication Topic (Table 2); and eliminate Command and Command Answer from the Communication Grammatical Format; (2) until greater control of potential confounds is achieved in the field, series analysis are not appropriate using the C^4T and focus should be limited to general trends across time and sectors; (3) conduct controlled experiments to determine the affect that changes in workload and technology have on communication exchanges with intra-EST. These experiments would test the sensitivity of the C^4T to detect changes in communication exchanges and allow time series analysis of communication exchanges using a repeated-measures design; (4) test the ability to generalize laboratory experimental results to field settings; and (5) use laboratory simulations and field results to structure training recommendations for intra-EST communications.

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