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Determining the effectiveness of data link communications in the terminal environment

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DETERMINING THE EFFECTIVENESS OF DATA LINK COMMUNICATIONS IN THE TERMINAL ENVIRONMENT

A Thesis

Presented to

the Faculty of the Department of Psychology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

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December 2000

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UMI Number: 1402528

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ABSTRACT

DETERMINING THE EFFECTIVENESS OF DATA LINK COMMUNICATIONS IN THE TERMINAL ENVIRONMENT

by Michael Luis Montalvo

In the airspace environment voice transmission has been the primary means of communication between flight crews and air traffic control. Increased frequency congestion and blocked transmissions are giving way to a new communication medium called Data link. This technology will likely have an impact on flight crews procedural processes and timing within the different airspace environments. Data link communication requires increased transaction time and longer heads-down time. Both of these constraints may decrease time available for other more critical crew duties. In the enroute environment, time constraints are not as restrictive as they would be in the terminal area. With the assistance of human performance modeling, this research examined the impact of Data link communication in terminal airspace. Simulation research was conducted in order to replicate a flight through terminal airspace. Results indicated an interaction between the number of interrupts and activity segment. Some of the implications of these findings are discussed.

ACKNOWLEDGMENTS

This research was funded by NASA Cooperative Agreement #21-1614-2360 to San Jose State University. I would like to extend my gratitude to my thesis committee, Dr. Kevin Jordan, Dr. Kevin Corker, and Ms. Sandy Lozito. I thank you for having the confidence that I could handle such a project.

Having no experience with human performance modeling, Dr. Corker assisted me in gaining the knowledge required for this project. Coming from you Dr. Corker, I take it as a compliment that you believed I would be successful.

I need to give a special thank you to my committee chairman, Dr. Kevin Jordan. During graduate school, I had been pursuing another career goal. Having earned my first job in my dream career, I put the thesis work to the side. When I did come back to work on my thesis (more times than I can count) Dr. Jordan was *always* supportive – thank you Kevin.

Understanding modeling and specifically MIDAS could not have been possible were it not for Mr. Greg Pisanich. You were patient in re-explaining concepts when you noticed my many blank stares. In addition, I would like to thank Marilyn Bunzo for many hours spent working with the MIDAS data.

This thesis would be virtually impossible were it not for the assistance of my co-workers and friends Ms. Sandy Lozito, Ms. Paddy Cashion, Ms. Betsy Logsdon, Ms. Maggi MacIntosh, Ms. Alison McGann, and Ms. Melisa Dunbar. Thank you all for you statistical and technical expertise and most of all your support. I would especially like to thank Ms. Sandy Lozito for taking so much of her time in helping me during my last days of preparation.

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Abstract

In order to solve some of the problems associated with voice communication, such as frequency congestion and "stepped on" transmissions, the Federal Aviation Administration (FAA) has begun implementing a new communication system called data link. This system electronically transfers digital messages to and from displays located on the ground and in the aircraft, alleviating frequency congestion. Data link has the potential to supply both parties with more clear and accurate information in text form. However, data link research has consistently demonstrated that crew response times to data link messages are longer than crew response times in the voice environment. This increased transaction time may not be critical in the enroute environment. However, that may not be the case in terminal airspace where events occur at a much faster rate. The objective to this research was to determine an event along the approach where data link may interfere with other flight duties thus interfering with the safety of the flight. This research utilized data from previous "Human in the loop" simulated studies as input to multiple computer simulations of crew performance. Results indicated an interaction between the number of interrupts and activity segment. As flight crews progressed through the approach phase of flight, data link interruptions were found to have a strong impact on flight crew performance. The implications of these findings are discussed.

Determining the Effectiveness of Data link Communication in the Terminal Environment

Since the inception of air traffic control (ATC) services, maintaining a safe and efficient ATC system has depended primarily on accurate, two-way radio communications between pilots and air traffic controllers. During each flight, both parties must engage in an array of information transfer, ranging from explicit landing instructions to current weather information.

Because of a finite number of radio frequencies and a continual increase in air traffic density, a single controller may handle as many as 25 or more aircraft at one time. Thus, in order to reply quickly to their instructions, each flight crew must listen to the steady, fast-paced exchange of information among all parties (Federal Aviation Administration, 1993). Flight crews must be attentive so that their response will be quick and efficient. This system is called simplex communications and is used by the ATC facilities in the United States. An analogy would be that of many people trying to carry on conversations using only one phone line.

The problems accompanying voice communication increase directly with the amount of air traffic (Billings & Reynard, 1981). During periods of heavy traffic, the need for expedient information transfer can lead to error through misinterpretation and blocked transmissions, resulting in possible safety hazards.

The continued increase in air traffic and the need to maintain clear and concise communication between controllers and flight crews is placing a strain on the present system. Currently, during "peak" hours at some facilities, nearly all communication frequencies are saturated.

In order to relieve the problems associated with voice communications, the Federal Aviation Administration (FAA) has begun developing a non-voice communication system called data link. This system will electronically transfer digital messages to and from displays located on the ground and in the aircraft, alleviating overworked radio frequencies.

Once data link communication is in place, it has the potential to supply both parties with more clear and accurate information in text form. Data link delivery of the pre-departure clearance, which is one phase of data link implementation, has already taken place and participating airports report reduced frequency congestion (McLaurin & Melendez, 1991).

Data link Integration on the Flightdeck

The most likely candidate for the data link communication interface on current-generation flightdecks will be the control and display unit (CDU) (Figure 1) of the flight management computer (FMC). The FMC is also an integral part of the overall Flight Management System (FMS). The FMS, in conjunction with other equipment in the airplane, forms an integrated, full-flight management control and information system that provides automatic navigation, guidance, map display, and in-flight performance enhancement. It helps reduce flightdeck workload during each phase of flight by eliminating many routine tasks and computations normally performed by the flight crew, such as estimated time of arrival, fuel remaining, groundspeed, and tuning in of navigational aids (Honeywell FMS Pilot's Guide, 1994).

Issues in data link Implementation

Prioritization. Information provided to the flight crew should be presented in a clear and consistent method. Flight crews will then be required to prioritize this information according to their current tasks. Data link messages can at times be more critical to the safety of the flight than messages from the onboard systems of the aircraft, including the caution and warning systems. The crew's attention to a data link message may be dependent upon its relationship to other ongoing cockpit duties. In some instances, such as a traffic advisory issued by ATC, the urgency of the message may justify the interruption of these duties so that the crew can attend to the data link message (Corwin & Miles, 1990).

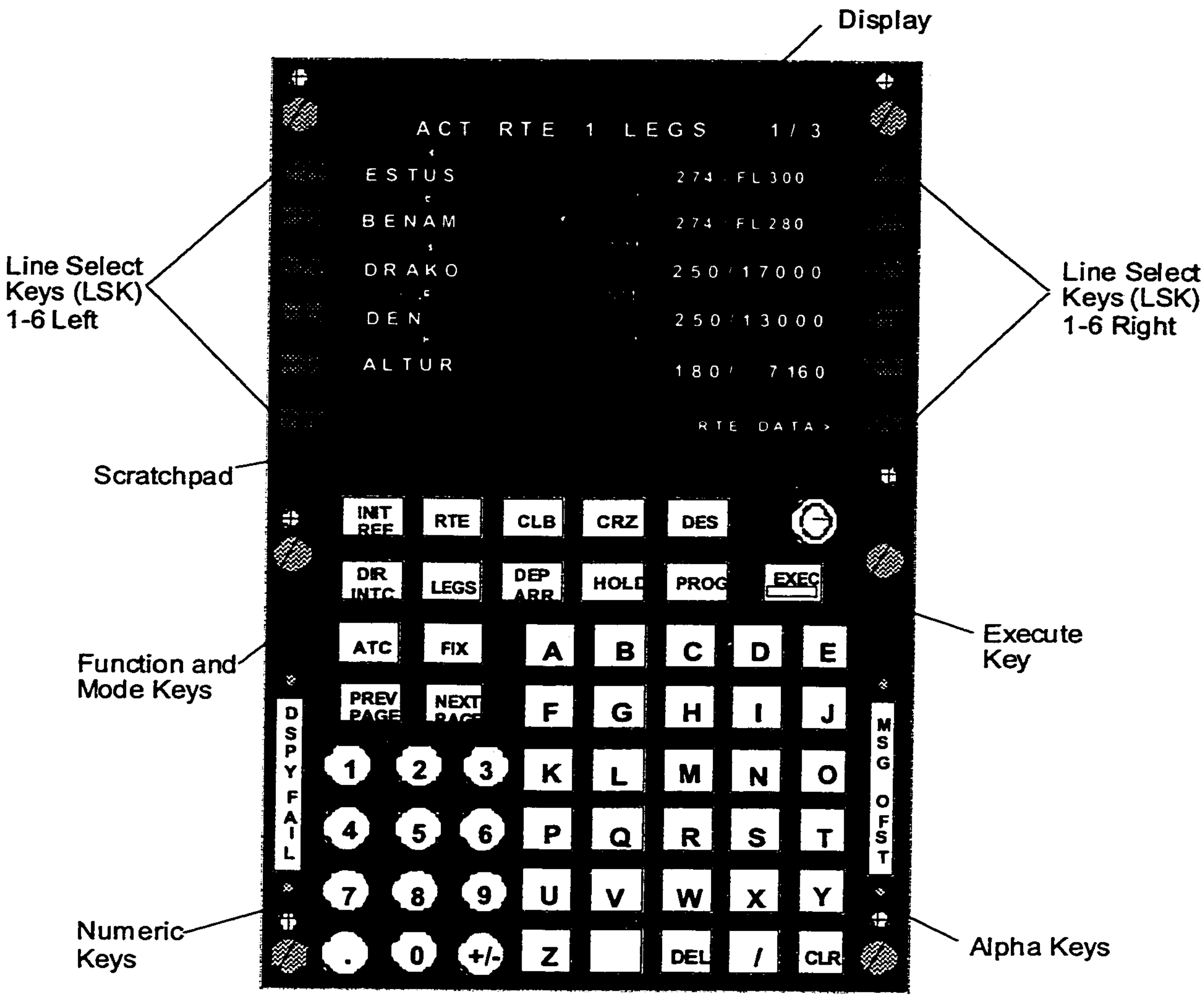

Figure 1. Control and Display Unit (CDU) for the Flight Management System (FMS)

Task Scheduling. Task scheduling refers to the ability of flight crews to *manage* incoming data link messages and cockpit duties. This data management might be more difficult in the voice environment. When ATC issues instructions via voice, it is normal for crews to stop what they are doing and concentrate on the message directed at them. With data link, however, flight crews may better manage how the duties at hand will be completed and when they will attend to the message (Kerns, 1990).

Loss of Party Line. Party line is the term used to describe the exchange of information while monitoring a specific frequency. With the implementation of data link, the elimination of party line information is best described as a loss of situational awareness with respect to other traffic and environmental conditions. In data link communications, a particular aircraft receives messages intended solely for it and not for any other aircraft. Discrete messages may contribute to the loss of potentially vital, tactical information (Corwin & Miles, 1990). For example, an aircraft on a 15 mile final, listening to approach control, can hear weather and advisories being given to other aircraft ahead. It is also reassuring to flight crews on an approach to an airport to hear the exchange between ATC and the aircraft off their wing as they both maneuver, even if the other aircraft is in view.

The positive benefits of party line must also be weighed against the negative aspects of having to filter out irrelevant information in order to get the information that is used for situational awareness.

Voice vs. data link transaction times

Flight-test research (Knox & Scanlon, 1992) has demonstrated the feasibility of data link operations. This research provided insight into the performance side of data link operations as compared with voice using response-time and pilot-acceptance measures. In addition, previous research (Kerns, 1990) indicates that data link operation reduces controller workload, shifts workload from the auditory to the visual modality, and reduces the amount of information communicated from the ground to air. Data link research has consistently demonstrated that crew response times to data link messages are longer than crew response times in the voice environment (Kerns, 1990; Logsdon, Infield, Lozito, McGann, Mackintosh, & Possolo, 1995).

Rationale for present study

Once a technology such as data link is introduced into the cockpit, it will have an impact on the procedural processes on the flightdeck. Measuring that impact is important. One of the methods used to measure data link's impact is to investigate the transaction time or communication time surrounding a data link message. As noted above, data link communication appears to take longer than the same communication time for voice. Once an ATC message is received by the fligthcrew via the CDU, it will require that the pilot not flying (PNF) access, read, and acknowledge the message thus increasing heads down time to the CDU. In a data link environment, the PNF will be required to read aloud the ATC message so that the pilot flying (PF) is made aware of an ATC instruction, thus increasing intra-cockpit communication.

In a voice environment, this would not be required since ATC transmissions would be heard simultaneously by the flight crew. Currently the CDU is used solely for flight management purposes. A possible data link implementation would be to blend its functions creating a dual purpose or time-shared CDU. This dual-purpose concept may tie up the CDU when another CDU function may be needed for more urgent reasons.

In the enroute phase of flight, data link transaction times may not play a "time critical" role in flightdeck procedures. However, problems may arise during descent into the terminal environment where traffic density increases. Responses must occur within a smaller window of time, ATC instructions are more frequent, and data link transaction times may be quite long. At the time of this writing, no determination has been made as to what criteria should be used for ATC and flight crews to cease usage of data link communication.

Utilizing human performance modeling, the present research examined the question, "where should data link communication cease".

Human Performance Modeling

Human-centered design is dependent on adequate models of human and system performance. Representation of the human operator(s), equipment, and the mission objectives are available to designers/researchers for experimental manipulation and modification. Designers can work with computational representations of the crew station and human operators, rather than relying solely on hardware simulators and human-in-the-loop studies, to discover problems and ask "what if" questions regarding the mission, equipment, and the environment. The advantages of this approach are found in reduced development time, reduced costs, early identification of human performance limits, and support for the integration of training system requirements and development.

The Man-Machine Integration Design and Analysis System (MIDAS), is an example of this type of predictive model development (Corker & Smith, 1993). MIDAS is designed to characterize the processes of perception, decision- making, activity selection, timing, and task-loading experienced by the operators as they interact with the system being studied. The modeling system describes the responses that can be expected of human operators (within their limits of accuracy) in areas that are critical to the safe operation of automated systems being studied.

MIDAS also offers a framework in which to test and implement models of human cognition. The MIDAS structure systematizes and unifies the interaction of human performance representation in a common framework and with a common language for interaction. Models of human performance ranging from perception through cognition and action are utilized within this framework. The interaction of these models produces simulations of behavior. A detailed description of MIDAS can be found in Corker and Smith (1993).

Air-MIDAS, a derivative of the MIDAS model, is engineered towards the commercial aviation domain. It models pilot performance when interacting with various levels of automation, specifically the Flight Management System (FMS). In this study, the Air-MIDAS representation of a human operator was used to simulate a descent through terminal airspace. Air- MIDAS provided a description of the responses that can be expected of human operators in several areas critical to safe and reliable operation of advanced aircraft systems (Pisanich & Corker, 1995).

The modeling process began by determining the sequence of activities to be replicated. This was accomplished by using an existing database from a full-mission simulation experiment conducted at NASA Ames Research Center, which was run using a generic glass cockpit simulator with full motion and visual capabilities (Logsdon et al., 1995).

Data link interrupts may have an impact on the time required to perform specific duties in the terminal environment. Based on the amount of traffic and communication density in a terminal area, there may be a specific saturation event where the advantages of data link usage will be offset by time delay in reading, acknowledging, and acting on a data link message for the flight crew.

The descent was divided into three activity segments defined by the primary tasks that the crew had to perform. Observation of activity segment duration should provide useful input for guidelines for data link implementation in this particular phase of flight.

It is hypothesized that the more frequently interruption events occur, the less time there will be to carry-out the data link message and/or to complete other required crew tasks as the aircraft continues its approach to land. The occurrence of frequent interrupts may increase the time of a given activity block and potentially induce failure to complete the next activity segment within the timeframe allowed.

Method

Participants

The participants in the 1992 Air-Ground study consisted of 10, two-person flight crews. Five crews used data link as the primary means of communication while the other 5 used voice. For the purposes of this experiment, only the data of five crews that used data link as the primary means of communication were coded. All participants were obtained from the same air carrier and each was required to be type-certified and current on the Boeing 757/767 advanced transport aircraft. The ages of the participants ranged from 27 to 53 with a mean of 43 years of age. Flight time on advanced transport aircraft (also known as "glass cockpit") ranged from 600 to 6,000 hours, with a mean of 2,140 hours.

Simulator Facility

The full-mission flight simulation facility that was used for the collection of procedural and timing data was the Crew-Vehicle Systems Research Facility (CVSRF) at NASA Ames Research Center. This included the Advanced Concept Flight Simulator (ACFS) which is a generic, full-mission transport that provided the aircrew with a computer-generated external visual scene. The ACFS is representative of a "glass-cockpit" aircraft (Figure 3). It is equipped with five cathode ray tube (CRT) monitors, which electronically depict primary and secondary flight display information. It is also equipped with sidearm controllers for pitch and roll control, an integrated flight management system coupled to the aircraft's autopilot and autothrottle systems, and an electronic engine indication and crew alerting system (EICAS) which provides aircraft cautions, warnings, and advisories to the flight crew. In addition to the ACFS, the CVSRF also includes an ATC simulation. The ATC system provides the capability of simulating the multi-aircraft, multi-ATC environment. For additional details of the CVSRF, see Shiner and Sullivan (1992).

Scenario. The Air-Ground experiment was designed as a line-oriented-flight-training scenario to include all elements of an actual flight originating in San Francisco enroute to Washington, D.C. (Dulles). Included in the scenario was a diversion to Denver Stapleton Airport due to a mechanical malfunction (non-emergency).

Coding

The Air-Ground Compatibility study was conducted in 1992 to examine routine communications using data link on the flight deck. Although the entire simulation was 2-3 hours in duration, this study examined a fifteen-minute segment of the descent. Videotapes were viewed from the beginning of the ATC hand-off from Denver Air Route Traffic Control Center (ARTCC) to Denver Terminal Radar Approach Control (TRACON). Viewing ended at approximately three miles from the runway threshold.

Repeated viewing of the videotapes allowed the coder to pinpoint specific segments of activity where crew workload was high. From the activity segments, sequence data were extracted to include coding individual activities such as data link message access, read, and acknowledgment times. Furthermore, time to complete checklists, lower gear and flaps, and timing for other necessary actions required before landing were collected. Coding of this nature was necessary in order to list the types of activities and to provide estimates of the time required to perform each activity that exists on the flightdeck when entering a terminal environment. This information was necessary in order to make the Air-MIDAS database as accurate a possible.

Protocol for coding. Although the Air-Ground study included both data link and voice crews, only videotapes for data link crews (five crews) were transcribed and coded for each communication event and activity that occurred during this 12-15 minute descent segment. Coding involved collecting data on start time, duration, end time, and a description of the activity. The PF calling for the approach checklist is an example of one activity. Coding began at the verbal request by the PF and end when the PNF indicates the checklist has been completed. During this activity block, start and stop time for each physical movement and any speech executed by either crewmember were coded. Since the coding involved overt activities and their duration, it was not necessary to use multiple coders to establish interrater reliability. However, a portion of the data was compared to previously coded data and determined to be consistent.

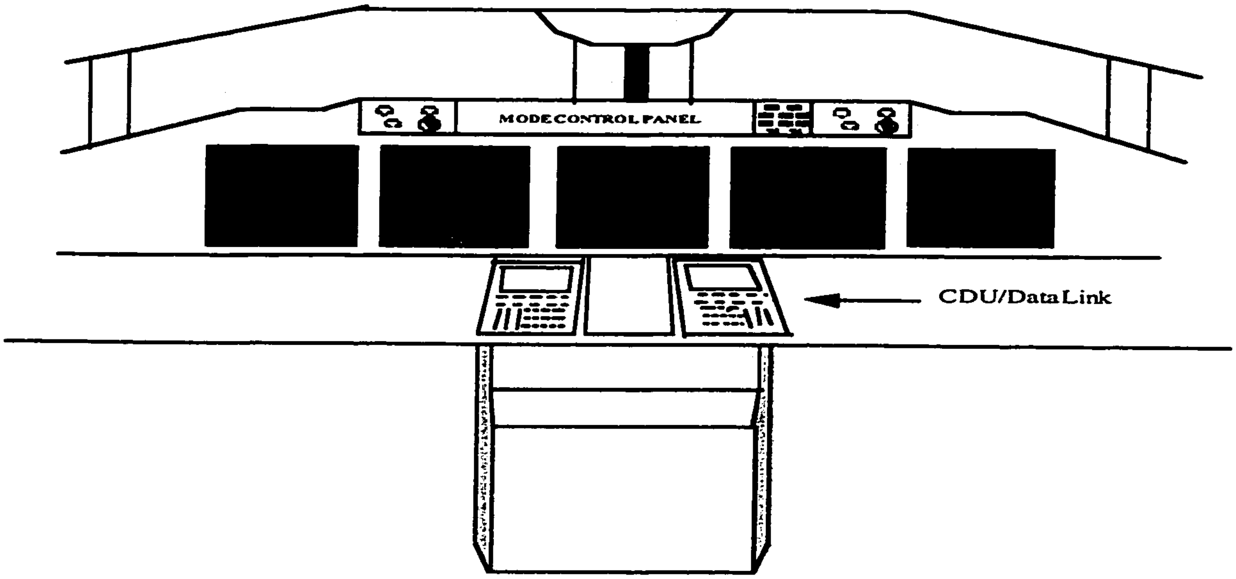

Figure 2. Flightdeck of the Advanced Concept Flight Simulator (ACFS)

Air-MIDAS

The Air-MIDAS structure contains the framework necessary to replicate some subset of human operations. The interaction of various Air-MIDAS components will produce a stream of simulated operator activities in response to mission requirements, equipment design, and models of human performance capabilities and limits. Although the Air-MIDAS framework consists of numerous models, not all of these models are required to be activated in any particular application (Pisanich & Corker, 1995).

Updatable World Representation (UWR). In Air-MIDAS, the Symbolic Operator Model (SOM), provides a mechanism whereby human agents representing individual and potentially cooperative teams of pilots and controller can access their own tailored or personalized information about the world. This internal representation of world knowledge is called an Updatable World Representation (UWR). The contents of an UWR are determined, first, by pre-simulation loading of required mission, procedural, and equipment information. Then data are updated into each operator's UWR as a function of the perceptual mechanisms modeled in the operator. The data in each operator's UWR are used to instantiate rules that guide behavior and are the sole basis for a given operator's activity.

Activity Representation. Activities are Air-MIDAS constructs that simulate actions performable by an agent in the system. Representations of activities available to an operator are contained in that operator's UWR and are organized by flight-system and mission goals. Activities in this scenario are characterized by: *preconditions* that define the allowable condition for their initiation; *satisfaction conditions* which define their successful completion; *spawning specifications* which detail the temporal and logical constraints on any underlying activities that might be needed for the activity performance; *decomposition methods* that describe in a context-sensitive way what children should be spawned to accomplish a higher-level activities goals; *interruption status* and *interruption specifications* which detail the interruption and resumption methods for that activity; and *duration* either estimated or calculated by an activity-specific function. These activities are the drivers for simulation action and are recorded as a function of simulation runs. The activities encoded here are those associated with activity in dealing with Top of descent and approach in a data link environment. These are described in the sections below.

Decision Rules. The simulated flight crews will utilize rules that will apply to a decision for action at any point in the flight. These rules are a specialized form of activities. Decision activities include an added element of contingent behavior represented in a propositonal structure. The data to decide the proposition are found in the UWR of the flight crewmember or are sought by perceptual interrogation of the external simulation world. If conditions are appropriate, a rule may spawn activities in response to changes in the simulation world.

Air-Ground data collection. Air-MIDAS requires instructions on how to function in the terminal environment. Activity data collected from videotapes of the Air-Ground experiment were added to the pre-existing Air-MIDAS database. These data produced an activity script (or scenario) which essentially instructs Air-MIDAS on the specific sequence of activities it will follow, though the actual performance sequence is determined by scheduling mechanisms at the time of simulated performance. This resulted in a terminal airspace platform in which a specific element of the environment may be manipulated in order to observe its effect on other activities. For this specific research, the number of interrupts was manipulated.

Interruption events. The primary experimental manipulation to be introduced to Air-MIDAS will be the random insertion of an interruption event, which may occur during the descent and approach phase of the flight. Air-MIDAS will handle interruption events by priority based suspension of activities, storage of interrupted activity in a queue, and attempts a resumption based on availability capacity and priority.

Type and frequency of interruption events were obtained through various sources: videotape observation, monitoring local ATC frequencies, and actual airline operations. Interruption events may include traffic advisories, heading/speed/altitude changes, clarification requests, or runway changes. Lastly, videotapes from the air-ground study were coded to obtain intra-crew communications related to interruption activities. Interrupts may either occur while executing a data link message *or* an incoming data link message from ATC may interrupt the crews' immediate duties and delay the completion of the specific task. If numerous messages are received within a narrow timeframe (as often occurs in the terminal environment), adequate time may not be available to complete a data link transmission in addition to performing other essential flying duties.

Time-share vs. Dedicated CDU

For this experiment a "time-shared" CDU was used. This refers to a CDU that is used for both data link communications and FMS functions. If the flight crew was utilizing the FMS functions while a data link message was received, additional button presses would be required to read the data link message.

Air-MIDAS generated activity data comparable to that generated by human participants (Pisanich & Corker, 1995). Within each activity segment simulated flight crews were exposed to the three levels of interrupts.

It should be mentioned that the model used for this experiment represents the activity of one crewmember performing a combination of the pilot-flying and pilot-not-flying duties.

Model Runs

A 3 x 3 experiment was run with 100 replicates for each level for a total of 900 runs. The factors under manipulation were: activity segment (approach checklist, approach clearance, and before landing checklist) and number of interrupts (low = 0, medium = 1-3, and high = 3-6).

Duration of the activity segment was the dependent variable in this experiment. These interruption events were inserted within the three activity segments allowing the activity blocks to fluctuate in duration. The purpose was to vary the number of interruption events and to assess the impact of these events on both the time to respond to data link messages and to complete required crew tasks.

Results

To better visualize the simulated activity segments, Figure 3 may be referenced. Air-MIDAS activities begin at controller "hand-off" from center to approach. Shortly thereafter, the initiation of the approach checklist is begun. The means are included within each activity segment and represent the time it took the flight crews to perform the activity segment, including interrupts for the medium and high interrupt levels. Between each segment is the time available from completion of a specific segment to the beginning of another. It was reasonable to expect that ample time would be available early in the approach. It is not until after the completion of the approach clearance that time available is dramatically reduced.

As stated earlier, coding ceased at 3 miles from the runway referenced by Distance Measuring Equipment (DME). It was determined that at this point, no other activities should be conducted other than the safe execution of the approach to land. The activity segments shaded in black (before-landing checklist) indicate that the activity duration time exceeds the coding limits. In other words, it took longer to complete the segment than the time available. For the medium interrupt level, time was exceeded by 1 second. For the high interrupt level, time was exceeded by 11 seconds.

In order to examine the impact of data link messages on crew procedures in the terminal area, activity segment (approach checklist, approach clearance, before landing checklist.) was compared to number of interrupts (low = 0, medium = 1-3, and high = 3-6). A mixed analysis of variance was performed. Activity segment is the within-subject condition and number of interrupts is the between-subject condition. The dependent variable was the duration of each activity block. The mean duration of each activity block as a function of activity segment and number of interrupts is presented in both Tables 1 and 2.

The main effect for activity segment was statistically significant, $F(2,594) = 1637.71$, $p < .05$, indicating that activity segments were shorter as the aircraft approached to land. The main effect for interrupts was also found to be statistically significant, $F(2,297) = 833.83$, $p < .05$, indicating that activity segments got longer as the number of interrupts increased. The interaction between interrupts and activity segment was found to be significant $F(4,594) = 12.57$, $p < .05$, indicating that the duration of the activity segment increased by a greater amount as the number of interrupts increased. Inspection of the means indicate that the approach checklist segment condition with high interrupts has the longest duration when compared to the other eight cells.

Effect of interrupts was different depending on the activity segment. In order to understand this interaction more clearly (Figure 4), it may be more important to look at the percentage increase in time vs. the number of interrupts received. For the approach checklist segment, duration increased 47.2% from the low to the high interrupt level. For the before-landing checklist segment, mean segment duration increased by 63.5% from the low to the high interrupt level.

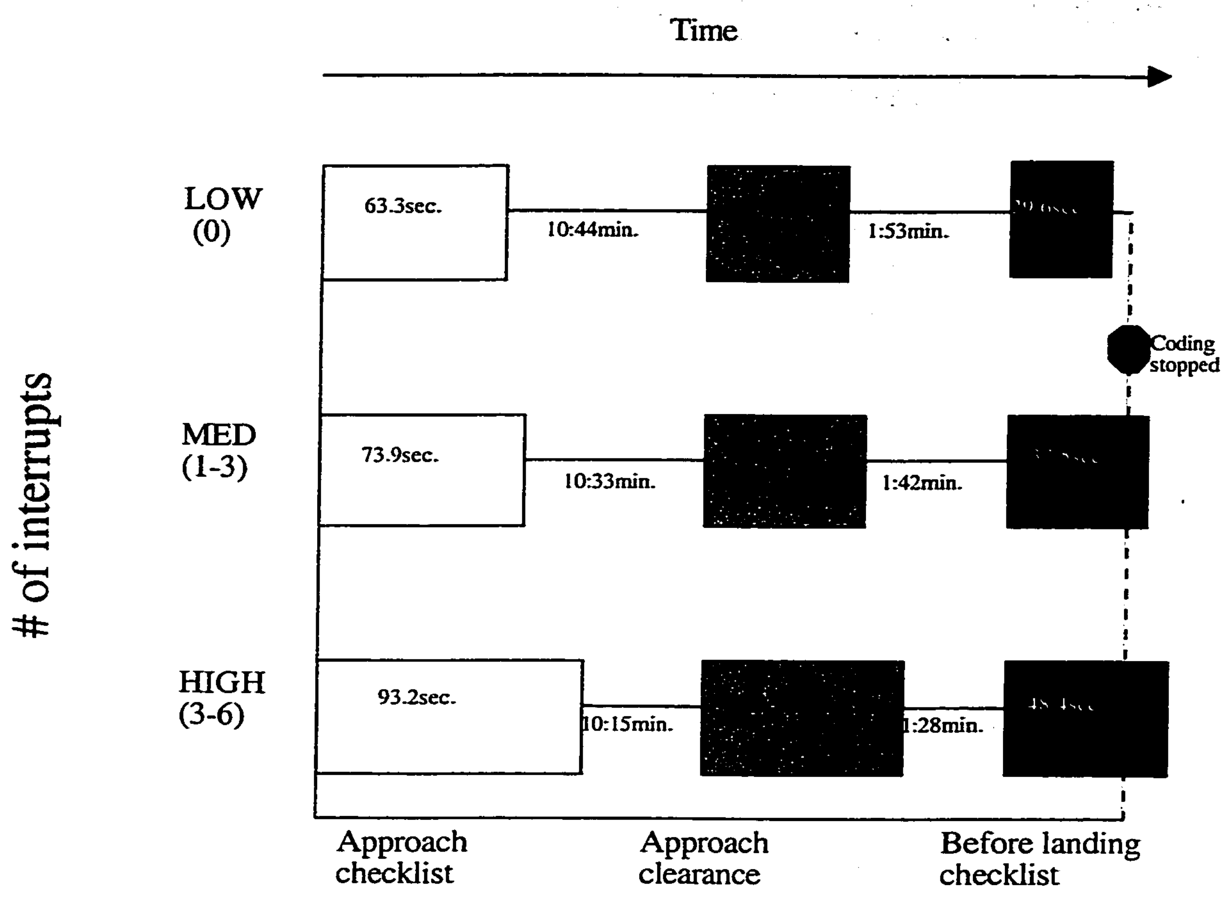

Figure 3. Timeline for activity segments

Table 1

Activity segment times with interrupt levels – Means

# of interrupts	Approach checklist	Approach clearance	Before-landing checklist
Low (0)	63.3sec.	40.0sec.	29.6sec.
Med. (1-3)	73.8sec.	50.4sec.	37.6sec.
High (3-6)	93.2sec.	64.5sec.	48.4sec.

Activity Segment

Table 2

Activity segment - detailed statistics

# of interrupts

	Approach checklist			Approach clearance			Before-landing checklist		
	Low	Med	High	Low	Med	High	Low	Med	High
N	100	100	100	100	100	100	100	100	100
Mean	63.3	73.8	93.2	40	50.4	64.5	29.6	37.6	48.4
SD	10275	11389	13442.9	2166	7322.4	6360.2	1627.6	6064.9	4948
SE	1027.5	1138.9	1344.3	216.6	732.2	636	162.8	606.5	494.8

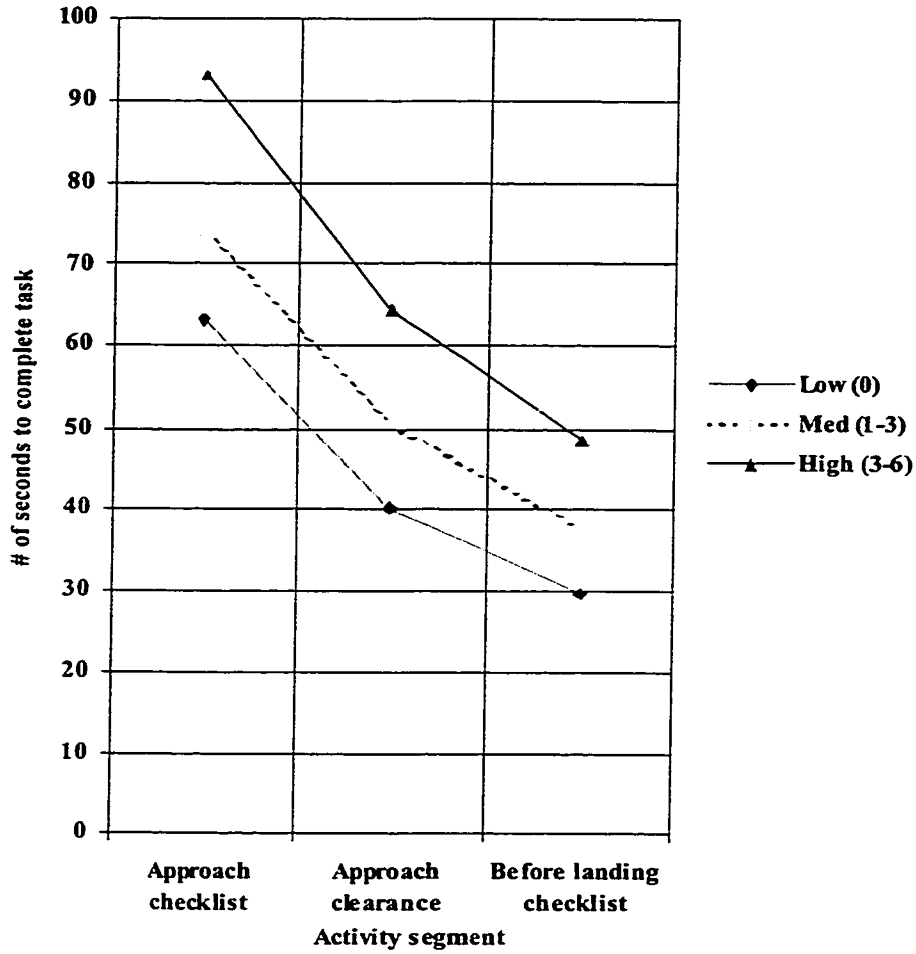

Figure 4. The interaction of interrupts and activity segment on total activity time

Discussion

The objective of this research project was to investigate the impact of data link communication on crew performance in the terminal environment. Based on the amount of traffic and communication density in the terminal area, there may be a specific saturation event where the advantages of data link usage will be offset by time delay in reading, acknowledging, and acting on a data link message for the flight crew.

The hand-off from the enroute structure to the approach airspace varies by facility. For this experiment, the hand-off occurred approximately 15 minutes from end of coding. Within each activity segment were specific tasks which the flight crew performed in order to prepare the aircraft for landing. There may be from four to seven items within each segment depending on the air carrier. It should be noted that there are timing difference among the individual activity segments which can be viewed in Table 2. The segments become shorter as the aircraft approaches to land. With regard to the approach checklist segment, it can be concluded that even in a high traffic airspace and with the inherent timing differences among activity segments, responding to numerous data link messages should still give ample time for arrival preparation. As can be seen in Figure 3, a minimum of ten minutes is available between the approach checklist segment and the approach clearance segment.

Approach checklist segment

Table 1 indicates that the approach checklist segment takes more time when comparing high vs. medium interrupt levels. This activity segment is the furthest from the point of touchdown, which may have some significance for the interaction. Flight crews understand that as they enter a TRACON, any interruption that distracts them typically will not have as much impact as one that occurs later in the approach. This "extra time" may be what appears in the data and in the performance of the simulated flight crews. When comparing the approach checklist segment (high interrupts) and the before landing checklist segment (high interrupts), it appears that the simulated flight crews becomes more efficient in handling the interrupts. One possible reason may be that the flight crews are careful about not allowing interrupts to distract them when they get too close in, unlike how they handled interrupts when further out. This trend of "efficiency" appears in each activity segment when examining the means from low interrupt to high interrupt (Table 1).

Approach clearance segment

As the controller vectors the simulated aircraft from the arrival gate to a position in which to intercept the final approach course, both crewmembers are controlling and monitoring the aircraft position and performance. Receipt of a data link message will require the pilot-not-flying to adjust his/her attention to the incoming message. The visual display of messages necessitates that one pilot verbalize the contents to another. This is required even if both messages are displayed for both crewmembers, as the pilot flying will normally be attending to flight control activities. This contrasts with voice communication which allows monitoring by all crewmembers. Verbalization of the data link message tends to increase the frequency and extent of conversation about the message content over that of voice transmissions (Lee, 1989). Data link communications will probably increase internal cockpit communications to some degree.

The other compelling issue of data link in the terminal area is that of heads-down time. The change from an auditory to visual presentation could have significant impact on the amount of head-down time experienced by the crew. This increase in the visual workload may not be acceptable during certain phases of flight. A document titled, "Human engineering issue for data link systems", developed by SAE-G10 Flight Deck Information Management Subcommittee in 1990, made the following recommendation regarding head-down time for pilots: "Any data link design that results in a net decrease in traffic situation awareness below 18000 feet is unacceptable".

In the time surrounding an approach clearance, not only is the crew monitoring situational and aircraft awareness, but in instrument meteorological conditions (IMC), the

PNF is required to make necessary call-outs regarding altitude, aircraft configuration, localizer/glideslope movement and deviations in aircraft performance. Sending messages quickly in succession (within 15 seconds of acknowledging the first short message) may overload cognitive resources and mitigate some of the benefits of data link (McGann, Morrow, Rodvold & Mackintosh, 1998). As can be seem in Figure 3, the addition of interrupts during the approach clearance segment did not cause any overlap of the activity segments. However workload during this phase is an issue that should be considered and more thoroughly researched.

Before-landing checklist segment

The finding that is of most interest occurs at the Before-landing checklist segment. At the low interrupt level, 7 seconds remained from the completion of the segment to the end of coding. At both the medium and high interrupt levels, the duration for these segments exceeded the time limitations. The before-landing checklist is typically performed after the final flap setting, which usually occurs after the outer marker (approximately 5 miles). Extra time available to flight crews is at minimum in this segment. Time taken away by a data link message will have an effect on the remaining portion of the approach. When compared to earlier segment, time between segments was sufficient for all tasks to be performed. The before-landing checklist segment has little time available for flexibility in managing the tasks at hand. If more time is needed, performing a go-around may be the only option available. It should be noted that if another implementation of cockpit data link has been used for this study, such as a dedicated CDU, it may have had an effect on the response times.

As stated earlier, as of this writing, no determination has been made as to what criteria should be used for ATC and flight crews to cease the use of data link communication. In the early minutes of the experiment, flight crews appear to handle numerous data link messages and normal crew tasks with no problems. However, based on the data from this experiment, specifically the before landing segment, it may be recommended that data link communication cease at or near the outer marker.

Conclusion

One important question is the consideration of exposing the flight crews to data link messages on approach with relatively little time/distance available prior to landing. If the approach is being conducted down to landing minimums, the flight crew's attention should only be focused on the safe execution of the approach and landing phase. The introduction of a visual data link as a means of conveying those clearance data may be more difficult for the flight crew and use of data link in this situation would be inconsistent with SAE-G10 (1990) recommendation cited on previous page.

Over the last several years, The Federal Aviation Administration (FAA) has begun to develop and implement a wide range of initiatives aimed toward improving the ATC system. One of these initiatives is improving the information transfer problems that constrains the capacity of the current ATC system with the use of data link communications.

The potential benefits of data link technology used as a communication medium are many. It may eliminate frequency congestion and miscommunication. However, these benefits cannot be realized unless it can be demonstrated that data link will improve the process of air-ground information transfer when compared to the existing voice system. Existing disadvantages of data link communication are increased head down time (particular concern in the terminal environment where programming the CDU takes time away from looking outside the cockpit or performing other time critical duties), increased transaction time, and potential loss of party line information resulting from data link communication. Pilots often monitor the frequency to locate other aircraft and their intentions as well as to assess the possibility of, and plan for, delays/rerouting that may occur.

Before data link is used the terminal environment, a systematic effort is needed to identify and resolve human-interface problems. The nature of the response and "delay" in acknowledging in data link may have a disruptive effect on task performance. The data in this experiment suggest that this disruption may occur in the final approach phase of flight. Before data link is used the terminal environment, a systematic effort is needed to identify and resolve human-interface problems.

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FROM: Serena W. Stanford *Serena W. Stanford*
AVP, Graduate Studies & Research

DATE: February 5, 1998

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Determining the Effectiveness of Datalink Communications in the Terminal Environment"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Serena Stanford, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.