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16. ABSTRACT

MITRE conducted this human-in-the-loop research project on Interval Management (IM) Controller Pilot Data Link Communications (CPDLC) to investigate the integration of two advanced Next Generation Air Transportation System (NextGen) capabilities across both the air and ground domains to uncover any complications that could arise from two key capabilities that were developed separately. The simulation study included three levels of IM clearance complexity and looked at aircraft equipped only with voice communication capability and those with both voice and CPDLC. An en route air traffic environment was simulated with 50 percent of aircraft equipped with the IM capability. **Results:** Most pilots and controllers in the experiment deemed the IM and CPDLC to be compatible, although the controllers seemed to have more difficulty with mixed IM equipped aircraft than with mixed CPDLC equipped aircraft. Concerns were noted for use of IM with voice communications, since the data entry requirement for the flight crew was increased when CPDLC autoload into the FMS was unavailable. Not surprisingly, this was particularly the case with the most complex IM clearances. **Application:** The results are intended to be used by the FAA as well as EUROCAE and RTCA when developing the technical standards for the interface between the IM and CPDLC equipment. FAA Aviation Safety (AVS) sponsors who develop the regulatory and guidance material for CPDLC and ADS-B are expected to use the results in the development of Advisory Circulars (ACs) and Technical Standard Orders (TSOs) based on the international standards material. Recommendations for consideration by these groups are provided in the Conclusions and Recommendations section of the report.

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MITRE TECHNICAL REPORT

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Flight Crew and Air Traffic Controller Interactions when Conducting Interval Management Utilizing Voice and Controller Pilot Data Link Communications

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Executive Summary

The goal of the Interval Management (IM) Controller Pilot Data Link Communications (CPDLC) human-in-the-loop simulation activity was to investigate the integration of two advanced Next Generation Air Transportation System (NextGen) capabilities across both the air and ground domains in order to uncover any complications that could arise from capabilities that have been developed separately. In addition, the findings from this research are intended to support answering outstanding questions for IM and CPDLC such as the validity and acceptability of currently defined IM CPDLC messages as well as their performance parameters and procedures.

In order to examine IM and CPDLC together, IM communications would need to be included in current day operations. Of particular interest was the IM clearance since it is expected to be the most complex IM communication. Therefore, the simulation focused on three levels of IM clearance complexity (Lower, Moderate, and Higher) and two different modes of communication (i.e., all aircraft with voice only versus some aircraft with CPDLC and some aircraft with only voice). Pilot CPDLC communications were further examined by allowing for the CPDLC message to either be manually loaded or directly loaded into the flight deck IM equipment. Voice communications were only manually loaded. The simulation was conducted with pilots and controllers in an en route arrival environment with 50 percent of the traffic having flight deck IM equipage.

The majority of pilots and controllers found the integration of the NextGen capabilities of IM and CPDLC acceptable. Controllers seemed to have more difficulty with traffic with a mix of aircraft equipage for IM than they did for a mix of aircraft equipage for CPDLC. Both pilots and controllers found the procedure for accepting an IM clearance, prior to entering the information into the flight deck IM equipment, to work well for CDPLC. However, some concern was expressed for using the same procedure for voice communications. Both pilots and controller preferred CPDLC over voice communications. However, both recognized that voice is still necessary for urgent instructions, such as some IM terminations.

Results indicated that the necessary messages were available for IM as tested, and were communicated within an acceptable amount of time. CPDLC reduced the time both controllers and pilots spent on the voice frequency. Overall, pilot and controller responses indicated that the IM clearance was well phrased but that shortening it would improve acceptability. Pilots consistently showed a preference for the Lower and Moderate complexity IM clearances as compared to the Higher complexity IM clearances. Pilots also consistently found the Higher complexity IM clearances when using the Voice with Manual Load communication method to be the least favorable set of conditions. Controllers had the most variability in their replies with the Higher Complexity IM clearances under both Voice and CPDLC. The Higher complexity IM clearances had more communication issues than any of the other conditions. While the Higher complexity IM clearances were less acceptable over voice, pilot results revealed that the use of CPDLC improved the acceptability of those clearances.

The simulation also examined additional IM messages (beyond just the clearance) in an extra scenario. These messages were part of the defined set of IM messages but were not believed to be necessary or expected to be used in the core scenarios. Controller and pilot responses to

several questions indicated that the additional IM messages are necessary, well phrased, and allow for acceptable and clear communication exchanges in both voice and CPDLC.

The Federal Aviation Administration (FAA) Surveillance and Broadcast Services (SBS) Program Office (that leads the Automatic Dependent Surveillance-Broadcast [ADS-B] activities) is expected to use these results to further scope the spectrum of IM operational applications as well as determine how to convey more complex IM clearances through voice communications. The results are also intended to be used by the FAA as well as EUROCAE and RTCA when developing the technical standards for the interface between the IM and CPDLC equipment. The sponsors in FAA Aviation Safety (AVS) who develop the regulatory and guidance material for CPDLC and ADS-B are also expected to use the results in the development of Advisory Circulars (ACs) and Technical Standard Orders (TSOs) based on the international standards material. Recommendations for consideration by these groups are provided in Section 6 – Conclusions and Recommendations.

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1 Introduction

The Federal Aviation Administration (FAA) along with the aviation community plans to implement an application called Interval Management (IM). IM utilizes Automatic Dependent Surveillance - Broadcast (ADS-B) technology to manage spacing intervals between aircraft more accurately and with less variance than today (RTCA, 2011). IM is intended to meet the need of improved delivery accuracy and aligns with the Next Generation Air Transportation System (NextGen) goals (FAA, 2012c). IM is intended to be used in multiple environments, but an initial focus is on arrivals. In this case, IM is intended to allow flight crews and Air Traffic Control (ATC) to efficiently achieve and maintain an Assigned Spacing Goal (ASG) between aircraft from the en route phase of flight through the final approach phase.

Another application being developed in support of NextGen is Controller Pilot Data Link Communications (CPDLC). CPDLC is planned to be implemented in the en route environment in the same timeframe as IM and is expected to provide efficiency and safety improvements over voice communications. Although voice communications are expected to be gradually replaced by CPDLC, voice communications will continue to be available for backup purposes and will also be used for non-routine or urgent communications.

The goal of this research was to conduct a human-in-the-loop simulation to investigate the integration of two advanced NextGen capabilities across both the air and ground domains in order to uncover any complications that could arise from capabilities that have been developed separately. In addition, the findings from this research are intended to support answering outstanding questions for IM and CPDLC such as the validity and acceptability of currently defined IM CPDLC messages as well as their performance parameters and procedures.

The research was intended to support the validation of the IM CPDLC messages and performance parameters defined in RTCA and the European Organisation for Civil Aviation Equipment (EUROCAE). CPDLC message and performance parameters had been defined in those standards bodies but validation activities were necessary prior to finalization of the material. This work was planned to act as a key input to that validation effort. Finally, the research examined the human performance impacts related to the complexity of IM clearances as they can contain a large number of parameters, as compared to some other air traffic control clearances. Some IM clearances may be difficult to convey over voice communications, and the most complex ones may be difficult to convey over CPDLC communications. This study was one of the initial steps in finding a threshold for complexity of IM clearances at which it might become too difficult to communicate over either voice of CPDLC.

This document presents the findings of the simulation and has six main sections, including this one. *Section 2 – Background* introduces the IM and CPDLC concepts and provides a review of past literature, including previous literature combining the two concepts. *Section 3 – Methods* describes how the simulation was conducted. *Section 4—Results* provides the results of the data collection, including the statistical analyses. *Section 5—Discussion* integrates the findings into an overarching discussion. *Section 6—Conclusions and Recommendations* reviews the key findings and details the recommended use of the results.

2 Background

2.1 Interval Management

IM is intended to create operational benefits through management of intervals between aircraft in various environments (e.g., arrival, departure, en route). IM is comprised of both Ground Interval Management (GIM) and Fight deck Interval Management (FIM) components. GIM supports the controller in determining which aircraft are capable of acting as participants. Depending on the operation, GIM can also help determine the sequence of aircraft, the desired spacing goal, and provide IM status information. The flight deck component has the displays necessary for the flight crew to enter the IM clearance information, conduct IM, and monitor conformance with the IM clearance.

IM has been explored internationally in simulations (e.g., Hebraud et al., 2004; Barmore, Abbott, and Capron, 2005; Mercer, Callatin, Lee, Prevot, and Palmer, 2005; Bone, Penhallegon, and Stassen, 2008), has initial standards developed (e.g., RTCA, 2011), has been field tested (e.g., FAA, 2001; Lohr, Oseguera-Lohr, Abbott, Capron, and Howell, 2005) and fielded (e.g., Penhallegon and Bone, 2014). The US and Europe are also currently funding development of international Minimum Operational Performance Standards (MOPS) for IM and the United States (US) is developing plans for a full field implementation in the post-2020 timeframe. Additionally, IM was prioritized as the second highest ADS-B In application for accelerated development by a committee comprised of the US aviation industry (ADS-B In Aviation Rulemaking Committee, 2011).

The following paragraphs describe a sample IM operation in the arrival environment. While it describes IM in that context, the conduct of IM in other environments is very similar.

An IM Arrival operation typically starts in the en route airspace once the controller has used ground automation (e.g., Traffic Management Advisor [TMA], Time-Based Flow Management [TBFM]) to sequence and schedule aircraft. At the appropriate point, the en route GIM automation displays to the controller an aircraft pair (i.e., an IM aircraft and a reference aircraft) that is capable of conducting IM, as well as the desired spacing goal. The controller then decides whether or not to initiate IM on a capable aircraft based on sector traffic, knowledge of ADS-B surveillance range requirements, arrival flow sequence, and the spacing requirement for a given IM pair. The controller uses this information to provide the initiation information to the flight crew in the form of a clearance (FAA, 2011a).

Once the IM clearance is provided to the flight crew, it is entered into the flight deck IM equipment which then checks that the information is appropriate for the operation and that the reference aircraft is in ADS-B surveillance range. If the reference aircraft is not in ADS-B surveillance range, the system cannot arm or engage. Once the reference aircraft is in range, is on the expected trajectory, and meets the necessary performance requirements, IM is initiated and the flight deck IM equipment provides an IM speed for the flight crew to fly. Situation awareness information is available to assist the flight crew in monitoring the progression of the spacing operation. IM information can be provided on a Cockpit Display of Traffic Information (CDTI) traffic display, although guidance information could be provided on other displays as well.

With the presentation of each new IM speed, the flight crew ensures it is feasible for the aircraft's current configuration and environmental conditions. The crew is expected to follow the IM speeds in a timely manner consistent with other flight deck duties unless conditions prevent it (e.g., safety, operational, flight deck IM equipment, or regulatory issues). If unable, the flight crew stops following the IM speeds and contacts ATC to convey that they are unable to conduct IM. The controller then terminates IM or provides a new IM clearance, if possible and desirable.

Similarly, if the controller becomes aware of any conditions that prevent continued IM, such as a safety or an operational issue, the controller will contact the flight crew and terminate IM. If no issues arise for either ATC or the flight crew causing a suspension or termination, the flight crew continues following the IM speeds and the controller continues monitoring the operation until the aircraft reaches the planned termination point. At this point, the flight crew discontinues flying IM speeds and terminates IM. Throughout the IM operation, the controller remains responsible for separation between the IM aircraft and the reference aircraft as well as all other aircraft.

When IM operations are in effect, not all aircraft are required to conduct IM. Aircraft that are not capable of conducting IM can receive speed advisories from the controller that may be proposed by ground automation.

2.2 Communications

2.2.1 Interval Management (IM) Communications

To conduct IM operations, several different kinds of communications can occur. The following are expected transactions between the controller and flight crew. The term "interval spacing" is the consensus phrasing used in IM communications as decided by the international standards community (reflected in RTCA and EUROCAE, 2013).

- Initiating IM (also known as the IM clearance)
    - Samples to follow
- Querying / providing status of IM
    - e.g., "Report starting interval spacing."
- Reporting of key IM parameters
    - e.g., "Confirm assigned spacing interval behind [*Reference Aircraft Call Sign*]."
- Suspending and resuming IM
    - e.g., "Suspend interval spacing"
- Terminating IM
    - e.g., "Cancel interval spacing behind [*Reference Aircraft Call Sign*]."

Of the set of expected transactions, the IM clearance is expected to be the most complex message. IM clearances can include the following elements (as reflected in an updated version of RTCA, 2011):

- IM clearance type
- ASG type
- Special points
- Reference aircraft call sign
- Reference aircraft Intended Flight Path Information (IFPI)

Each of these elements has options which are discussed next. The four IM clearance type options available in the flight deck IM equipment that the controller can choose from when providing a clearance are shown below.

- Achieve-by then maintain
- Capture then maintain
- Maintain current spacing
- IM turn

The clearance type is chosen by the controller based on the desired operation. If the IM Aircraft is close to or at the desired ASG, the "maintain current spacing" or "capture then maintain" options can be used. If the aircraft is further from the ASG or does not need to achieve the ASG until a downstream point, the "achieve-by then maintain" option can be used.

The first three clearance types involve the use of IM speeds alone while the IM turn operation utilizes a one-time horizontal path change. For this operation, the controller may provide a vector and direct the flight crew to return at the intercept point or the controller may tell the flight crew to remain on course and to fly to the intercept point when directed by the flight deck IM equipment. After turning to the intercept point, the achieve stage will begin.

The clearance type options can be issued for immediate execution or execution based on a future event. The controller can also issue an expectation of a clearance to be issued in the future, with no crew action required. Once a clearance is ready to be issued, the controller can amend that clearance as necessary. Clearances can also be suspended or terminated (prior to the planned termination point). If a clearance is suspended, the controller may decide to resume that operation at a later point should initiation conditions and the clearance still be applicable.

The ASG types can be either a precise or an at-or-greater-than value. The at-or-greater-than value is used in situations where the controller desires an interval greater than or equal to the value specified. It could be used in situations where it is necessary to achieve and / or maintain an interval from an aircraft ahead but there are limited constraints from an aircraft behind. The ASG can be specified in either time or distance, with certain operational limitations for the choice of the dimension based on the desire for a stable and efficient operation. Time is logically used for a metering operation and distance is logically used for a miles-in-trail operation.

Three Special Points may need to be conveyed:

- Achieve-by point – point on IM aircraft's route where spacing is first required to be achieved.
- Planned termination point – point where IM terminates
- Intercept point – point on IM aircraft's route where the IM aircraft rejoins their original route when conducting the IM turn

In order to establish the proper reference aircraft, the Third Party Call Sign (TPCS) of the reference aircraft must be conveyed. The TPCS will be communicated by the controller to the flight crew who will then correlate the TPCS with the information displayed on the CDTI traffic display. The TPCS will be used to aid the positive and unambiguous identification of a designated aircraft prior to the initiation of IM.

In order for the flight deck IM Equipment to perform the necessary calculations, the flight path from initiation to the achieve-by point for ownship and the IFPI of the reference aircraft are necessary. The IFPI of the reference aircraft information will be one of the following:

- Same route or procedure as ownship
- Direct to a common point on the IM Aircraft route then same route or procedure as the IM Aircraft
- Named procedure (including transitions)

When putting all the options together, a clearance could have the following format. Not all elements are required to be used for all operations.

- "...for interval spacing, [IM turn instruction] cross [achieve-by point] [IM clearance type and ASG] behind [reference aircraft call sign] on [reference aircraft IFPI]. Terminate at [planned termination point]."

The following is a sample communication following this format:

"For interval spacing, cross KEEEN 120 seconds behind Cactus 355 on WUDEE ENSOR KEEEN. Terminate at ESFOR."

Figure 2-1 shows a sample IM operation and clearance with the key IM Clearance parameters.

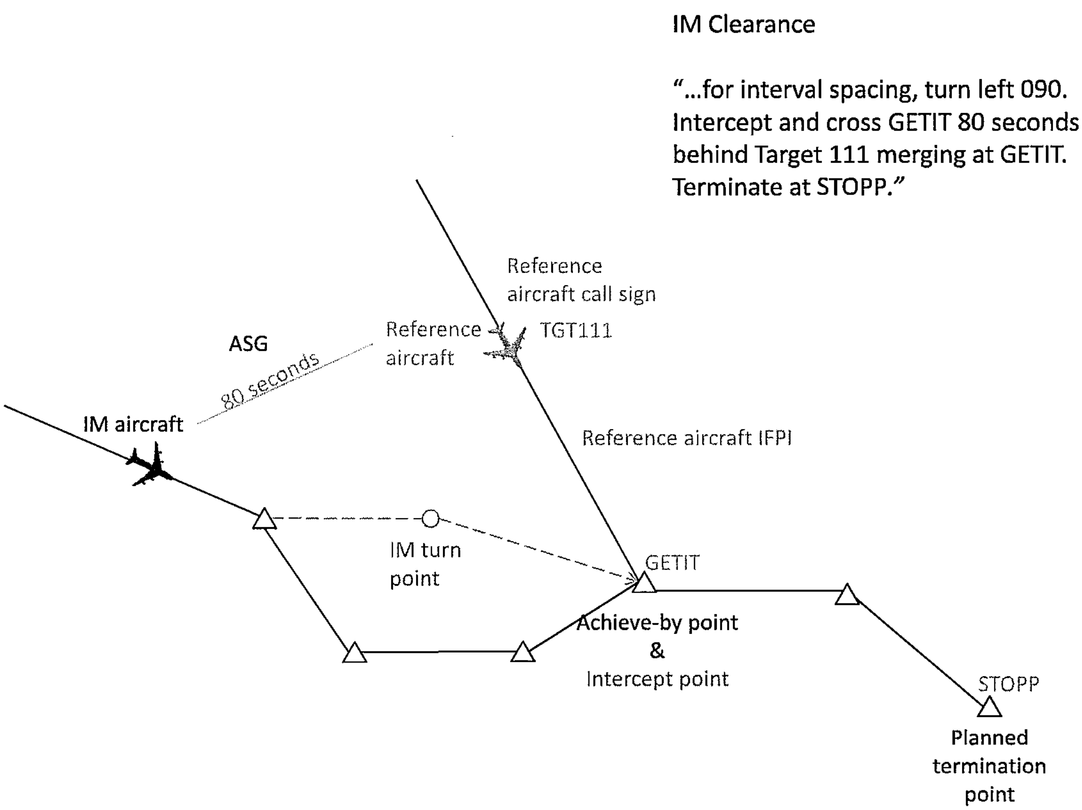


Figure 2-1. Plan View of Sample IM Operation with Key IM Clearance Elements

2.2.2 Current Day Voice Communications

Voice over radio is the main communication method between flight crews and air traffic controllers. Flight crew and controller communications involve clearances, instructions, and requests, for example. Complete, current / timely, and unambiguous communications are essential for safe and efficient operations. Flight crews and controllers must receive, comprehend, acknowledge, and act upon their communications. Controller and flight crews communicate by a formalized language termed standard phraseology, which includes the prescribed words and their sequential order, pronunciation, and enunciation (Kerns, 1991). Controllers in the US have phraseology specified for them in the ATC handbook (FAA, 2012b). Flight crews have guidance on communications in the Aeronautical Information Manual (AIM) (FAA, 2012a). The Pilot / Controller Glossary (FAA, 2013) contains the terms to be used in flight crew and controller communications. The communication procedure typically involves four steps (McMillan, 1999).

- Sender transmits a message
- Receiver listens to the message
- Receiver retransmits the message to the sender
- Sender listens to the reply for accuracy

The third and fourth steps are in place to reduce the potential for errors in the original message or the reply.

2.2.2.1 Current Day Voice Communication Issues

Miscommunications such as errors and requests for repeats can occur in any of the four steps in the communication procedure. The chances of a miscommunication increase with factors such as high workload, blocked transmissions, non-standard phraseology, and fast rates of speech. Miscommunications, in turn, increase frequency congestion and can lead to increased workload and even an aircraft accepting a message that was intended for another aircraft. Most literature reports that a small percentage (less than 1%) of communications that are read back result in miscommunications. This was found for the en route (e.g., Cardosi, 1993), tower / local control (e.g., Cardosi, 1994), and the Terminal Radar Approach Control (TRACON) (e.g., Cardosi, Brett, and Han, 1996; Morrow, Lee, and Rodvold, 1993; Van Es, 2004) environments. Additionally, controllers and pilots correct the majority (60-80%) of the communication problems (Cardosi, 1994) and can often do so without a reduction in communication efficiency (e.g., Prinzo's [2002] analysis of a Departure Spacing application conducted at an operational evaluation).

Nevertheless, the consequences of even a single miscommunication can be significant. Perhaps the most dramatic example of this was the runway collision between two Boeing 747s in 1977 at Tenerife, Canary Islands. The accident had the highest number of passenger fatalities of any aviation accident. Low visibility was a factor but radio frequency issues, blocked communications, and misunderstandings during ATC and flight crew communications contributed to a flight crew taking off without a clearance and hitting another aircraft taxiing on the runway. Issues such as runway incursions can be caused by miscommunications and the outcome can be hazardous (Van Es, 2004).

In high density environments, frequency congestion can be an issue. In such environments, pilot and controller transmissions can be truncated or non-existent due to the workload of both parties. For example, several studies found high partial readback rates (e.g., 12% in the en route [Cardosi, 1993], 37% in the tower / local control environment [Cardosi, 1994], and 26% in the TRACON [Cardosi et al., 1996]). Additionally, frequency congestion creates other problems such as inability to access the frequency and stepped on transmissions (Carlson, Jacobs, Kelly, Rhodes, 1998; Van Es, 2004). Further exacerbating the problem, controllers tend to increase their speech rate to correct pilot errors in readbacks or provide clarification during periods of congestion (Cardosi and Boole, 1991).

In an issue related to expectations during "hearbacks" and "readbacks," pilots expect to get affirmation of a request and controllers expect correct acknowledgement of the given clearance. Expectations based on past experiences help pilots and controllers process information more quickly and more accurately (Wickens, Lee, Liu, and Becker, 2004). However, this can lead to problems such as pilots and controllers hearing what they expect to hear, as opposed to what was actually said. Although readback errors are low and the majority are caught by ATC, 65% of Aviation Safety Reporting System (ASRS) reports on communication errors analyzed by Cardosi, Falzarano, and Han (1999) involved controllers either failing to catch incorrect pilot readbacks or correct pilot readbacks based on incorrect information initially provided by the controller. Van Es (2004) also found that readback / hearback was the most common type of communication problem category based on analyses of safety reports.

Past research on voice communications also indicates that as the number of elements in a communication increase, so does the potential for errors. Elements have been defined as "each word, or set of words... [that was] critical to the understanding of the message" (Cardosi, 1993, p. 3). Each element can be considered an opportunity for an error. As an example, "Delta 1 3 5, turn **right** heading **180.**" Both "right" and "180" are considered one element each. In the body of Cardosi work (e.g., Cardosi, 1993; Cardosi, 1994), the call sign of the recipient aircraft was not considered an element.

Cardosi (1993) found a doubling of readback errors as the complexity of the instruction or clearance increased from three to four elements in an en route environment. The study also found that in the few very complex cases where the communications included five or more elements, the number of errors increased dramatically. In the TRACON environment, instructions / clearances that contained four or more elements comprised only about one fourth of the readbacks but accounted for about half of the total readback errors (Cardosi et al., 1996). On the local / tower frequency, Cardosi (1994) found the complex communications with five or more elements to be more frequent (31% of the communications), but did not find an increase in readback errors with increasing complexity, even up to 9 or more elements. All complexity levels were very similar and below 1% (with a slight spike at 8 elements). These tower results were inconsistent with research in en route and the TRACON. The authors suggested this was due to predictability in the terminal environment, the information available on Automated Terminal Information Service (ATIS) and the common frequency, and pilot's expectations of communications from ATC.

Bürki-Cohen (1995) also found that there was a relationship between readback errors and message complexity: errors increased as complexity increased. The number of errors spiked at 7 elements to approximately twice (to about 2.0%) that of the other complexities. Morrow et al. (1993) found an increase in incorrect readback when the "speech acts" (a measure of length and complexity) increased from one to two or more.

Past research also shows that when there is an increase in message complexity or number of elements, there is also a chance for an increase in the number of repeat requests from pilots. These requests indicate some confusion within the flight deck and can use up valuable frequency time. Cardosi (1993) found that as the complexity of the messages increased to five or more elements, the rate for pilots asking for a repeat of all or part of a transmission increased about 1.5 to 3% in an en route environment. Cardosi (1994) found a slight (0 to 1%) increase in pilot requests for repeats with an increase in message complexity beyond five elements. Bürki-Cohen (1995) found the number of pilot requests for repeats on the ground control frequency increased with message complexity. Eight elements showed a spike that more than doubled the number of readback requests (to about 3.6%). However, there were no repeat requests when there were 9, 10, or 11+ elements.

Past research also shows that when there is an increase in message complexity or number of elements, there is a chance for incomplete readbacks from flight crews. Cardosi (1993) found that the more complex the message, the less likely pilots would give a full readback. The percentage of full readbacks drops significantly with a complexity rating of five elements. Without a full readback, it is unclear whether the pilot received all the information and just didn't read it all back or whether the pilot did not receive all the information and read back only what was received. In either case, the controller does not have the opportunity to catch an error. Cardosi (1994) found in tower operations that the more complex a controller's communication was (four or more elements seemed to be a breakpoint), the more likely the pilot would reply with a partial or full readback versus a simple acknowledgement. Bürki-Cohen (1995) found the number of partial readbacks and acknowledgments only increased (as compared to full readbacks) with increased message complexity or number of elements. Bürki-Cohen (1995) also found the number of partial readbacks increased (as compared to full readbacks and acknowledgments only) with increased message complexity or number of elements. Partial readbacks increased from about 4% (for 1 element) to 13% (for 3 elements) to about 30% (for 6 elements) to about 64% (for 11+ elements). Morrow et al. (1993) found an increase in partial readbacks when the "speech acts" (a measure of length and complexity) increased from two to three or more.

With increasing complexity of the messages, the memory load on the pilot is higher and therefore is expected to lead to more errors and confusion. With several items in the transmission, it seems likely that more elements will have the potential to contain an error in the readback. It may be more difficult for the controller to catch multiple errors in a readback than it is to catch one error due to both expectations of a correct readback and the memory load demands. Therefore, not only do more complex messages introduce the potential for more readback errors, they also reduce the possibility of controllers catching the errors in their hearback.

Overall, as messages increase in complexity so do communication issues. In recommendations similar to others, Barshi and Farris (2013) recommend no more than three "aviation topics" in one ATC message. If more than three are necessary, they recommend using two separate messages or provide a warning (an "advanced organizer") to the pilot that a long clearance will be given so that the pilot can prepare to write it down.

2.2.3 Interval Management (IM) Voice Communication Issues

Most previous IM research utilized voice communications. The following bulleted items are sample IM clearances (and their associated complexities / number of elements based on the work of Cardosi [e.g., 1993]) used in key bodies of work. Each element is shown in brackets.

- "AF203CB, heading [020] then behind target [merge] to [OKRIX] to be [8] [miles] behind" – Co-space work, e.g., Aligne, Grimaud, Hoffman, Rognin, and Zeghal, 2003 for IM turn operations
    - 5 elements
    - This work also had a separate communication for reference aircraft identification
- "American 123, cleared [Precision Spacing], [maintain] [120] [seconds] spacing, reference [Continental 321]." - Barmore et al. (2005)
    - 5 elements

- "Scandinavian 123, [ASAS spacing], [merge behind] leader [Sierra Alpha Sierra 456], [60] [seconds] at [WAYPT]." - Nyberg (2006) for select voice messages
  - 6 elements
  - This work also had a separate communication for reference aircraft identification
- "DLH 456, fly [heading 180] then behind target, [merge] to [ATN] [maintain] [at least] [10] [miles]" - Fusai, Schaefer, and Ruigrok (2004) for IM turn operations
  - 7 elements
  - This work also had a separate communication for reference aircraft identification
- "Lufthansa 672, [remain] [10] [miles] behind [456 Air France]." - Hassa, Haugg, and Udovic (2005) for remain behind operations
  - 4 elements
  - This work also had a separate communication for reference aircraft identification
- "Lufthansa 672, turn [right] heading [090], [merge] to [WAYPT], [10] [miles] behind [456 Air France]." - Hassa, et al. (2005) for IM turn operations
  - 7 elements
  - This work also had a separate communication for reference aircraft identification
- "Delta 620, [merge behind then follow] [American 142], [100] [seconds] in trail." - Mercer et al. (2005)
  - 4 elements
- "United 123, [for interval spacing], cross [PECHY] [120] [seconds] behind [American 456]." - Bone, Penhallegon, Benson, and Orrell (2013)
  - 5 elements

As can be seen, several of the clearances have approximately the same number of elements that have been found to be an issue in past work on voice communications. However, few issues have been reported. Recent exercises exploring the voice breakpoint issue indicate that the IM clearances can get more complex than these samples (Bone, 2014). The messages can become too complex simply based on the total number of elements or based on confusing elements. The work done by Bone (2014) points to two areas of concern: TPCS and reference aircraft IFPI.

Problems exist today with similar call signs being confused (Monan, 1991; Grayson and Billings, 1981; Bürki-Cohen, 1995; Cardosi et al., 1999; Canadian Aviation Safety Board, 1990; Van Es, 2004). The use of TPCS may introduce new issues. In the US, the issue of which method to use for identifying the reference aircraft is being examined in an independent body of work (e.g., FAA, 2011c; Bone, et al., 2013). The TPCS use can be an issue for pilots receiving a clearance when the airline telephony designator (e.g., "Brickyard") does not closely match the airline three letter designator (e.g., "RPA") on the CDTI traffic display. Flight crews reported difficulties trying to decode the airline telephony designator and still pay attention / write down the remainder of the IM clearance (Bone, 2014). They reported getting "stuck" on the TPCS and missing the rest of the communication.

TPCS can also be an issue for the reference aircraft flight crew whose call sign is being used. Since the TPCS communication is over voice on a common frequency, the flight crew in the third party aircraft can hear their call sign used in the communication. Since hearing their call sign is normally what caused the flight crew to tune into the communication, they may start listening to the remainder of the communication. The reference aircraft flight crew may not know whether their call sign was being used as a reference aircraft identifier or not. This could result in two issues:

1. If reference aircraft flight crew overhears their call sign used on the frequency, they may think the communication is for them. This could lead to them querying ATC, which results in extra transmissions and use of valuable frequency time.
2. They could also possibly not ask but instead accept an instruction or clearance that was intended for another aircraft.

While both are undesirable, the latter is clearly the more concerning one.

The reference aircraft IFPI is expected to be an element that can be the lengthiest and most difficult element in the IM clearance. It can contain several navigational elements such as waypoints and procedures. Flight crews reported difficulty with complex reference aircraft IFPI in recent activities (Bone, 2014). The flight crews reported the reference aircraft IFPI as being difficult when it included many elements. They also reported difficulties when receiving unknown, uncommon waypoints that had to be decoded (e.g., after hearing a waypoint like "KEEEN," knowing that it was spelled K E E E N instead of the numerous other ways it could be spelled). Confusion on the spelling of the reference aircraft IFPI waypoints can lead to pilots missing other parts of the clearance and / or requests for ATC to (phonetically and slowly) spell each waypoint. Pilots may request a full readback or a partial readback of just the reference aircraft IFPI. Requests for readbacks indicate some confusion within the flight deck and can use up valuable frequency time, thereby increasing both flight crew and controller workload. Receiving the reference aircraft IFPI was compared to receiving a reroute clearance, which has also been noted as a currently challenging, complex communication for similar reasons. Prinzo, Hendrix, and Hendrix (2009) found this issue of difficulty with communications involving navigation fixes in the current en route environment.

In order to overcome some of these issues and those mentioned previously (e.g., readback errors, repeat requests, and partial readbacks), IM operations should be limited, or methods of managing the required IM clearance complexity, should be considered. The IM clearance should be kept as concise as possible. It should also allow the flight crew to understand the operational goal and how to achieve it. It may also be highly desirable to have the clearance be able to be committed to memory by the flight crew, even if they plan to write it down (Airbus, personal communication, April 8, 2013). Being able to memorize the clearance will help in high workload environments where writing down the clearance could be challenging.

Something that can help with pilot's acceptance and readiness for the more complex IM clearances is an advanced organizer communication such as "Interval Spacing clearance available. Advise when ready to copy." It is also possible to place some of the information such as the achieve-by point or the planned termination point in notes in a published arrival procedure, thereby avoiding having to communicate those points over voice.

Another consideration for reducing the length and complexity of the IM clearance is the use of two separate communications. It may be desirable to break the communications into one communication including information on the reference aircraft (e.g., position information and IFPI) and another communication for the remainder of the information.

2.2.4 Controller Pilot Data Link Communications (CPDLC)

Voice is currently the primary means of communication between flight crews and controllers. However, data communications via Future Air Navigation System (FANS) is being used in oceanic airspace. Data communications for domestic airspace are also under development (FAA, 2011b). CPDLC has been explored internationally in simulations (as summarized in Kerns, 2010) and has been fielded (Gonda, Saumsiegle, Blackwell, and Longo, 2005).

CPDLC over ATN is planned to be implemented in the en route environment post-2020 (around the same timeframe of IM) and is expected to provide improvements over voice communications. When CPDLC becomes operationally available, voice communications are expected to be gradually replaced by digital communications. However, voice communications will continue to be available and will be used for communications such as non-routine or urgent instructions. CPDLC is expected to initially replicate current day communications and then is expected to support the evolving Air Traffic Management (ATM) system as it moves toward trajectory-based operations (Gonda, Chavez, Hung, and Anderson, 2006). CPDLC is expected to provide the following improvements over voice communications: reduced voice frequency congestion, reduced pilot and controller workload, the ability of the flight crew to print a message, the ability for the flight crew to directly load clearance information into other aircraft systems, the ability for the controller and flight crew to store and review messages, and reduced flight crew errors (International Civil Aviation Organization [ICAO], 2013).

CPDLC includes Uplink Messages (UM) from the controller to the flight crew and Downlink Messages (DM) from the flight crew to the controller. A CPDLC message element has text and variables associated with it. A CPDLC message can be either an individual element or a concatenation of individual elements. Concatenation allows for the sending of one longer message instead of several smaller messages (RTCA and EUROCAE, 2013). Figure 2-2 shows a sample concatenated CPDLC message.

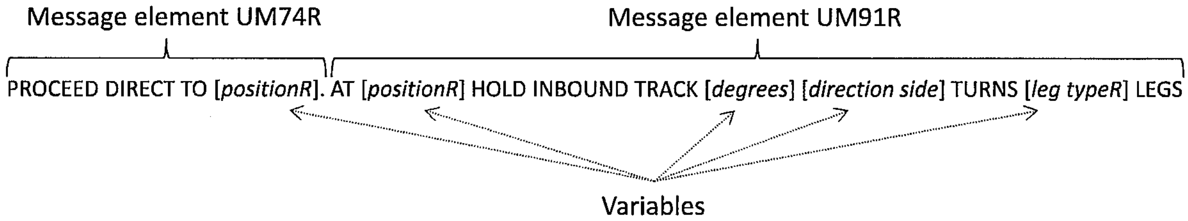
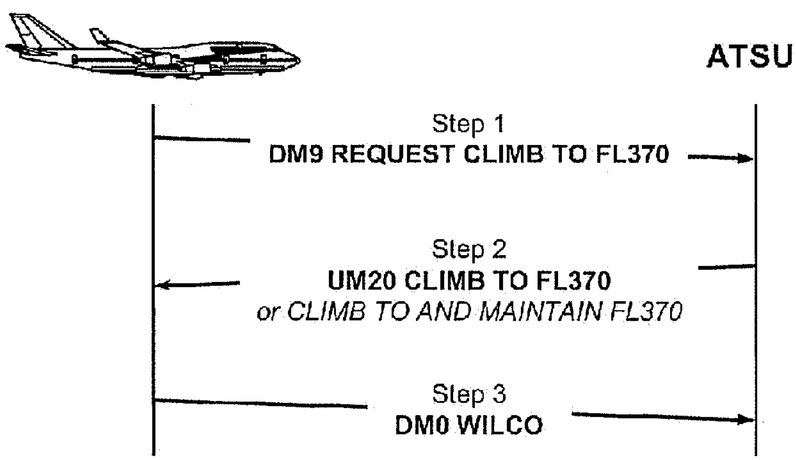


Figure 2-2. Sample CPDLC Concatenated Message

Certain elements from the CPDLC message can be directly loaded into other on-board systems (e.g., the FMS), which may reduce the potential for errors and flight crew workload. The ability to directly load a message has been reported as favorable by flight crews; however, some concerns such as the impact on shared situation awareness have been expressed (Pepitone, Letsu-Dake, and Bell, 2013).

CPDLC, like voice, can involve a series of transmissions from the controller and flight crew. A series of transmissions is known as a dialog. A CPDLC dialog can either be opened or closed. A CPDLC dialog is open if any of the CPDLC messages in an exchange are open. A dialog is open if a "stand-by" or no reply is sent / received. The dialog is considered closed when all CPDLC messages in the exchange are closed (ICAO, 2013). See Figure 2-3 for an example of a closed dialog.



Step	CPDLC Message	Response Attribute	UM Status	DM Status	Dialogue Status
1	Downlink request	Y	N/A	Open	Open
2	Uplink response	W/U	Open	Closed	Open
3	Downlink response	N	Closed	Closed	Closed

Figure 2-3. Closed CPDLC Dialog (Image from ICAO, 2013)

The following are select data communication procedures relevant to this simulation (ICAO, 2013).

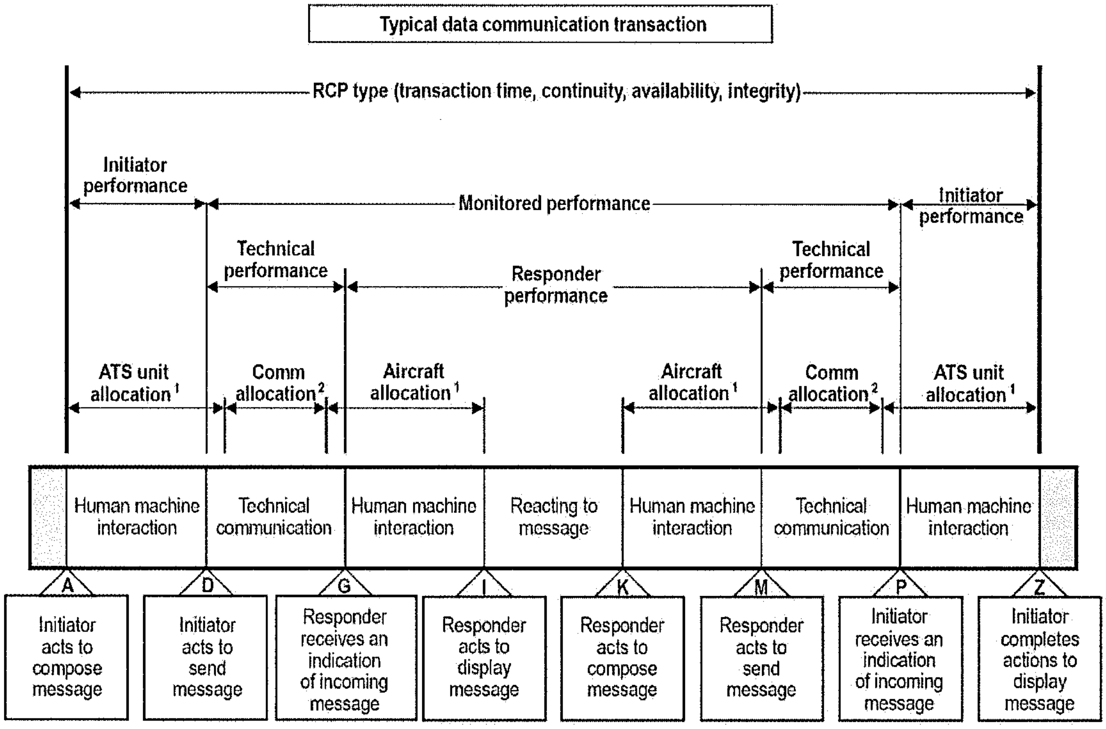
- A data communication / CPDLC message received by an individual is expected to be replied to with another data communication / CPDLC message.
- If there is a conflict between voice and data communication messages, there has not been a reply to a data communication message, or CPDLC fails, voice should be used.
- Controllers should keep message size to a minimum.
- Controllers should only combine message elements that are interdependent.
- Each flight crew member should review UMs and DMs prior to taking action related to the message.
- The flight crew should respond to CPDLC messages as soon as practical without being pressured into a quick reply. One minute is expected to be sufficient time to read and respond to most messages. If additional time is expected, a stand-by message can be sent (note that a stand-by reply does not close a dialog).
- Flight crews should exercise caution when complying with conditional clearances. Errors can occur if the clearance is executed prior to the required condition.
- When a message can be directly loaded into the Flight Management System (FMS), the flight crew should load the message prior to responding with a WILCO.

Some of these procedures may lead to delayed responses from the flight crew, as compared to voice communications. For example, pilots need to individually access and review the CPDLC message via on-board systems versus simply hearing the message as done in voice. Also, pilots need to take time to read the message and coordinate on the message within the flight deck prior to replying. These issues are related to the topic of Required Communication Performance (RCP) which is covered in the next section.

2.2.4.1 Required Communication Performance (RCP)

The RCP concept exists "to ensure the acceptable performance of communications within a complete ATM system" (ICAO, 2013, p. 2-2). An RCP type is defined as the point from which the controller starts to generate a message to the point when the controller receives a response to that message (as can be seen in Figure 2-4). RCP types include the following parameters:

- Communication transaction time – "The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure."
- Continuity – "The probability that an operational communication transaction can be completed within the communication transaction time."
- Availability – "The probability that an operational communication transaction can be initiated when needed."
- Integrity – "The probability of one or more undetected errors in a completed communication transaction." (ICAO, 2008, p. 3-1.)



Note 1.— A controller-initiated transaction is shown. ATS unit and aircraft allocations are transposed for a pilot-initiated transaction.
Note 2.— The aircraft and ATS unit allocations include HMI and a portion of the technical communication to provide a basis for the different types of approvals.

Figure 2-4. Required Communication Performance (RCP) transaction (Image from ICAO, 2008)

RCP types are determined by considering the operational context (e.g., airspace characteristics, operational capabilities) of the ATM function. RCP types are applied to ATM functions and multiple RCP types can exist within a given airspace (ICAO, 2008). An example RCP type is RCP130. The communication maximum transaction time for RCP130 equals 130 seconds. After this time, the controller would be expected to revert to an alternate procedure. RCP types also have nominal times (95%) specified, e.g., RCP130 has a 67-second nominal transaction time. Select RCP130 requirements are shown in Table 2-1 (RTCA and EUROCAE, 2014). The human is likely the main contributor to the allocated time. For Aircraft Communications Addressing and Reporting System (ACARS) over Very High Frequency (VHF) Digital Link (VDL) Mode 2, the technical performance has been found to be 4.8 seconds on average, 11.0 seconds for 95%, and 90.3 seconds for 99.9% (Matyas, 2013). The human times (initiator and responder performance) will likely be interface and operation dependent.

Table 2-1. Select RCP130 Time Requirements

Coverage Area in Figure 2-4	Title	Nominal Time in Seconds (95%)	Maximum Time in Seconds (99.9%)
A-D and P-Z	Initiator performance	13	30
D-G and M-P	Technical performance	20	32
G-M	Responder performance	44	100
D-P	Monitored performance	60	120
A-Z	Transaction time	67	130

RCP types also have continuity, availability, and integrity numbers associated with them. In order to perform the function in a given airspace, a specified RCP must be met. Past work has identified the need for additional research into RCP for specific messages / operations (Willems, Hah, and Schulz, 2010).

2.3 Interval Management (IM) and Controller Pilot Data Link Communications (CPDLC)

2.3.1 Controller Pilot Data Link Communications (CPDLC) use for Interval Management (IM)

Voice is expected to be an acceptable near-term communication method for certain, basic IM implementations. However, both the complexity of some messages and frequency of use are potentially problematic when using voice. Certain complex IM clearance messages conveyed over voice may require too much time on frequency and therefore may be difficult to convey in high density environments. Complex messages may also tax controllers' and pilots' memories and induce errors. When using voice communications, the amount of the information contained in the IM clearance may need to be limited, or more than one transaction may be required, to avoid communication errors.

CPDLC has been cited as a better means than voice to convey complex messages (Kerns, 2010) although controllers in some activities have even reported concerns over using CPDLC for complex messages (Willems et al., 2010). When CPDLC becomes available, it is expected to be used to issue IM clearances. CPDLC can be used for IM clearances that are possible over voice but can be improved through the benefits realized with CPDLC. For example, CPDLC allows for "permanency" of lengthy messages thereby reducing the memory load and reducing the chances of entry and execution errors. CPDLC may also enable new IM clearances / operations that were not possible over voice because the messages were too complex to be handled over voice.

Whether improving current communications or enabling new communications, CPDLC can also allow for the loading of the message directly into systems such as the flight deck IM equipment, which reduces flight crew workload and the potential for errors. The ability to directly load a message into on-board systems has also been reported to reduce controller workload based on reduced flight crew reply times (Willems et al., 2010). Additionally, since CPDLC messages are not broadcast on a common voice frequency, CPDLC can help overcome the issue of the reference aircraft flight crew hearing their call sign and thinking the instruction / clearance was for them.

However, use of CPDLC can lead to some issues. For example, the time to receive a reply to the CPDLC message can be longer than that seen in voice communications. As noted previously, that delay is related to the chosen RCP for IM.

Based on this desire for CPDLC in IM operations, the international standards community started activities in 2010 to develop IM CPDLC messages and the associated requirements (reflected in the draft document RTCA and EUROCAE, 2013). Twenty messages enabling operations possible through RTCA, 2011 are currently defined for CPDLC. The messages were defined by a group of operational experts as well as individuals involved in the development of standards in RTCA Special Committee (SC)-186 and SC-214 and in EUROCAE Working Group (WG)-51 and WG-78. The group was tasked with identifying the messages based on the expected merging of the capabilities in the field, and the potential need for CPDLC for certain, complex IM messages. The group also chose a RCP type for IM. RCP180 was derived for IM. This RCP was shown to have acceptable transaction time, integrity, continuity, and availability for IM. At the time of the simulation, the messages and the RCP requirements were in final draft form in RTCA SC-214 and EUROCAE WG-78 Safety and Performance Requirements (SPR) and Interop documents (RTCA and EUROCAE, 2013). Those documents were finalized in 2014 (RTCA and EUROCAE, 2014). The messages defined in those documents are expected to be very similar if not the same as those to be used over voice. The messages and the chosen IM RCP type require validation activities such as this simulation. It should be noted that after completion of the simulation, RCP180 was no longer specified. RCP130 was the next closest RCP type and was chosen for IM (RTCA and EUROCAE, 2014).

Past research has been conducted on both IM and CPDLC. That research is reviewed next. At least one of the research efforts had the messages defined in RTCA and EUROCAE (2013) available and tried to align with those messages.

Hassa et al. (2005) conducted an IM simulation with controllers in the en route environment. The controllers reported some issues with IM in the airspace simulated (e.g., distance-based spacing during descent and airspace complexities). As part of their recommendations, they suggested developing an easier and shorter phraseology for the IM clearance. The controllers also recommended considering the use of CPDLC in follow-on simulations. The authors agreed that further work should be done on the integration of IM and CPDLC.

In a study of IM in Paris airspace, controllers used a mix of voice and data link communications. Controllers could use either data link or voice for the identification of the reference aircraft, but other communications, such as the IM clearance, were done over voice. Controllers used data link a vast majority of the time. The author reported "From controllers' point of view, Data-Link is essential for the target aircraft selection as it saves a lot of time" (Hébraud and Cloërec, 2007, p. 28). The authors also reported that data link added to the acceptability of IM. Controllers reported that data link helped coordination between the tactical (radar) and planner (data) controllers. Controllers also reported that having mixed data link and voice communications with an individual aircraft was acceptable. However, controllers found the IM clearance phraseology conducted over voice to be too complex and lengthy.

Prevot et al. (2007) examined a condition with IM and data link with pilots and controllers in an arrival operation. The message included the scheduled runway, a Scheduled Time of Arrival (STA) that could be used as a Required Time of Arrival (RTA), cruise and descent speeds, reference aircraft call sign, merge point, and the ASG. The IM clearance and STA message could be directly loaded from the data link system to the flight deck IM equipment. A sample message and the associated number of elements are shown below.

- "SDF arrival UPS913 [17R] at [17:03:20 UTC] CRZ [.78] Des [.78/275]. Lead: [UPS907]. [Merge Pt]: [CHERI]. Spacing: [105] [sec]."
    - 9 elements

Nyberg (2006) compared CPDLC to voice when initiating an IM operation. Participants included flight crews, Multiple Sector Planners (MSPs), and sector controllers. The IM clearance was either sent over voice or CPDLC. The MSP did the coupling of aircraft pairs across multiple sectors controlled by individual sector controllers. When CPDLC was used, the coupling of aircraft and sending of the IM clearance was conducted by the MSP. The sector controllers could view the CPDLC messages along with the responses from flight crews. When voice was used, the coupling of aircraft was conducted by the MSP and then coordinated with sector controllers to issue the clearances. Both pilots and controllers reported favorably on CPDLC. Pilots reported CDPLC being easier than voice communications. MSP controllers reported improvements in safety and workload when using CPDLC (but it was also reported as potentially being too slow to be used by the sector controller in the terminal environment). A sample communication and the associated number of elements from Nyberg (2006) are shown below.

- "[For spacing], fly heading [180] then [remain] [120] [seconds] behind leader until [WAYPT]."
    - 6 elements
    - This work also had a separate communication for reference aircraft identification

Work done by Baxley et al. (2013) potentially tested the limits of CPDLC messages. The group examined IM operations during parallel dependent runway operations. CPDLC was used for the IM clearance, but voice was used for the rest of the communications. The authors attempted to align their messages with the messages available at the time (i.e., an earlier version of RTCA and EUROCAE, 2013). RTAs were used to get aircraft into position for IM. An example communication with the RTA, IM clearance information, and the associated number of elements is shown next. The flight deck equipment was able to directly load the IM clearance from the CPDLC system into the flight deck IM equipment.

- "Cross [R-17C] at [0028:26Z]. [When able], cleared [IM-Spacing] [95] [sec] with [NASA1] and [2.2] [NM] with [NASA2]. [Achieve by] [R-17C]. [Terminate] at [R-17C]. [NASA1 route] [GGG] [CQY6] [PENNY] [ILS17C], [FAS 130 kt]. [NASA2 route] [INK] [JEN9] [YOHAN] [ILS18R], [FAS 130 KT]. [Report commencing IM-Spacing]."
    - 27 elements

Baxley et al. (2013) acknowledged that the IM clearance was very complex and that the CPDLC interface was "sub-optimized" (p. 25). However, the pilots agreed that the messages were acceptable. The authors stated that, in debrief discussions, pilots reported the use of CPDLC reduced stress and miscommunications.

Baxley et al. (2013) also examined RCP. The mean time for the flight crew to read the clearance was approximately 5 seconds. The mean respond time was under 60 seconds across the various flight deck simulation platforms. Only 13% of the response times were greater than 60 seconds. Pilots suggested procedural and interface improvements that were estimated to reduce the response times by 15 to 30 seconds. While these times are only from a flight deck perspective, they seem to support the use of RCP180.

2.3.2 Procedures

Normal controller and flight crew procedures are expected for IM and CPDLC. Some new procedures may be specified for IM and / or CPDLC but they will align with current operations. Those procedures are defined elsewhere in IM (e.g., RTCA, 2011) or CPDLC (e.g., RTCA and EUROCAE, 2013) material so they will not be reviewed here. However, the procedure related to the acceptance of the IM clearance was a matter of debate in the standards community at the time this simulation was being defined. Gonda, Blackwell, and Zeng (2013) discuss it in the context of route clearances. This section will discuss it in the context of IM and CPDLC.

Flight crews can use two methods to accept a clearance: Accept-then-Process (A-P) and Process-then-Accept (P-A) (Gonda et al., 2013). A-P and is typically followed currently in voice communications. For IM it is applied in the following manner: the controller issues an IM clearance, the flight crew does a reasonableness check and then accepts the clearance, enters the IM clearance information into the CDTI, conducts a cross-flight deck verification, and then arms the flight deck IM equipment. The flight crew only needs to come back to the controller and report an issue if they are not able to conduct IM (e.g., the IM speed cannot be flown). The ground automation setting up IM will be developed such that this will be a rare event. The A-P method is the planned implementation for IM and is specified in standards material (RTCA, 2011). Past research has shown that flight crews follow A-P when using CPDLC. For example, Lozito, Verma, Martin, Dunbar, and McGann (2003) found flight crews were usually implementing the clearance / instruction before acknowledging the data link message. However, Gonda et al., 2013 reported that it may be an issue because the controller may not be clear about when a clearance (for a route in their case) is actually being executed.

The second method is P-A. In this situation, the flight crew does not accept the clearance until after reading, loading, and executing the clearance information. In the context of IM, the flight crew must read and process the clearance information, enter it into the system, wait for system feedback, determine feasibility, then reply to the controller. The P-A method clearly has a delay in the flight crew reply to the controller.

The Baxley et al. (2013) experiment mentioned previously followed a P-A method. The authors lay out the following steps for the flight crew for the IM clearance: notification of message arrival, review of the message, loading of the clearance into the flight deck IM equipment, activating the flight deck IM equipment, sending reply, and executing IM. Several events occur during the activation of the flight deck IM equipment. During this step, the flight deck IM equipment takes about 15 to 20 seconds to calculate and present the first IM speed. Once that speed is presented and the flight crew determines that it is acceptable to fly, they can move to the next step and accept the IM clearance message. The procedures seemed to be generally acceptable to pilot with the direct loading of the IM clearance information. However, controllers were not participants so data was not available for controllers.

2.3.3 Interfaces

Ground and flight deck displays have been developed in simulations and the field for IM and CPDLC independently. Additionally, some research has examined the integration of CPDLC and current day operations. For example, Pepitone et al. (2013) examined the integration of non-IM systems (e.g., the FMS) and the CPDLC system. However, only a limited amount of research has been done on the integration of IM and CPDLC. Research examining flight deck implementations of IM and CPDLC are reviewed next.

Prevot et al. (2007) utilized a CPDLC system that was presented on a display along with the Primary Flight Displays (PFDs), the FMS, and a Mode Control Panel (MCP) (further details on the displays are found in Prevot et al., 2006). The CPDLC interface was its own window and was not integrated into an existing display / system such as the Control and Display Unit (CDU) or Engine-Indicating and Crew-Alerting System (EICAS). There were buttons to perform actions such as loading the IM clearance into the flight deck IM equipment and replying to the IM clearance message. It also had an area to display the uplinked CPDLC message. Little detail was provided on acceptability of the interfaces.

Some flight deck implementations included the CPDLC interface within the CDTI traffic display (e.g., Nyberg, 2006). The display included a window with graphical traffic information presented on a typical Navigation Display (ND), a window with TPCSs, and windows for CPDLC. Pilots reported having the information that was necessary and that it was easy to find.

Baxley et al. (2013) used two interfaces for CPDLC when examining IM and CPDLC. One was an EICAS implementation and the other was a CDU implementation. The difference between the two implementations did not appear to be a significant issue for the respond times of flight crews. However, crews did report that there were too many button pushes associated with the IM clearance when using the CPDLC interface. As mentioned previously, pilots recommended an option to reduce the complexity of the procedures.

For the integration of IM and CPDLC in ground displays, Nyberg (2006) utilized a CPDLC window that showed messages and associated information (i.e., time, sender, receiver, and the message content). The status of the message was shown in the data block of the IM aircraft. The MSP controller used an Arrival Manager (AMAN) to determine suitable aircraft pairs for IM.

Sometimes the MSP controllers coupled aircraft on one interface but forgot to send an IM clearance over CPDLC in another interface. Sector controllers appeared to miss when a flight crew did not acknowledge a CPDLC message. The authors recommended providing better feedback to the sector controller when the message is not acknowledged by the flight crew.

Prevot et al., 2007 utilized a controller display that included scheduling and spacing information along with CPDLC (further details on the displays are found in Prevot et al., 2006). It was a Display System Replacement (DSR)-like implementation with the integration of CPDLC based on past research and fielding activities. The displays seemed to be well received and no recommended improvements were discussed.

2.4 Study Purpose

Based on the desire to use IM and CPDLC in a NextGen future environment, a simulation was designed to examine issues related to the combination of the two concepts. The goal of the study was to conduct a human-in-the-loop simulation to investigate the combination of two advanced NextGen applications across both the air and ground domains in order to expose any complications that may arise from utilizing two technologies that have been developed separately. The important need to consider the integration of ground and flight deck systems in new operations has been noted as an area that is often neglected (Weiner, 1989; Kerns, 2010). In addition, the findings from this research are intended to support answering outstanding questions for IM and CPDLC that have been covered in previous sections (e.g., IM clearance complexity, message set validation, and RCP validation).

The simulation was designed to examine the IM and CPDLC concepts in a full air and ground simulation environment. The key areas of study were the IM communications message set, the RCP, message return times, pilot and controller procedures, the complexity of IM clearances, as well as pilot and controller interfaces. Pilots and controllers conducted operations in an en route environment during arrival procedures that included voice only and mixed voice and CPDLC communications and mixed IM and non-IM operations.

3 Methods

3.1 Simulation Environment

The study was conducted in the MITRE Aviation Integration Demonstration and Experimentation for Aeronautics (IDEA) Laboratory, using its en route and flight deck simulation capabilities. The study utilized controller, flight crew, and pseudo-pilot workstations. An overview of the capabilities and workstations is provided below, with an emphasis on highlighting specific features added to support this research.

It should be noted that in this section, and in some products of the simulation, the term FIM is used. The use of "FIM" is based on historic terminology. At the time of final report development, the term "IM" was the appropriate term for the overall operation, even if "FIM" had the same meaning in the past. Therefore, the report itself uses the term "IM" where items such as the questionnaires or interfaces used the term "FIM."

3.1.1 Controller Workstation

The medium-fidelity controller workstation used for the study consisted of a Display System Integration (DSI) workstation, with a representative 2K display, Cortron keyboard, trackball, and standard Display Interface Keypad (DIK).

The DSI is an upgrade from the current DSR, and consists of an en route NextGen Mid-term display, which contained some expected En Route Automation Modernization (ERAM)-like functionality and capabilities. These included problem notification, interface enhancements such as customizable toolbars, tear-off functionality for buttons and sub-lists, and improved data interaction areas. The DSI screen used in the simulation is shown in Figure 3-1.

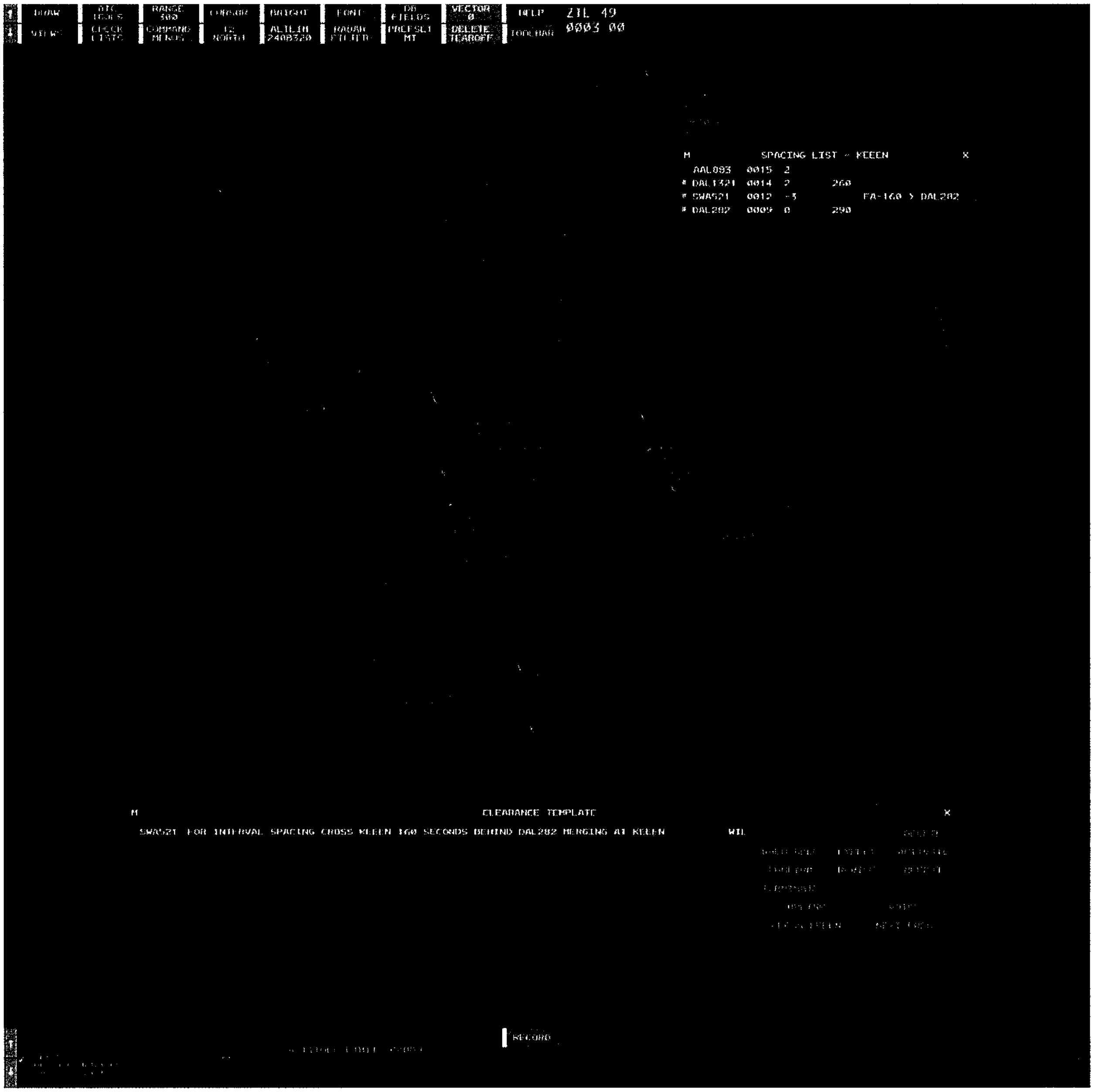


Figure 3-1. Display System Integration (DSI) Screen

Notional interfaces were added to the DSI display to allow interaction with both IM information and CPDLC messages. These interfaces were designed specifically for this simulation and were limited to the specific operations and desired data collection for the scenarios. The interfaces include a Spacing List, a Clearance Template, and modifications to the aircraft data blocks. The following sections provide details on these interfaces.

3.1.1.1 Spacing List

Past work determined that IM information should be added to the current TMA metering list (Peterson, Penhallegon, and Moertl, 2012). Therefore, this simulation built upon that work. The TMA Metering List is used today by en route controllers to smooth traffic flows when airport arrival demand nears capacity. The information displayed in the Metering List included the aircraft call signs, in order of arrival schedule, along with the STA and the Meet Time Error (MTE) in one minute increments. The MTE was the calculated difference between the STA and the Estimated Time of Arrival (ETA).

In addition to the information included in the current TMA Metering List, the Spacing List developed for this study displayed non-IM speed advisories for ground sequencing and spacing as well as IM information. This simulation also added an indication of CPDLC capable aircraft. The presentation of the additional information was designed based on previous work done at MITRE (Peterson et al., 2012) along with the Conceptual Use Case for Arrival Interval Management-Spacing and Ground Based Interval Management-Spacing (National User Team FAA ATO ERAM, 2012).

Once aircraft came under sector control, the Spacing List displayed the aircraft IM capability, the desired spacing goal for that IM pair, and the reference aircraft call sign. The controller could use the Spacing List to indicate when IM initiation had taken place. The Spacing List and the associated fields are shown in Figure 3-2.

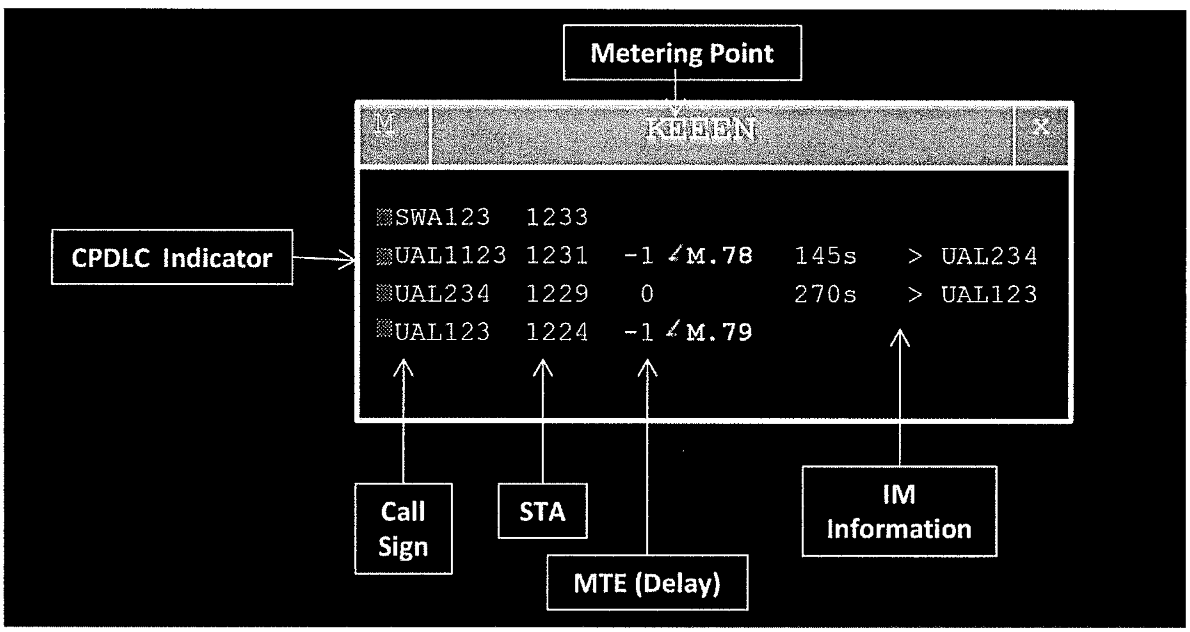


Figure 3-2. Spacing List and the Associated Fields

3.1.1.2 Clearance Template

The Clearance Template was based on an interface described in the CPDLC Draft Thinspec (FAA, 2010). The authors of this report developed the specific Clearance Template used in this simulation so that the necessary routine and IM communications could occur via CPDLC. The Clearance Template was intended to allow the controller to build and track CPDLC messages. It had several columns for the necessary information. The left hand column contained an indication of uplink and downlink message status. An uplink indicator showed that the uplink message was sent, and a downlink indicator showed a downlink message was received. The next column contained the aircraft call sign, followed by the text of the CPDLC message. The column on the right indicated the status of the message. The status could be one of three states: (1) message was still being constructed, (2) message had been sent, or (3) response had been received. The interface also included buttons allowing the controller to take actions on a message. IM information was sent from the Spacing List system to the Clearance Template where the message was automatically generated for controller. The controller could review the proposed message and then send the message if desired. (see Section 3.2.1 for further details). The Clearance Template and the associated fields are shown in Figure 3-3.

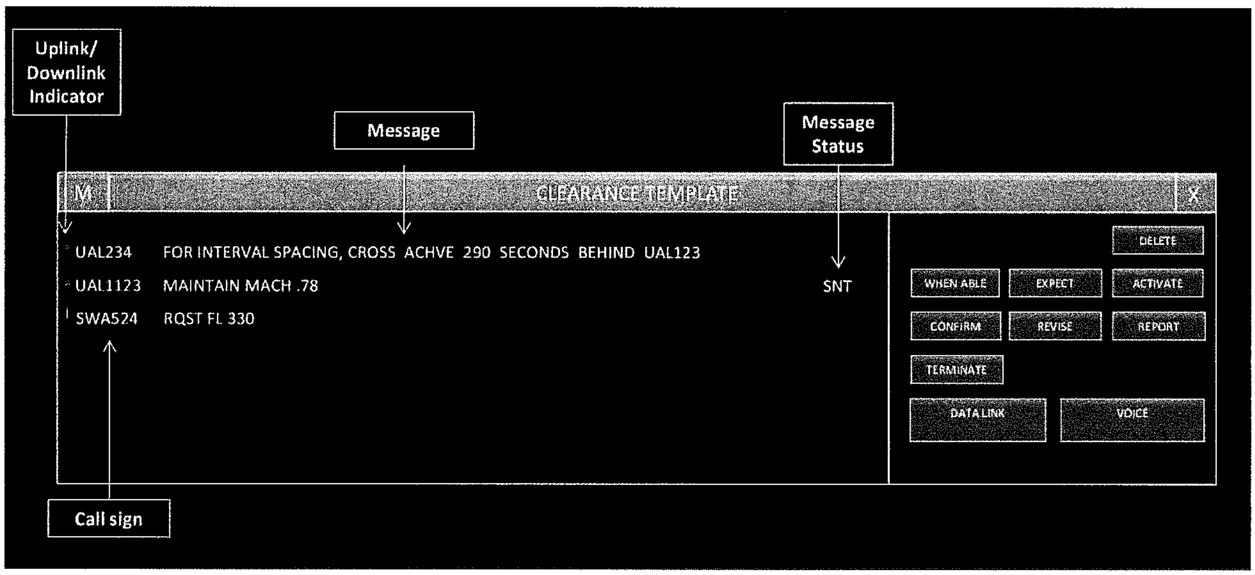


Figure 3-3. Clearance Template and the Associated Fields

3.1.1.3 Data Blocks

Changes to Data Blocks to include IM information and interactions were based on the Conceptual Use Case for Arrival Interval Management-Spacing and Ground Based Interval Management-Spacing (National User Team FAA ATO ERAM, 2012). Existing aircraft data blocks were modified to allow for IM and CPDLC operations. The first addition to the data block was an indication of availability of CPDLC. If an aircraft was CPDLC capable, a square was placed next to the aircraft call sign. Similarly, an indication of IM capability was added. This was shown by presenting the letters "FC" (indicating "FIM / IM Capable") in the fourth line of the data block. The Data Blocks are shown in Figure 3-4.

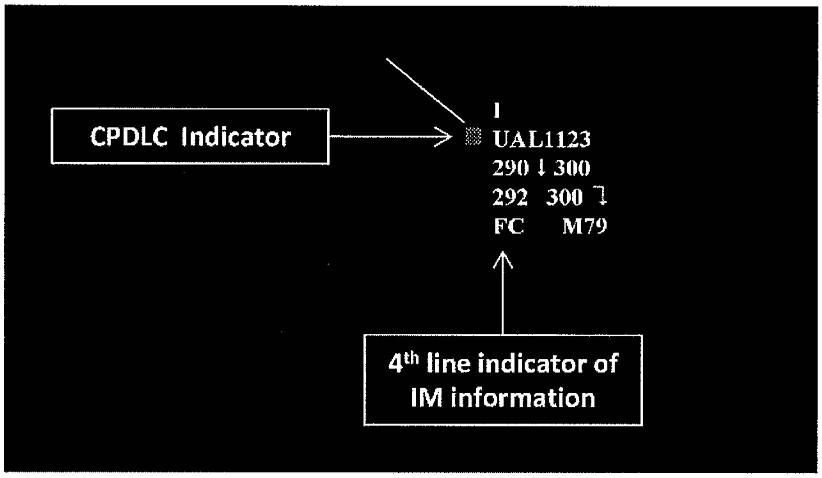


Figure 3-4. Data Block Presentation of IM Information

3.1.2 Flight Deck Workstation

3.1.2.1 Flight Deck

The Boeing 777 flight deck simulator consisted of a standard Boeing 777 flight deck layout as shown in Figure 3-5. The equipment included standard elements such as a MCP, two radio management panels, EICAS, a FMS with CDU interfaces, dual PFDs, dual NDs. The simulator also included a 180-degree out-the-window visual capability. New interfaces were added for IM (i.e., the CDTI and ADS-B Guidance Display [AGD]) and for CPDLC (i.e., new pages on the CDU).

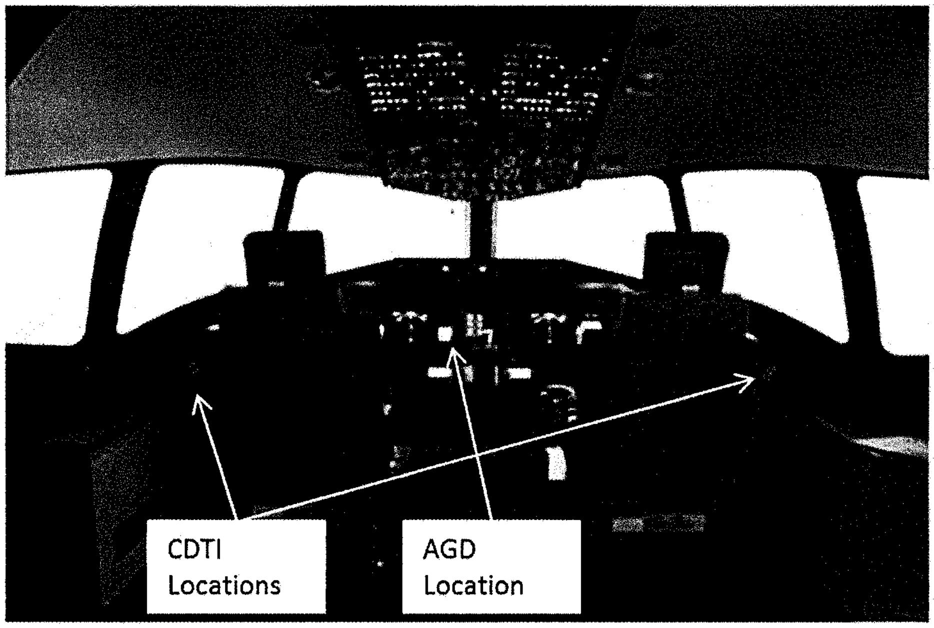


Figure 3-5. Boeing 777 Flight Deck Simulator

3.1.2.2 Cockpit Display of Traffic Information (CDTI)

The flight deck simulator was equipped with two CDTIs that were hosted on auxiliary displays: one at the captain's eleven o'clock position and the other located at the first officer's one o'clock position. The CDTI provided basic traffic information to the flight deck, and was used to set up IM as well as monitor IM operations. The CDTI used in this simulation was designed to allow for the integration, control, and operation of multiple ADS-B functions / applications in a seamless manner. The overall design philosophy is described in Stassen, Penhallegon, and Weitz (2010) and Estes, Penhallegon, and Stassen (2010). The CDTI is shown in

Figure 3-6. The original CDTI design described in those papers was updated in order to meet the requirements of the current simulation and to bring it in line with the current IM standards requirements (RTCA, 2011). This included adding a setup page that allowed for the entry of the required information for several of the different IM operational applications. The CDTI traffic display during IM setup is shown in Figure 3-7.

After the appropriate information had been entered into this setup page and the initiation requirements were met, the flight deck IM equipment provided an IM speed for the flight crew to fly. The flight deck IM equipment utilized an algorithm to provide the IM speeds so the flight crew could achieve the ASG at the achieve-by point. The algorithm used was based on the EUROCONTROL CoSpace algorithm (Hoffman, Ivanescu, Shaw, and Zeghal, 2003). New IM speeds were presented to the flight crew in 10 knot or greater increments to keep flight crew workload at a reasonable level but still deliver the ASG within the defined tolerance. ASGs issued by the controller were the precision type between 90 seconds and 250 seconds.

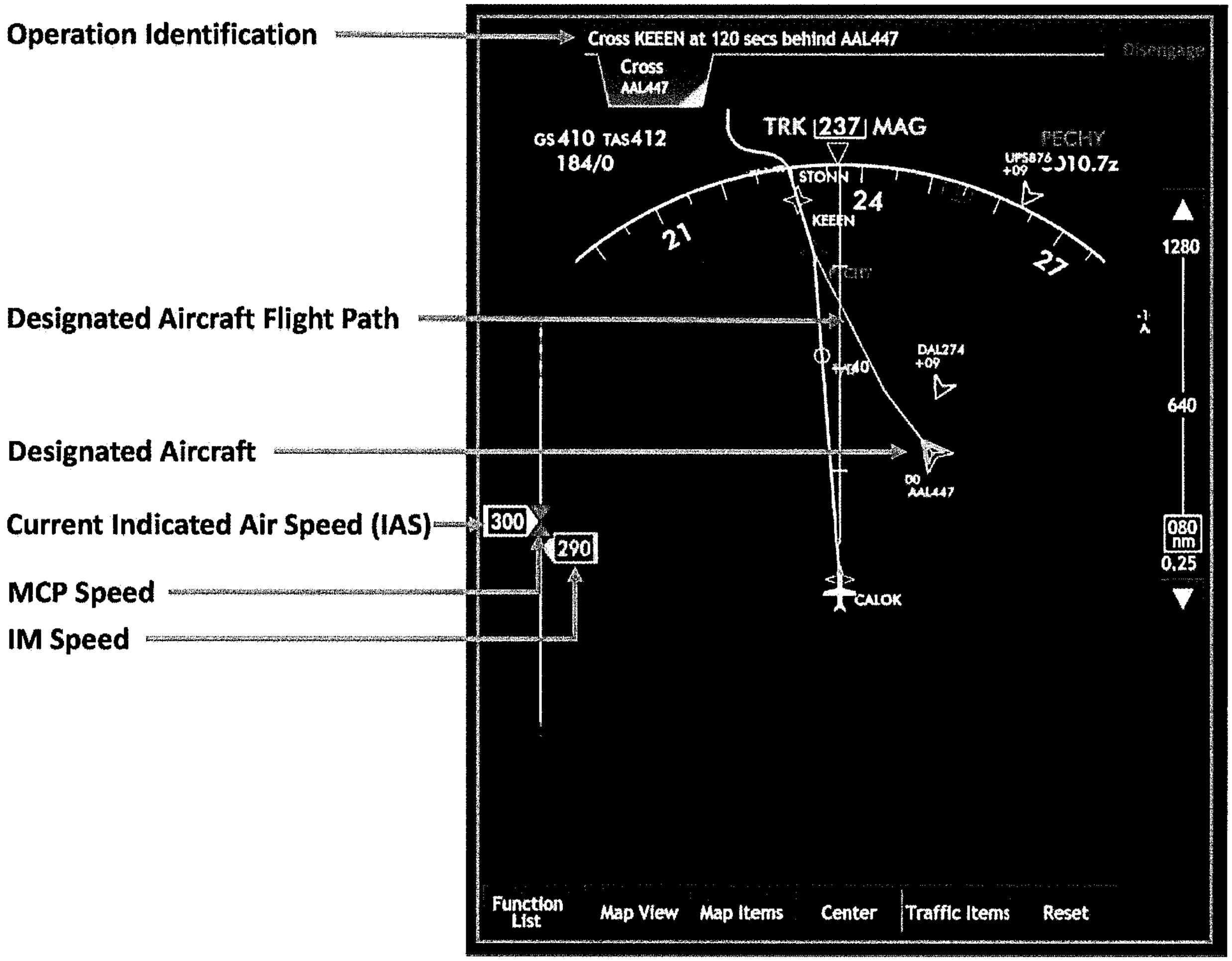


Figure 3-6. Cockpit Display of Traffic Information (CDTI) with Interval Management (IM) Engaged

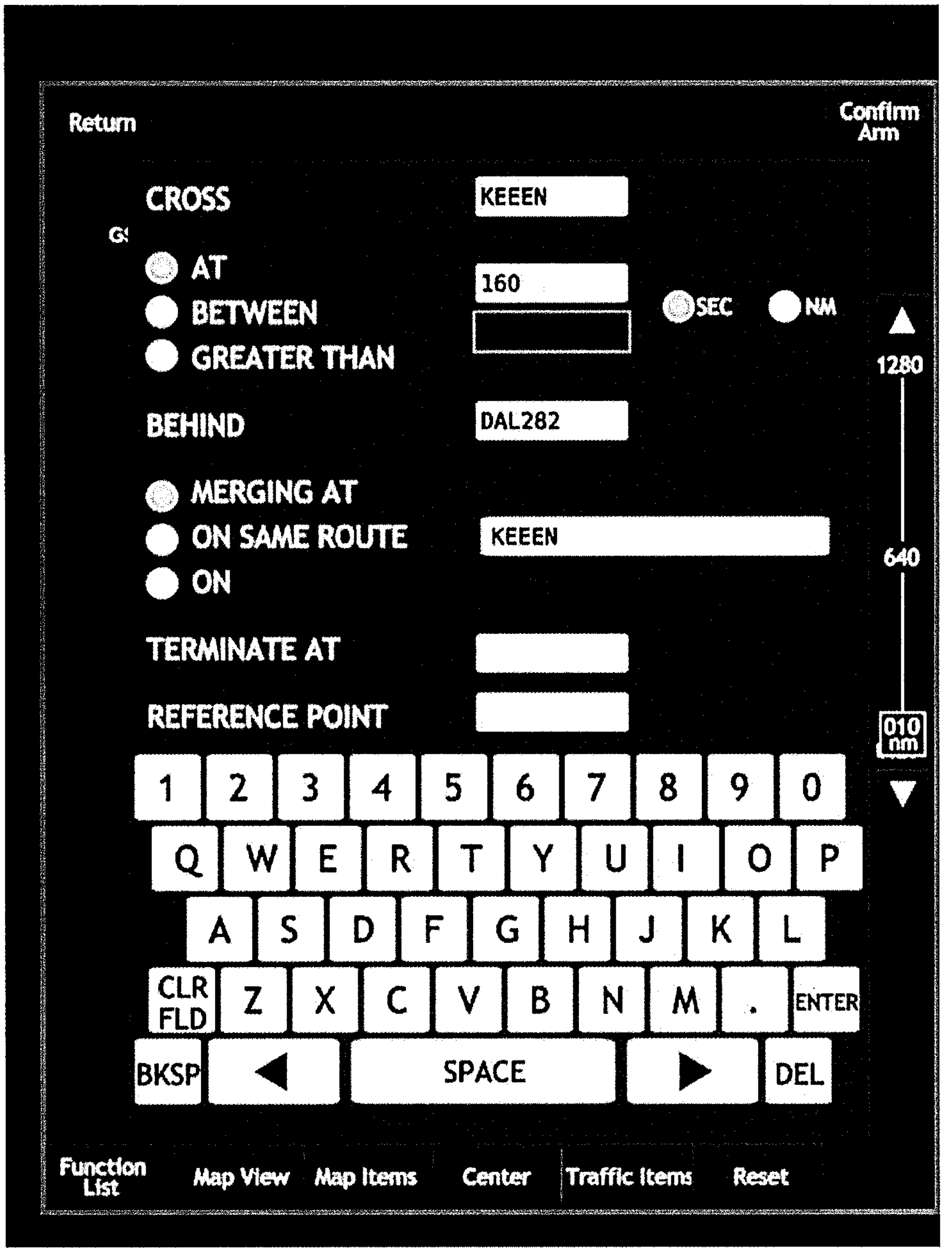


Figure 3-7. Cockpit Display of Traffic Information (CDTI) Interval Management (IM) Setup Page

3.1.2.3 ADS-B Guidance Display (AGD)

The AGD provided a forward field of view display of key IM information. The AGD was located between the left ND and the EICAS display. Four pieces of information were provided to the crew via the AGD: reference aircraft call sign, IM speed, the current in-trail time, and the ASG. The current in-trail time was defined as the number of seconds ago the reference aircraft was at the same distance from the achieve-by-point as ownship is now. As mentioned previously, the AGD was a display that was developed for this simulation. However, it is similar to AGDs used in past IM simulations (e.g., Bone et al., 2008) and contains information similar to that used in UPS aircraft certified for an initial implementation of IM (Penhallegon and Bone, 2014). It is also similar to that planned to be used by US Airways in their planned implementation of IM in 2014 (Huber, 2013, July 4). The AGD and the associated information are shown in Figure 3-8.

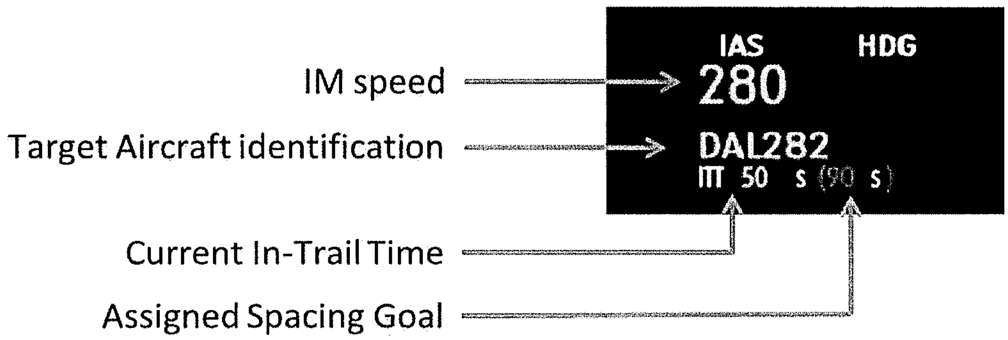


Figure 3-8. Automatic Dependent Surveillance-Broadcast (ADS-B) Guidance Display (AGD) and the Associated Information

3.1.2.4 Controller Pilot Data Link Communications (CPDLC) Display

Data communications were received through the CDU and notifications were displayed on the EICAS display. The implementation was similar to that in a Boeing 737 aircraft. This option represents a more challenging implementation than that where the EICAS is used, there are dedicated reply buttons, and there is a display with a cursor device (like in a Boeing 777 implementation). This implementation allowed for the collection of RCP data on a more challenging display implementation.

When a new message was received, the flight crew was notified by a "•ATC" visual advisory on the EICAS display and an aural chime. The message could be accessed by pressing the ATC button on the Multifunction CDU (MCDU) as shown in Figure 3-9.

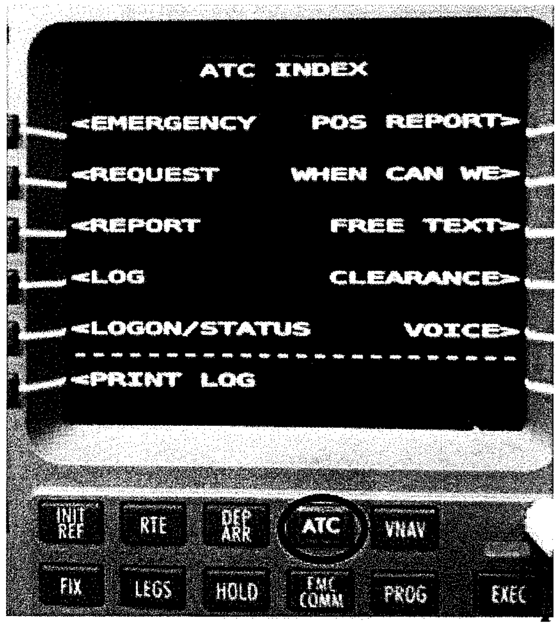


Figure 3-9. Multifunction Control and Display Unit (MCDU) ATC Index

After pressing the button, an available message will be shown as in Figure 3-10. Some of the messages were long enough that two pages were necessary to display the message and provide the reply options. The MDCU provided options for replying to the message (i.e., standby, reject, and accept) as well as to load the message into the flight deck IM equipment (i.e., "load") during the appropriate scenarios. The "log" option could be selected to show all messages that were received and sent by the flight crew.

Figure 3-10. Multifunction Control and Display Unit (MCDU) Displaying Uplinked IM Clearance

Options were also provided to initiate a message such as reporting being unable to continue IM. To do so, they also accessed the ATC index page by pressing the "ATC" button on the MCDU.

3.1.3 Pseudo-Pilot Workstation

Pseudo-pilots act as pilots for all aircraft other than the participant pilots' aircraft. This allows for the controller to manage a normal set of traffic. It also allows aircraft to maneuver based on ATC instructions, which is reflected on both the controller and flight crew displays. The pseudo-pilots for this simulation used an interface termed Simpilot. Simpilot allowed users to control multiple simulated aircraft simultaneously. It provided basic information about the aircraft (e.g., aircraft call sign, type) and allowed the user to control various aspects of the aircraft (e.g., heading, airspeed, altitude, route, communications frequency) and respond to controller instructions by entering commands. The interface was also adapted specifically for this simulation by adding the ability to respond to CPDLC messages. In addition, the pseudo-pilots were able to initiate IM according to the clearance from the controller. The interface is shown in Figure 3-11.

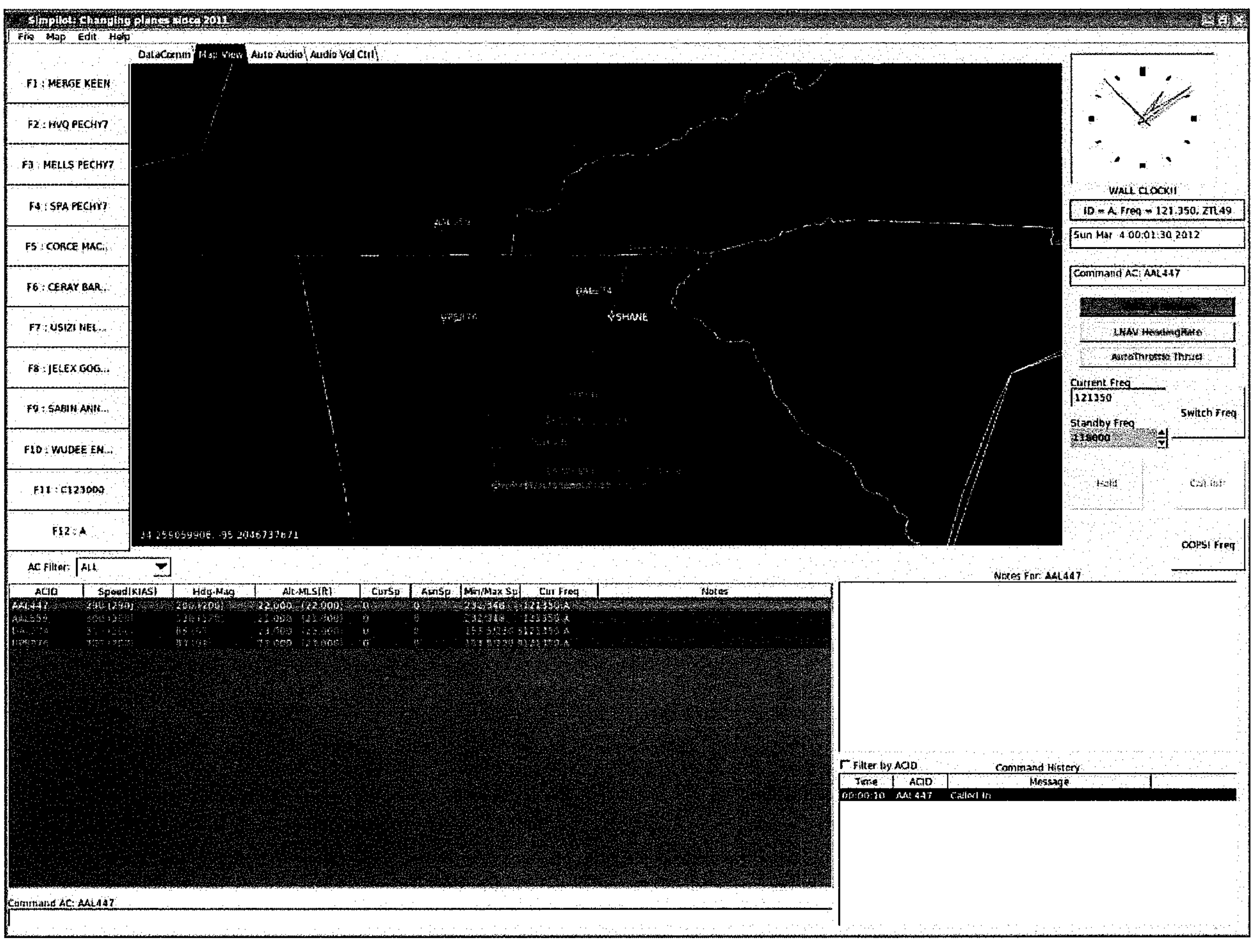


Figure 3-11. Simpilot / Pseudo-Pilot Interface

3.1.4 Airspace

The airspace modeled for this simulation was Atlanta Center, sector 49, with some modifications to fit the needs of the simulation. The sector was expanded to be approximately 80 by 100 miles and include altitudes of 10,000 to 24,000 feet. In order to achieve the trajectories needed for the IM operation within the one sector, aircraft flows for arrivals into Hartsfield-Jackson Atlanta International Airport (KATL) were modified to include three flows merging prior to the entry to terminal airspace. The flight paths of aircraft on the three merging flows were changed slightly from scenario to scenario according to the complexity of IM clearances for that scenario, but the general direction and timing of the flows remained the same. In addition to the arrival flows, some crossing streams were added in order to increase the number of aircraft to a realistic level. The addition of these particular crossing streams was one of the modifications made for this simulation. Crossing traffic was necessary for traffic counts but was undesirable if it created conflicts. The added altitude-separated streams reduced conflicts.

The participant flight crew always flew the KATL arrival, and flew through the sector twice during each scenario. After the first run, the flight crew was told by the participant Center controller to contact the Atlanta Approach controller. At this point, they were repositioned as a new aircraft outside of the Atlanta Center simulation sector in order to fly the arrival again. The flow that the participant flight crew followed was alternated among the three arrival flows depending on the scenario. The airspace and traffic flows are shown in Figure 3-12.

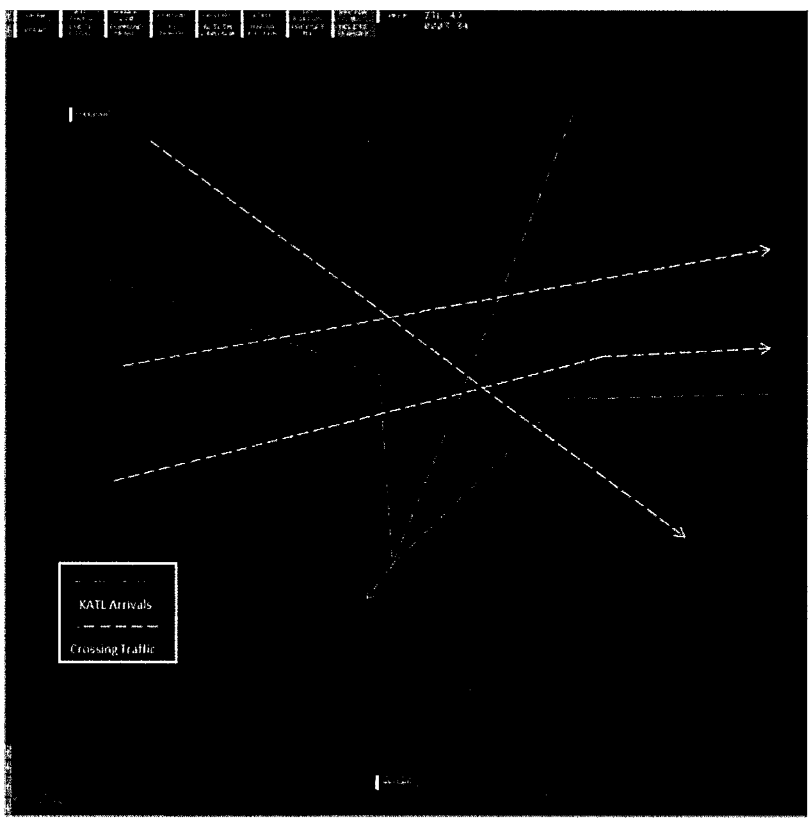


Figure 3-12. Simulated Airspace with Traffic Flows

3.1.5 Traffic

Traffic for the simulation included the participant aircraft along with other aircraft on the KATL arrival, and crossing traffic. Traffic levels were designed to represent a realistic airspace without increasing controller workload to unacceptable levels. At all times during the scenarios, there were between 10 and 16 aircraft under sector control. A subject matter expert consulted on the development of the scenarios to ensure traffic levels remained manageable. Equivalent traffic levels were used through the entire simulation to avoid workload differences between scenarios, with only changes to aircraft call signs and timing of flows between scenarios to avoid the same communication and task patterns. All aircraft flying into KATL in the simulation were either following ground-derived speed advisories or conducting IM. All aircraft were capable of receiving ground-derived speed advisories since it requires no additional flight deck capabilities. Fifty percent of the traffic was capable of IM. Fifty percent was chosen because it seemed to be a reasonable level of equipment in the expect implementation timeframe. The participant aircraft was always capable of IM. The crossing traffic was not capable of IM.

The scenarios were split between voice and CPDLC communications. In the voice scenarios, all traffic was only capable of voice communications. In the CPDLC scenarios, fifty percent of the aircraft were capable of conducting communications over voice alone. The other fifty percent were capable of conducting communications over CPDLC and voice. The participant aircraft was always capable of CPDLC in these scenarios. Fifty percent was chosen because it seemed to be a reasonable level of equipment in the expect implementation timeframe. It had also been shown in past work to be a point where CPDLC provided a significant contribution, even though higher levels (e.g., 100%) were preferred (Willems et al., 2010). It seemed reasonable to test in conditions that were favorable to CPDLC but not ideal conditions.

3.2 Interval Management (IM) and Controller Pilot Data Link Communications (CPDLC) Operations

3.2.1 Procedures

During IM operations, controllers decided whether to initiate IM based on automation suggestions. In order to initiate IM, the controller accessed the IM message by selecting either the IM information in the Spacing List or the "FC" indicator in the data block. By selecting the IM information in the Spacing List, the IM clearance for that aircraft appeared in the Clearance Template for review. By selecting the "FC" indicator in the data block, the IM fly-out menu was invoked and the IM message simultaneously appeared in the Clearance Template. The IM fly-out menu contained the IM message along with the relevant interactive buttons from the Clearance Template for sending messages. For CPDLC capable aircraft, the controller selected "DATA LINK" in either the Clearance Template or the IM fly-out menu to send the message. For non-CPDLC capable aircraft the controller communicated the clearance via voice and indicated such in the automation by selecting the "VOICE" button. The IM fly-out menu and Clearance Template are shown in Figure 3-13.

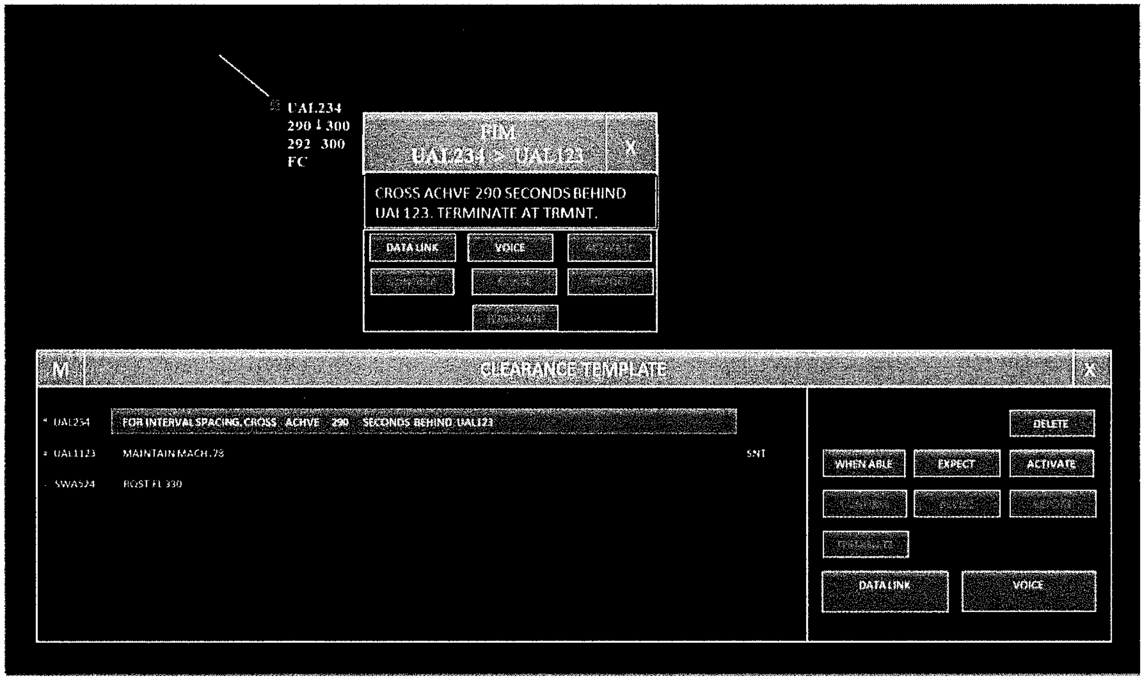


Figure 3-13. IM Fly-out Menu and Clearance Template

Once the IM clearance was sent via CPDLC, the IM Aircraft entered the IM (FIM) Pending (FP) state. This was indicated on the automation by displaying an "FP" in the fourth line of the data block. In addition, an "FP," the ASG, and reference aircraft call sign were displayed on the Spacing List. While aircraft were in the IM Pending state, ground-derived speed advisories could still be presented and acted upon by controllers to set-up the aircraft, as the flight crew was not yet actively conducting IM. After the flight crew responded to the CPDLC message with a "WILCO," the "FP" was replaced by "FA" to indicate that the aircraft was actively conducting IM. If IM initiation occurred using voice communications, the aircraft was considered IM Active once the read back of the IM clearance was complete and the controller selected the "VOICE" button, at which point the automation would display "FA."

The ground automation also supported terminating IM, and the controllers were able to terminate IM for any aircraft if they felt it was necessary. Controllers were instructed that IM would be procedurally terminated if they assigned a speed or heading to an aircraft conducting IM. Under these conditions, a termination message did not need to be sent to the IM aircraft. IM could also be terminated by sending the IM termination message. To access this message, the controller would select either the IM information in the Spacing List, or the "FA" indicator in the data block, and select "TERMINATE." The controller could include a speed instruction for the flight crew to fly upon termination.

The flight crew procedures are covered next. After receiving an IM clearance from ATC, flight crews followed the A-P procedure as defined previously, which means they accepted the clearance after doing a reasonableness check and then entered the information into the CDTI. After the appropriate requirements were checked and satisfied within the flight deck IM equipment, the first IM speed was presented to the flight crew via the CDTI traffic display and AGD. The flight crew determined whether flying the IM speed was feasible. If it was, the flight crew entered the IM speed into the MCP. The same feasibility check and entry of each IM speed was done for each new IM speed until the run was complete or termination was necessary.

The flight crews were instructed that if at any time termination was necessary, they were to press the "DISENGAGE" button on the CDTI. This could be necessary after either receiving a cancel IM communication from the controller or determining IM operations were no longer possible. If the flight crew initiated the termination, they were responsible for advising the controller that they were unable to continue IM operations. The flight crew was also instructed that when termination of IM occurs, procedures dictate that they return to their filed speed, unless advised otherwise by the controller.

Responsibilities of the flight crew were divided between the pilots as per normal, current day operations, with one participant acting as the Pilot Flying (PF) and the other participant acting as the Pilot Monitoring (PM). The PF was ultimately responsible for all aircraft control actions (e.g., speeds, altitudes) and was instructed to comply with all IM speeds, when possible. The PM was responsible for all communications with the controller and for setting up and arming IM.

3.2.2 Communications

Communications for the simulation included non-IM messages (e.g., speed, altitude, and procedures clearances / instructions) as well as IM messages (e.g., IM clearance and termination clearances / instructions). For CPDLC capable aircraft, controllers were asked to communicate solely using CPDLC, as long as the interface allowed. While this is not necessary in a real world implementation, it was desirable to have the controllers utilize CPDLC as much as possible so they could provide the appropriate feedback. It should be noted that traffic advisories and altimeter settings were not available in CPDLC for this simulation; therefore, these communications were done via voice. For any aircraft not capable of CPDLC, voice communications were conducted as per current day operations.

The IM messages were constructed based on the draft IM CPDLC message set established for CPDLC standards activities in RTCA SC-186 / EUROCAE WG-51 and RTCA SC-214 / EUROCAE WG-78 (RTCA and EUROCAE, 2013). The majority of the scenarios examined variations in the IM clearance. The IM clearance is expected to be the most complex IM message and therefore was an independent variable in the simulation. Specific IM clearances were developed to represent the complexity desired for each scenario. The first step in developing the messages was to extrapolate the entire IM clearance message set to all possible options. From that, varying levels of complexity were chosen. While several clearances of low complexity were available, it was determined that those clearances would not be used. The clearances were not used because similar messages had been used in previous simulations without issue, and they were not complex enough to enlighten breakpoint issues. There were also messages that were believed to go beyond that which would be acceptable with voice but may still be acceptable for CPDLC. These messages were determined to be worth examining to determine the point at which voice communication become too difficult. The final set of IM clearance chosen were relatively complex but were still believed to be possible over CPDLC and potentially over voice communications. The messages were not concatenated with other messages, and all elements of the IM clearance were directly loadable.

The IM clearance elements used in this simulation across all scenarios were the reference aircraft call sign, ASG, and achieve-by point. The reference aircraft IFPI was also used. It was varied across the scenarios to allow for additional complexity since it was cited as being the most challenging element in the IM clearance in past work (e.g., Bone, 2014). In order to remain consistent with the complexity of messages within each scenario, the routing information was not changed between the first and second run of the participant flight crew during a scenario. The only information that did change between runs was the ASG, and reference aircraft, as these were dependent on the ground scheduler. Examples of the IM clearances, and the associated complexity / number of elements, used during the simulation are included next. Note that when voice communications were used, the airline telephony designator (e.g., "United) was used for the reference aircraft call sign. When CPDLC was used, the airline three letter designator ("UAL") was used.

- Lower Complexity –"[For interval spacing], cross [KEEEN] [120] [seconds] behind [United 123], [merging at KEEEN]"
    - 6 elements
- Moderate Complexity – "[For interval spacing], cross [KEEEN] [120] [seconds] behind [United 123], on [MELLS] [PECHY7]"
    - 7 elements
- Higher Complexity – "[For interval spacing], cross [KEEEN] [120] [seconds] behind [United 123], on [WUDEE], [ENSOR], [KEEEN]. [Terminate at] [ENSOR]"
    - 10 elements

When IM was initiated using voice communications, controllers were asked to also use the advanced organizer "Interval spacing clearance available. Advise when ready to copy" to inform the flight crew that an IM clearance was going to be issued.

Finally, additional IM messages were included in a final scenario to get feedback on these additional messages. The messages included a "When able" IM clearance, which was designed to allow controllers to issue an IM clearance to an IM aircraft that is still out of ADS-B range of the reference aircraft. Once within range, the IM aircraft would notify ATC that IM has commenced. Samples are shown next.

- ATC clearance – "When able, for interval spacing, cross KEEEN 120 seconds behind United 123, merging at KEEEN. Report starting interval spacing."
- Flight crew notification upon starting IM – "Interval spacing behind United 123"

Another message included in the final scenario allowed controllers to inquire about the ASG given to an IM aircraft. A sample message and reply are shown next.

- ATC request – "Report assigned spacing interval behind United 123."
- Flight crew reply – "Assigned spacing interval 120 seconds behind United 123"

Finally, IM termination messages for both the controller and flight crews were included.

- ATC termination – "Cancel interval spacing."
- Flight crew termination – "Unable to continue interval spacing"

Since RCP was a topic of interest for the simulation, a decision had to be made about how to represent actual communications over CPDLC. It was determined that pilots would be allowed to have unlimited time to reply to the messages. This way any extreme times could be captured and compared against RCP180. It was also determined that since the technical performance is not normally a major contributor to the allocated time that a delay would not be introduced into the communications.

3.3 Participants

One controller and two pilots were scheduled for each two day session. Participant controllers were coordinated through FAA ANG-C1 and National Air Traffic Controllers Association (NATCA). Controllers were required to have actively controlled traffic within the preceding twelve months and have experience in the sector type simulated. A total of 10 controllers participated in the study from a variety of Air Route Traffic Control Centers (ARTCCs) with average experience of 16 years. During the simulation, controllers acted as Radar (R)-side controllers. The Data (D)-side role was not staffed.

Flight crews were recruited from a list of pilots who have expressed interest in participating in MITRE simulations. A total of 20 pilots, with an average of 13,348 flight hours, participated in the study. During the simulation, one pilot acted as the PF, and one pilot acted as the PM. The roles were not switched during the simulation.

One MITRE staff member acted as a pseudo-pilot for each simulation day. The pseudo-pilot participated in training sessions with each controller participant and was provided with simulation briefings and scripts.

3.4 Simulation Procedure

The first day of the two-day simulation, started with separate introductory briefings for the controllers and flight crews. Each participant was given a consent form and demographics questionnaire. Participants were then introduced to the IM and CPDLC concepts and briefed on their responsibilities, the interfaces they would be using, and the communications procedures.

At the conclusion of the introductory briefing, controller participants were taken to their workstation and allowed to familiarize themselves with the DSI workstation, set up their displays according to their preferences, and ask any questions about the workstation. The IM and CPDLC interfaces and procedures were then briefed to the controllers. Each controller participant completed two training runs independent of the pilot participants: one for airspace and CPDLC familiarization (no IM) and one for IM interface familiarization.

After the flight crews had been given the introductory briefing, the participants were brought to the flight deck simulator for familiarization and training on the various interfaces and procedures they would encounter during the data collection scenarios. Pilot participants completed 11 training scenarios, and a final training run took place with both pilots and controllers in order to familiarize them with the full simulation environment.

Once training was completed, three data collection runs were conducted on the first day. Each data collection run lasted approximately 40 minutes and post-scenario questionnaires were given after each scenario.

On the second day, participants were reminded of the procedures for the simulation. At the conclusion of the review, the remaining four data collection runs were completed. At the conclusion of the final data collection runs, participants were provided with a final questionnaire encompassing the entire simulation. Once they completed the final questionnaire, both controllers and flight crews were brought together for an informal debrief before they were released.

3.5 Experimental Design

Seven total data collection scenarios were presented to the controllers, with the participant flight crews flying through the airspace twice per scenario. Three scenarios contained no aircraft that were capable of CPDLC communications, and three contained fifty percent CPDLC capable aircraft. One additional scenario was run that also contained fifty percent CPDLC capable aircraft. Details on that scenario will be provided in this section.

Two independent variables were used. The first independent variable was IM clearance complexity with three levels: Lower (with 6 elements), Moderate (with 7 elements), and Higher (with 10 elements). The IM clearance complexity variations were used to determine different levels of acceptability for both voice and the two CPDLC implementations (i.e., direct versus manual load).

The other independent variable was communication method. For pilots this variable has three levels: CPDLC with Direct Load, CPDLC with Manual Load, and Voice with Manual Load. For controllers, this variable has two levels: voice and CPDLC. In the CPDLC scenarios, the ability of the flight crews to directly cross-load the IM information from the CPDLC system to the flight deck IM equipment was compared to manual loading procedures. During each CPDLC scenario, the participant flight crews used the direct load functionality on one run and manual load functionality on the other run. Voice scenarios always required the manual loading of the IM clearance information. Table 3-1 and Table 3-2 show the differences between the controller and flight crew variables.

Table 3-1. Controller Independent Variables

Communication Method	IM Clearance Complexity
Voice (100%)	Lower
	Moderate
	Higher
CPDLC (50%) and Voice (50%)	Lower
	Moderate
	Higher

Table 3-2. Flight Crew Independent Variable

Communication Method	IM Clearance Complexity
Voice with Manual Load	Lower
	Moderate
	Higher
CPDLC with Manual Load	Lower
	Moderate
	Higher
CPDLC with Direct Load	Lower
	Moderate
	Higher

The same traffic was used for each IM clearance complexity across CPDLC and voice scenarios (Scenario 1 had the same traffic as Scenario 4, Scenario 2 had the same traffic as Scenario 5, and Scenario 3 had the same traffic as Scenario 6) in order to make a direct comparison of communication method. The six comparison scenarios are shown in Table 3-3. A seventh scenario was used to examine the additional CPDLC IM messages that were not used during the core scenario operations (as noted in section 3.2.2). These messages were not included in the balanced design for the IM clearances but were included as an extra scenario to get participant feedback. The extra scenario is also shown in Table 3-3.

Table 3-3. Scenario Design

Scenarios								
Communication Method	**Lower IM Clearance Complexity**		**Moderate IM Clearance Complexity**		**Higher IM Clearance Complexity**		**Extra IM Messages**	
CPDLC	Scenario 1		Scenario 2		Scenario 3		Scenario 7	
	Traffic Set 1		Traffic Set 2		Traffic Set 3		Traffic Set 4	
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Voice only	Scenario 4		Scenario 5		Scenario 6			
	Traffic Set 1		Traffic Set 2		Traffic Set 3			
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2		

Each participant experienced the same set of data collection scenarios (in a repeated measures design). The order of the scenarios was counter balanced across participant groups. For CPDLC scenarios, the direct load function was also counter balanced across flight crew participants. Table 3-4 shows the scenario presentation order for each participant group. In the table, the scenario number is first, followed by the run number for the flight crew (i.e., 2-1 stands for scenario 2, run 1 for the flight crew).

Table 3-4. Run Presentation Order

	Run Order											
Crew#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	2-1 Mod	2-2 Mod	3-1 High	3-2 High	6-1 High	6-2 High	1-1 Low	1-2 Low	4-1 Low	4-2 Low	5-1 Mod	5-2 Mod
2	3-1 High	3-2 High	1-1 Low	1-2 Low	5-1 Mod	5-2 Mod	4-1 Low	4-2 Low	6-1 High	6-2 High	2-1 Mod	2-2 Mod
3	1-1 Low	1-2 Low	4-1 Low	4-2 Low	2-1 Mod	2-2 Mod	6-1 High	6-2 High	5-1 Mod	5-2 Mod	3-1 High	3-2 High
4	4-1 Low	4-2 Low	6-1 High	6-2 High	3-1 High	3-2 High	5-1 Mod	5-2 Mod	2-1 Mod	2-2 Mod	1-1 Low	1-2 Low
5	6-1 High	6-2 High	5-1 Mod	5-2 Mod	1-1 Low	1-2 Low	2-1 Mod	2-2 Mod	3-1 High	3-2 High	4-1 Low	4-2 Low
6	5-1 Mod	5-2 Mod	2-1 Mod	2-2 Mod	4-1 Low	4-2 Low	3-1 High	3-2 High	1-1 Low	1-2 Low	6-1 High	6-2 High
7	2-1 Mod	2-2 Mod	3-1 High	3-2 High	6-1 High	6-2 High	1-1 Low	1-2 Low	4-1 Low	4-2 Low	5-1 Mod	5-2 Mod
8	3-1 High	3-2 High	1-1 Low	1-2 Low	5-1 Mod	5-2 Mod	4-1 Low	4-2 Low	6-1 High	6-2 High	2-1 Mod	2-2 Mod
9	1-1 Low	1-2 Low	4-1 Low	4-2 Low	2-1 Mod	2-2 Mod	6-1 High	6-2 High	5-1 Mod	5-2 Mod	3-1 High	3-2 High
10	4-1 Low	4-2 Low	6-1 High	6-2 High	3-1 High	3-2 High	5-1 Mod	5-2 Mod	2-1 Mod	2-2 Mod	1-1 Low	1-2 Low

(shaded)	Voice with Manual Load	Low	Lower IM clearance complexity
	CPDLC with Manual Load	Mod	Moderate IM clearance complexity
	CPDLC with Direct Load	High	Higher IM clearance complexity

3.6 Hypotheses

The hypotheses are listed below. They are organized around the four main topic areas of the simulation.

3.6.1 Communications

3.6.1.1 IM Message Set

Are the CPDLC messages defined for IM the necessary messages for both pilots and controllers?

M-1 The messages currently defined for IM using CPDLC are those that are necessary for the conduct of IM over CPDLC.

M-2 The messages currently defined for IM using CPDLC are those that are necessary for the conduct of IM over voice.

Are other messages needed?

M-3 Messages other than those currently defined for IM using CPDLC are not necessary for CPDLC communications.

M-4 Messages other than those currently defined for IM using CPDLC are not necessary for voice communications.

Are pilots and controllers able to understand and communicate effectively with these messages?

M-5 Pilots will sufficiently understand the terminology utilized in the IM CPDLC messages such that they are able to conduct IM operations.

M-6 Controllers will sufficiently understand the terminology utilized in the IM CPDLC messages such that they are able to conduct IM operations.

What limitations are there with voice communications for IM which will necessitate CPDLC?

M-7 Lower complexity IM clearances over voice will be found acceptable.

M-8 Moderate complexity IM clearances over voice will be found acceptable.

M-9 Higher complexity IM clearances over voice will be found unacceptable.

M-10 Lower complexity IM clearances over CPDLC will be found acceptable.

M-11 Moderate complexity IM clearances over CPDLC will be found acceptable.

M-12 Higher complexity IM clearances over CPDLC will be found acceptable.

3.6.1.2 **Required Communication Performance**

Is the flight crew reaction time acceptable for CPDLC under the scenarios being investigated?

RCP-1 Flight crew reaction time is sufficient for IM clearances under all IM clearance complexity conditions.

Given that a controller may not receive a pilot response to a clearance for up to 180 seconds, what is the impact on controller situation awareness and workload?

RCP-2 The RCP of 180 currently defined for IM CPDLC messages does not increase controller workload to an unacceptable level.

3.6.2 Procedures

Should the flight crew procedure be A-P or P-A?

P-1 The A-P method of IM clearance acceptance is sufficient under all IM clearance complexity conditions.

What is the impact of an A- P procedure on controller workload?

P-2 The A-P method of IM clearance acceptance does not increase controller workload to an unacceptable level.

Can the flight crew and controller transition easily to voice in a non-normal situation?

P-3 Under conditions where necessary, the process of transitioning out of CPDLC into voice communications will be acceptable.

Is a mixed voice and CPDLC environment when conducting IM acceptable to controllers?

P-4 A mixed voice and CPDLC environment when conducting IM is acceptable to controllers.

3.6.3 Interfaces

Can the flight crew and controller perform his / her task safely and efficiently with the specified interface?

- I-1 For pilots, Lower complexity IM clearances over voice with manual message loading will be found acceptable.
- I-2 For pilots, Moderate complexity IM clearances over voice with manual message loading will be found acceptable.
- I-3 For pilots, Higher complexity IM clearances over voice with manual message loading will be found unacceptable.

- I-4 For pilots, Lower complexity IM clearances over CPDLC with manual message loading will be found acceptable.
- I-5 For pilots, Moderate complexity IM clearances over CPDLC with manual message loading will be found acceptable.
- I-6 For pilots, Higher complexity IM clearances over CPDLC with manual message loading will be found acceptable.

- I-7 For pilots, Lower complexity IM clearances over CPDLC with direct message loading will be found acceptable.
- I-8 For pilots, Moderate complexity IM clearances over CPDLC with direct message loading will be found acceptable.
- I-9 For pilots, Higher complexity IM clearances over CPDLC with direct message loading will be found acceptable.
- I-10 For controllers, the IM Spacing List and the clearance Template will be acceptable interfaces for conducting IM operations using CPDLC.

3.7 Data Collection

Four methods of data collection were used for this simulation: questionnaires, system recorded data, observation, and final debriefs. Four types of questionnaires were used, including:

1. **Demographics:** Upon arrival, participants were asked to fill out a demographics questionnaire. This addressed participants' experience. (Appendix A)
2. **Post- Scenario:** After each scenario, participants were asked to fill out a questionnaire based on the scenario just experienced. All Post-Scenario questionnaires included the Bedford Workload Rating Scale (BWRS) along with additional rating scale questions. Pilot participants completed a Post-Scenario questionnaire after each run during a scenario (two runs per scenario) (Appendix B).
3. **Post-Simulation:** A series of rating-scale questions were used to provide subjective measurements of various items taking the entire simulation into account. (Appendix C)
4. **Debrief:** Open ended questions in a discussion format were used between participants and experimenters after the simulation was concluded.

Participants were asked to provide subjective feedback on IM operations, communications, displays, human factors (e.g., workload and situation awareness), simulation realism, and integration issues with IM and CPDLC.

Data for objective metrics was automatically recorded by the simulation platform and included:

- Loading of audio frequency and Push-To-Talk (PTT) events.
- Recording of audio frequency.
- Time between controller up-link of an instruction and pilot down-link of response.

Additionally, each participant was observed during each data collection run. During the run, human factors observers took general notes as well as recorded any anomalies that may have affected the data collection.

3.7.1 Rating Scales

Most response-scale questions consisted of a seven point scale along with an opportunity for open-ended comments. Most of the questions were presented as a statement, and participants were asked to rate their level of agreement. Ratings that fall between one and three on the seven point scale are interpreted as "disagree," ratings of four are interpreted as "neutral," and ratings of five to seven are interpreted as "agree." Figure 3-14 shows an example of the seven point scale used in the questionnaires. Other questions were open response or yes / no.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Figure 3-14. Sample Seven Point Scale

The BWRS was also used. It is modeled after Cooper-Harper (Gawron, 2008). It is a ten-point rating scale designed to identify the operator's spare mental capacity while completing a task. In this simulation, the BWRS was provided to participants after every run in the Post-Scenario questionnaire to measure overall perceived workload in the run just experienced. The BWRS is contained in the Post-Scenario Questionnaires located in Appendix B.

4 Results

4.1 Analysis Methods

4.1.1 Subjective

The subjective results are based on responses to the rating scales, the informal debrief, and questions from both the post-scenario and post-simulation questionnaires. Participants were asked to provide subjective feedback regarding the concept for both IM and CPDLC along with procedures and interfaces for both. Participants were also asked questions specific to the IM clearances used in the simulation.

Subjective rating results are summarized as frequency counts and presented with the mean for all responses when the question contained the seven point response scale. The frequency count is presented as a fraction with the number of a particular response as the numerator, and the total number of responses to the question as the denominator. Subjective results are from the post-simulation questionnaire unless otherwise specified. Relevant comments included in the open ended response portion of a question are reported along with those made in the debrief discussion and events noted by the observers. Graphs of frequencies are provided for particular responses that exhibited high variability. For responses to questions with the seven-point scale, the following legend explains the notation on the charts (Figure 4-1). Responses are shown as tally marks along the scale and are placed above the bins that correspond to the rating along the scale. Means are shown as the green point along the scale and the confidence interval on either side of the mean shows the 95 percent probability that the population mean lies within the bounds of the sample mean.

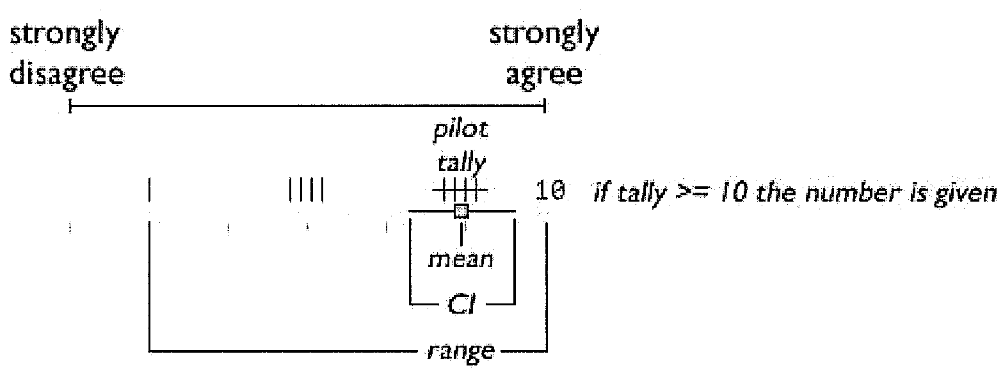


Figure 4-1. Legend for Charts of Responses to Questions with a Seven-Point Scale

For pilot participants, three analyses were performed to assess the impact of the independent factors (message complexity [Lower, Moderate, and Higher] and communication method [Voice with Manual Load, CPDLC with Manual Load, and CPDLC with Direct Load]) on subjective feedback received through the post scenario questionnaire.

1. Repeated measures ANOVA to assess the impact of the independent factors on perceived complexity of the messages (see Section 4.4.1.2).
2. Repeated measurers ANOVA to assess the impact of the independent factors on perceived workload (see Section 4.4.3).
3. Repeated measures MANOVA to assess the impact of the independent factors on agreement with various statements regarding the messages and the IM operation.

For number 3, the omnibus MANOVA result for this analysis is presented here. The repeated measures MANOVA found significant main effects (Wilks' Lambda) for complexity [F(18,60)=1.997 p=.024], communication method [F(18,60)=2.270 p=.009] and the interaction of complexity and communication method [F(36,256.565)=1.690 p=.011]. This omnibus result suggests that complexity and communication method impact the pilots' feedback about the operation. Individual univariate results are discussed in the appropriate sections.

The same three analyses were performed for controllers to assess the impact of the independent factors (message complexity [Lower, Moderate, and Higher] and Communication Method [Voice and CPDLC]) on subjective feedback received via the post scenario questionnaire.

For number 3, the omnibus MANOVA result for this analysis is presented here. The repeated measures MANOVA found a significant main effect (Wilks' Lambda) for communication method [F(9,1)=613.896 p=.031] only. This omnibus result suggests that the communication method impacts the controllers' feedback about the operation, while clearance complexity may not. Individual univariate results are discussed in the appropriate sections.

On univariate analysis where the assumption of sphericity was violated, the Greenhouse-Geisser correction was used. For all comparisons, significance is reported at the .05 level. For all tests that revealed statistical significance, the results are provided.

4.1.2 Objective

Data for the objective results were recorded by the simulation platform and included: interface interactions for both controllers and pilots, time stamp of CPDLC messages sent and responses, number of PTT events, and time spent on frequency. Transcripts of all voice communications were also collected and used to identify communication errors that occurred between controller and pilot participants. Repeated measures ANOVAs were run to assess the impact of the independent factors on various objective measures. For all comparisons, significance is reported at the .05 level. For all tests that revealed statistical significance, the results are provided.

4.2 Interval Management (IM)

Results were mixed (M=4.7, SD=1.8) when controllers were asked if IM is compatible with current operations (Figure 4-2). The controller with a neutral reply said it will be better when almost all aircraft are equipped. Those that disagreed provided different reasons related to trust, temporal demands, and difficulty keeping the sequence.

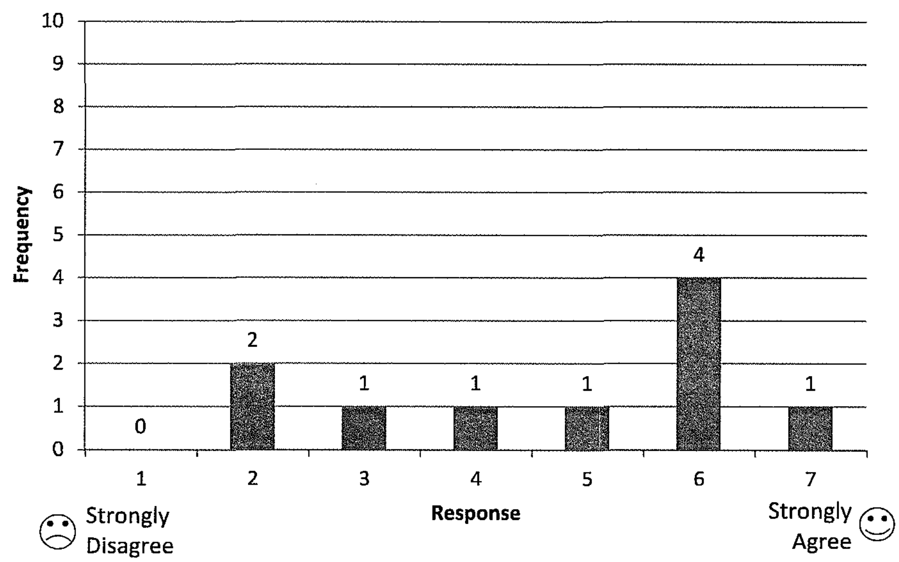


Figure 4-2. Controller Responses to "[IM] is compatible with current ATC operations"

Results were mixed (M=4.4, SD=1.6) when controllers were asked if they were confident that the spacing being maintained by IM aircraft would remain outside of minimum separation (Figure 4-3). One controller that agreed with the statement commented that he was confident as long as flight crews give a verbal warning when IM was terminated, and one controller who disagreed with the statement commented that confidence in IM increased over time during the simulation.

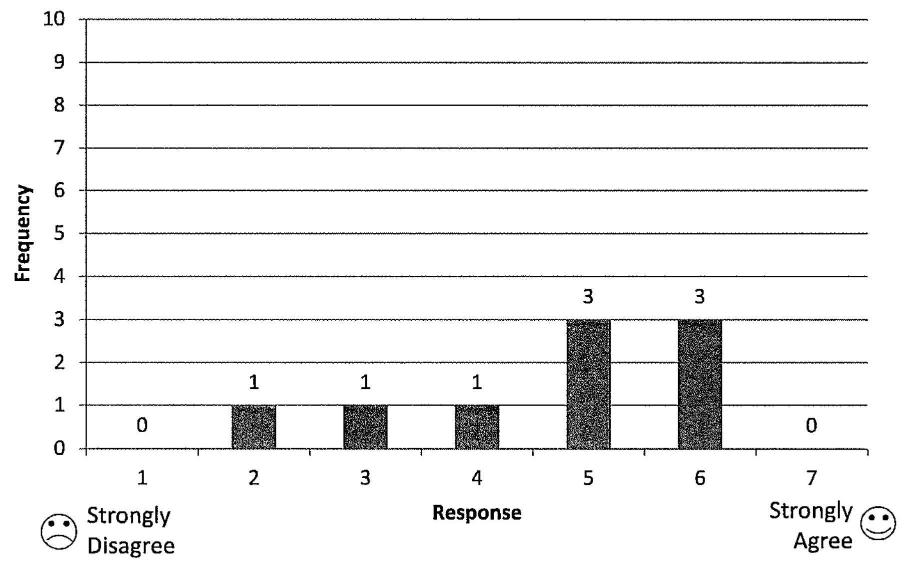


Figure 4-3. Controller Responses to "I was confident that the spacing being maintained by the [IM] aircraft would remain outside my separation responsibility"

Controllers were also asked about their confidence in IM aircraft in achieving the ASGs and a majority (9/10; 90%) of controllers reported being confident, though two controllers commented that in the real world their confidence may not be as high (including the controller that disagreed with this statement) (M=5.7, SD=1.3).

A majority (7/10; 70%) of controllers reported that it was acceptable to retain responsibility for separation during IM operations, and two that did not agree commented that the pilots should assume responsibility for separation with the reference aircraft while conducting IM (M=5.0, SD=2.2). A majority (7/10; 70%) also reported that it was difficult to control traffic in a mixed environment in which some aircraft were conducting IM and some were being assigned ground-derived speeds. Comments from two controllers indicate concerns that the length of some of the IM clearances take up too much frequency time. Two controllers commented that they did not trust ground system recommended speeds and IM to work together efficiently to avoid separation violations. One controller indicated a concern using IM in the real world with more complex situations. When asked if IM is operationally acceptable, the majority (9/10; 90%) of controllers agreed, and the one controller that did not agree cited the length and complexity of the IM clearances as the main reason (M=5.6, SD=2.0).

Pilots were also asked if IM is compatible with current flight deck operations. The majority (14/20; 70%) agreed with this statement (M=5.2, SE=1.6). Two pilots that agreed commented that the use of CPDLC would be a requirement for conducting IM. When asked if IM is operationally acceptable, the majority (16/20; 80%) of pilots agreed (M=5.9, SD=1.8).

4.3 Controller Pilot Data Link Communications (CPDLC)

When controllers were asked if it was difficult to control traffic in a mixed environment in which some aircraft are capable of CPDLC and some are capable of only voice, the majority (8/10; 80%) responded that it was not difficult. The two that replied that the mixed environment did cause difficulties commented that it was difficult for them to not automatically communicate over voice, and one was concerned CPDLC would lead to less attention to detail in the communications.

When asked if they ever wanted to revert to voice communications with an aircraft that was capable of CPDLC, half of the controllers (5/10; 50%) responded "yes." Of those that responded "yes," two commented that terminating IM is time critical and therefore should be conveyed using voice communications. One commented that it was habit to revert to voice. Another controller commented that the difficulty of using the interface made it easier to communicate over voice. The final controller did not like the wait associated with receiving a response to a CPDLC message.

When asked the same question, the majority of pilots (16/20; 80%) responded that at some point in the simulation, they felt the need to revert to voice communications. Comments indicate that they contacted ATC over voice to either let them know of problems with the CDTI when trying to enter the IM information (common problems included misspelling or mistyping waypoints or arrival routes), or some other problems such as terminating IM when the speeds were unacceptable (this case only happened in the extra scenario), or clarifying messages that seemed to be contradictory. The potentially contradictory messages were instances in which ATC sent a speed to fly followed by an IM clearance. Pilot comments indicate that they contacted ATC to clarify whether to fly the assigned speed or initiate IM.

After each scenario involving CPDLC, participants were also asked about the acceptability of all non-IM CPDLC messages, and the majority of the controller responses (29/30; 97%), as well as the majority of pilot responses (87/89; 98%) rated them as acceptable across all CPDLC scenarios.

4.4 Interval Management (IM) and Controller Pilot Data Link Communications (CPDLC)

4.4.1 Communications

4.4.1.1 General Communications

All communications that occurred over the voice frequency were recorded during the simulation, and transcripts were made in order to find and classify any communication errors that occurred between the controller and pilot participants. Communication errors were classified into five categories with one additional category that was not considered to be a communication error, but rather request for clarification. The five categories of errors included the following.

- Non-Responsive – When either the controller or pilot participants did not respond to a communication intended for them
- ATC Execution – When the controller made an error in the communication to the flight crew
- TPCS – When either the controller or pilot participants mistook call signs, stole a clearance intended for another aircraft, or asked for clarification of the call sign of the reference aircraft
- Readback – When the pilot participants read back incorrect information
- Request for Repeat – When either the controller or pilot participants requested a repeat of the previous communication

Throughout the entire simulation, communications between the controller and pilot participants totaled 1115 communications. These communications represent the total number of opportunities for communication errors to be made. Table 4-1 shows the number of each type of communication error and Requests for Clarification during the entire simulation.

Table 4-1. Total Communication Issues

Errors					Other
Non-Responsive	ATC Execution	TPCS	Readback	Request for Repeat	Request for Clarification
13	9	10	7	18	20

The following bullets provide more details on the errors and the Requests for Clarification.

- Non-Responsive Error – One of 13 (8%) was related to the IM clearance. It occurred in the Voice Lower complexity clearance condition. The majority of the other non-responses were related to more routine communications such as frequency changes or altimeter settings and mainly occurred across the voice conditions.
- ATC Execution Error – Seven of 9 (78%) were related to the IM clearance. The majority of the errors (5/7; 71%) were related to the reference aircraft IFPI. Four of the 7 (57%) were in the Voice Moderate, and 3 of the 7 (43%) were in the Voice Higher complexity clearance conditions.
- TPCS Error – Five of 10 (50%) were directly related to the IM clearance. Of those 5, one (20%) was committed by a controller who used the wrong call sign for the recipient / IM aircraft. The other four (80%) were committed by the pilots and were related to the airline telephony designator (e.g., "Brickyard") not closely matching the airline three letter designator (e.g., "RPA") on the CDTI traffic display. Either the flight crew asked for confirmation of the three letter designator or read back an incorrect three letter designator.
- Readback Error – All (7/7) were related to the IM clearance. Four of 7 (57%) were related to the reference aircraft IFPI. Of those 4, all were in the Voice Higher complexity clearance condition. The other 3 of 7 (43%) were related to TPCS (but not counted as part of the TPCS Errors). Of those 3, all were in the Voice Lower complexity clearance condition.
- Requests for Repeat Error – Three of 18 (17%) were committed by the pilots and were related to the IM clearance. Two of the three (67%) were related to the reference aircraft IFPI. All three were in the Voice Higher complexity clearance condition.
- Requests for Clarification – All (20/20) were committed by the pilots and were related to the IM clearance. Sixteen of 20 (80%) were related to the reference aircraft IFPI. Of those 16, all occurred in the Voice Higher complexity clearance condition.

All five error categories and one clarification category were combined to calculate the total number of communication issues. A repeated measures ANOVA was run to assess whether significant differences were present. The ANOVA revealed main effects for complexity [$F(2,18)=5.500$ $p=.014$], communication method [$F(1,9)=30.752$ $p=.000$] and an interaction of complexity and communication method [$F(2,18)=5.604$ $p=.013$]. The pairwise comparison for complexity revealed that there were more errors for the Higher ($M=2.150$, $SE=.454$) than there were in the Moderate ($M=.600$, $SE=.163$) complexity conditions. The pairwise comparison for communication method revealed that there were more errors for Voice ($M=2.300$, $SE=.300$) than there were for CPDLC ($M=.267$, $SE=.097$). This result is to be expected if for nothing other than more opportunities for errors to occur over voice, as the only issues possible over CPDLC were clarifications to clearances that seemed to be contradictory to one another (e.g. ATC sends a speed, followed by IM clearance and the flight crew inquires as to which clearance to follow). Figure 4-4 shows the relationship between complexity and communication method.

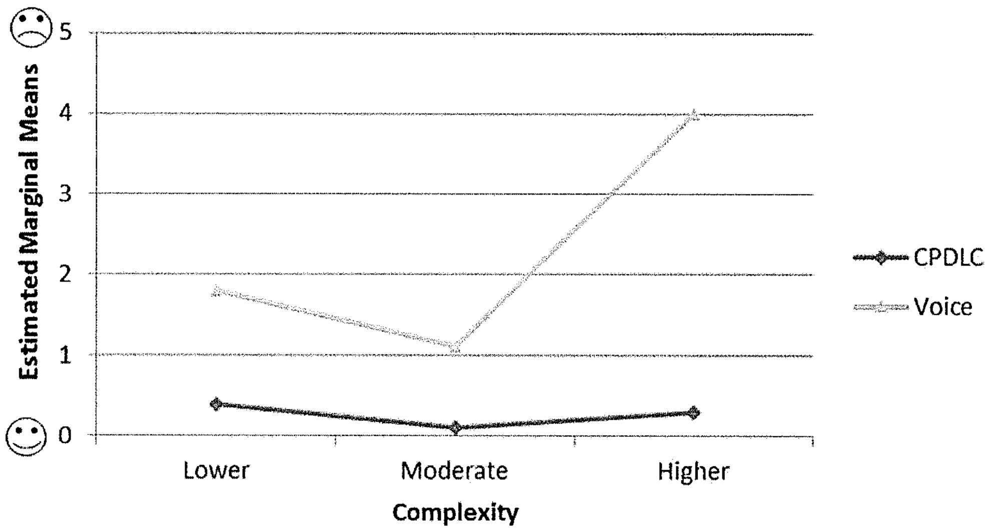


Figure 4-4. Relationship between Complexity and Communication Method for Communication Issues

After each scenario, pilots were asked if there were any follow-up communications necessary for the IM clearance and responses were mixed. In general, pilots did not find follow-up communications necessary. The Voice conditions had more follow-up communications in general (48 cases). The Higher complexity voice communications condition had the most (28 cases). Pilot responses are shown in Figure 4-5.

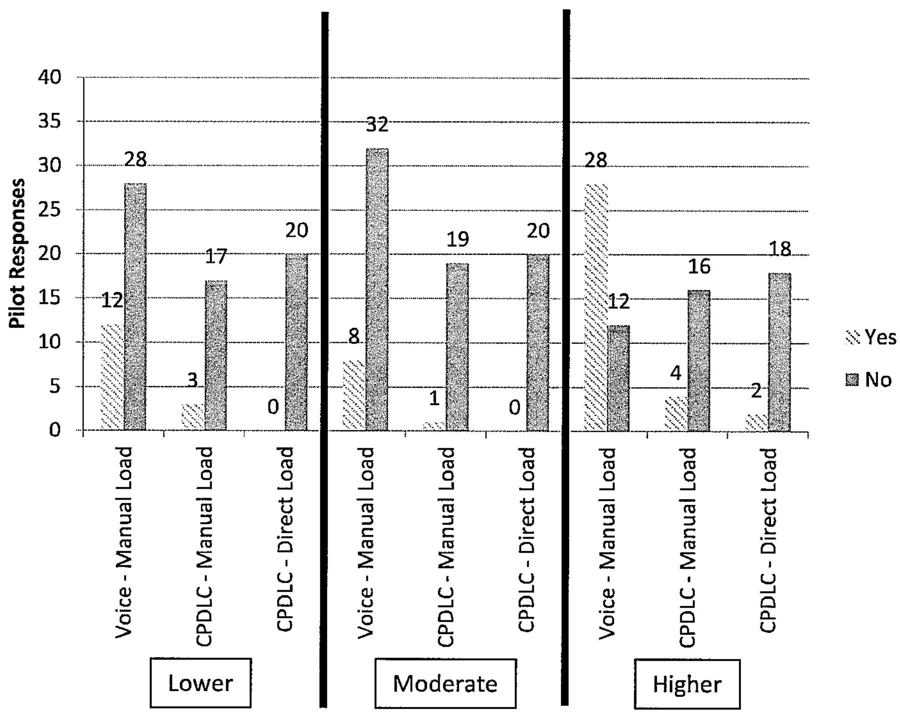


Figure 4-5. Pilot Responses to "Were there any follow-up communications necessary for the [IM] clearance?"

4.4.1.2 Interval Management (IM) Clearance

Participants were asked whether "The [IM] Clearances were phrased well." Controller results were mixed (M=4.4, SD=1.7) (Figure 4-6). Five controllers were neutral or disagreed, four of whom commented that the messages need to be shortened. The other five controllers agreed, but one still commented that the messages could be shortened. The majority (19/20; 95%) of pilots agreed (M=6.3, SD=1.0).

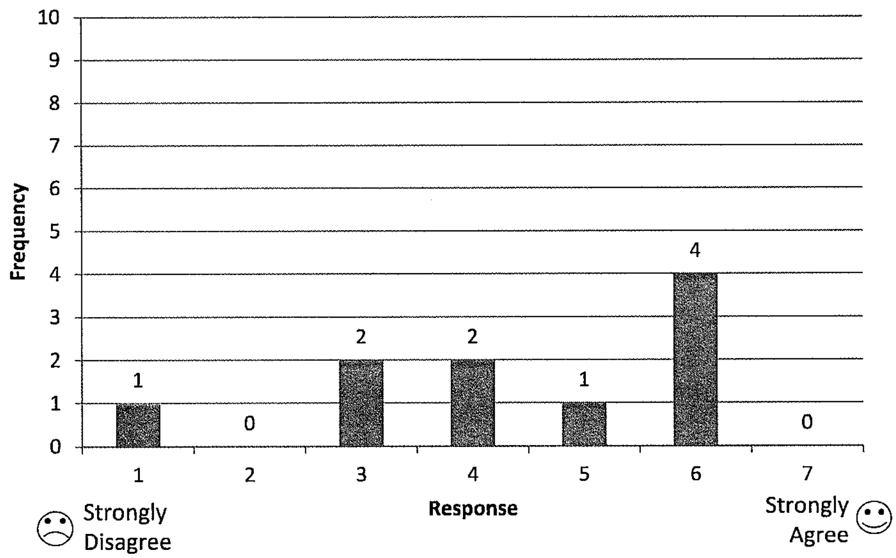


Figure 4-6. Controller Responses to "The [IM] clearances were phrased well"

After each scenario, participants were asked "Did any particular elements of the [IM] Clearance cause difficulties?" Overall, controllers reported more difficulties in the Higher and Lower complexity IM clearances but fewer difficulties for the Moderate level of complexity (Figure 4-7). However, the majority of the pilots only reported difficulty with the Higher complexity IM clearances with Voice with Manual Load (Figure 4-8). Four comments from controllers indicate that the reference aircraft IFPI in the IM clearances was the main source of difficulty, and two others mentioned that length of the message caused difficulty. Pilot comments were similar to those of controllers, with eight comments indicating the reference aircraft IFPI was difficult to retain, although one pilot also indicated the call sign of the reference aircraft caused some difficulty.

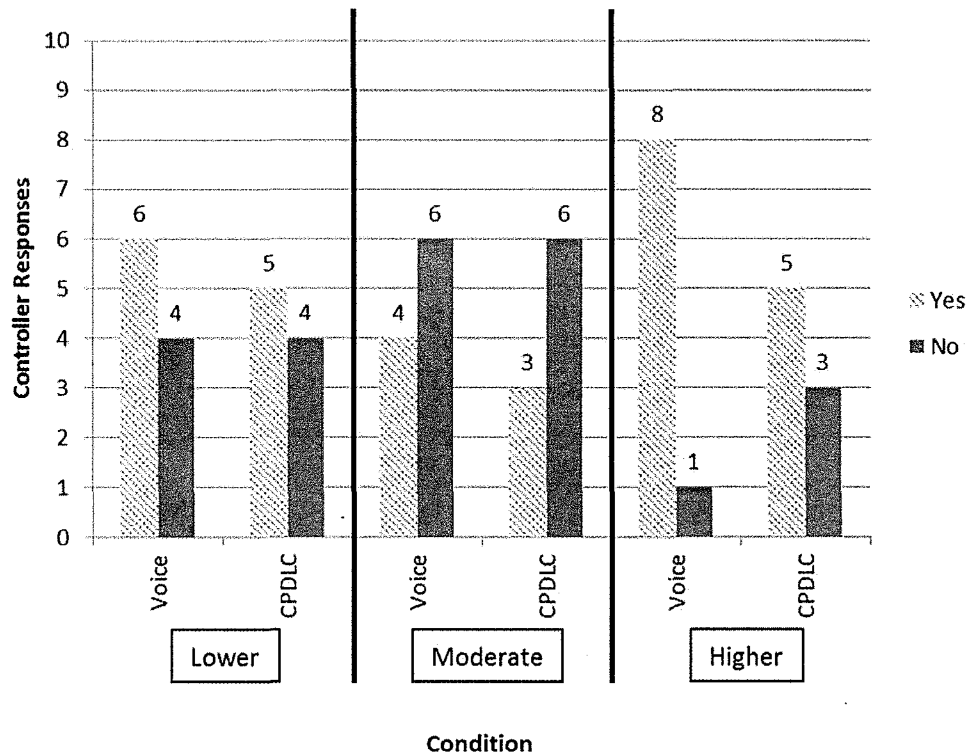


Figure 4-7. Controller Responses to "Did any particular elements of the [IM] Clearance cause difficulties?"

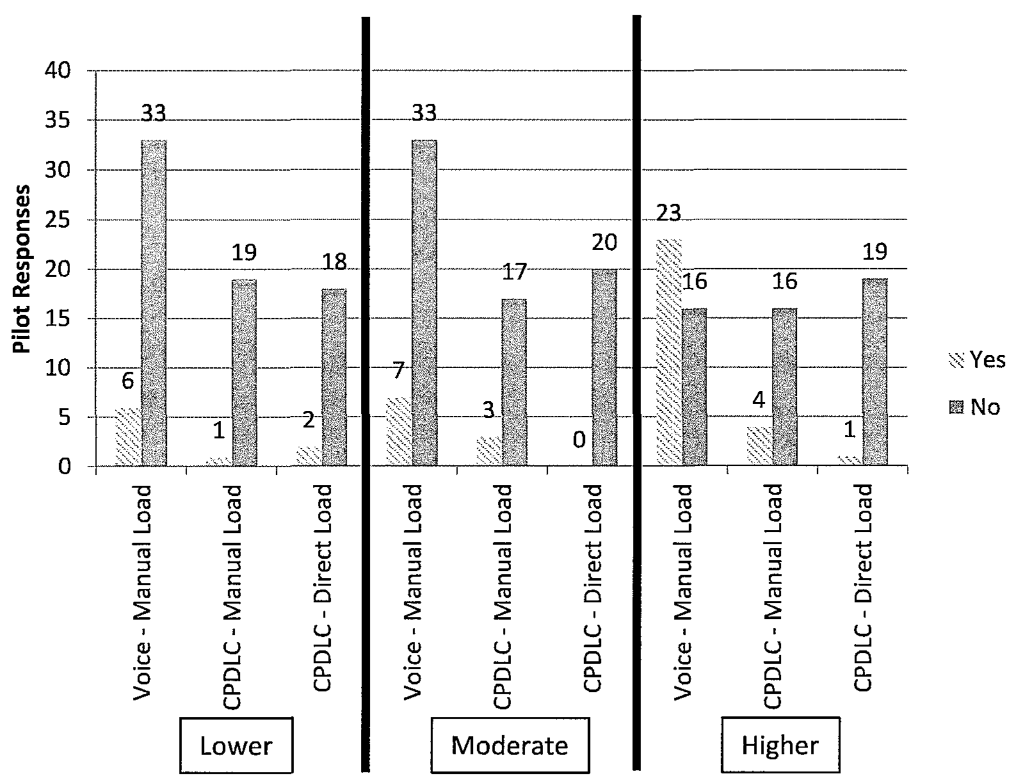


Figure 4-8. Pilot Responses to "Did any particular elements of the [IM] Clearance cause difficulties?"

A specific element of concern in the IM clearance was the reference aircraft call sign / TPCS. Controllers were specifically asked about any communication issues associated with TPCS. The majority (7/10; 70%) of controllers did not notice any TPCS errors during the simulation. The controllers that did notice TPCS errors commented that pilots did not know the three letter identifiers associated with the call signs of reference aircraft, or that the incorrect call sign was read back to them when similar call signs were nearby. A slight majority of controllers (6/10; 60%) answered "yes" it would be acceptable to issue the three letter identifier rather than the airline telephony designator of a reference aircraft. When controllers were asked whether the use of TPCS in a clearance would be operationally acceptable, the majority (8/10; 80%) agreed (M=5.4, SD=1.3).

Pilots were asked if they experienced any confusion about whether they were being talked to (i.e., receiving a communication) or being talked about (i.e., being addressed as a third party aircraft). The majority (17/20; 85%) of pilots disagreed that they experienced confusion (M=2.3, SD=1.5). When pilots were asked whether they could get used to being addressed as a third party aircraft, the majority (15/20; 75%) replied, "yes." Of the other 5 pilots, 4 replied "don't know" and 1 replied, "no." When pilots were asked whether they had any issues during communications with the controllers when using TPCS, the majority (16/20; 80%) replied, "no." Of the 5 comments, 4 were related to issues with the airline three letter designator. When pilots were asked whether they had any issues during display interactions when using TPCS, the majority (19/20; 95%) replied, "no." When pilots were asked whether the use of TPCS in a clearance would be operationally acceptable, the majority (17/20; 85%) of the pilots agreed (M=5.7, SD=1.8). Of the 2 comments, both were related to issues with the airline three letter designator.

After each scenario, controllers and pilots were asked to rate the complexity of the IM clearance. A repeated measures ANOVA was run to assess whether significant differences were present (test 1 noted in Section 4.1.1). The repeated measures ANOVA for controllers revealed a main effect for Complexity [F(2,18)=9.802 p=.001]. The pairwise comparisons for the conditions revealed that controllers found the Lower (M=3.825, SE=.384) and Moderate (M=4.200, SE=.467) complexity clearances were less complex than the Higher (M=5.025, SE=.377) complexity clearances. Controller responses are shown in Figure 4-9. Figure 4-10 shows the relationship between complexity and communication method. The repeated measures ANOVA for pilots revealed main effects for Complexity [F(2,36)=11.266 p=.000] and the interaction of complexity and communication method [F(2.390,43.021)=4.484 p=.013]. The pairwise comparison revealed that pilots found the Lower (M=2.886, SE=.293) and Moderate (M=3.246, SE=.303) complexity clearance were less complex than the Higher (M=3.702, SE=.355) complexity clearances. Pilot responses are shown in Figure 4-11. Figure 4-12 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load is the most complex. Both pilots and controllers found the Lower and Moderate complexity IM clearances to be less complex than the Higher complexity IM clearances.

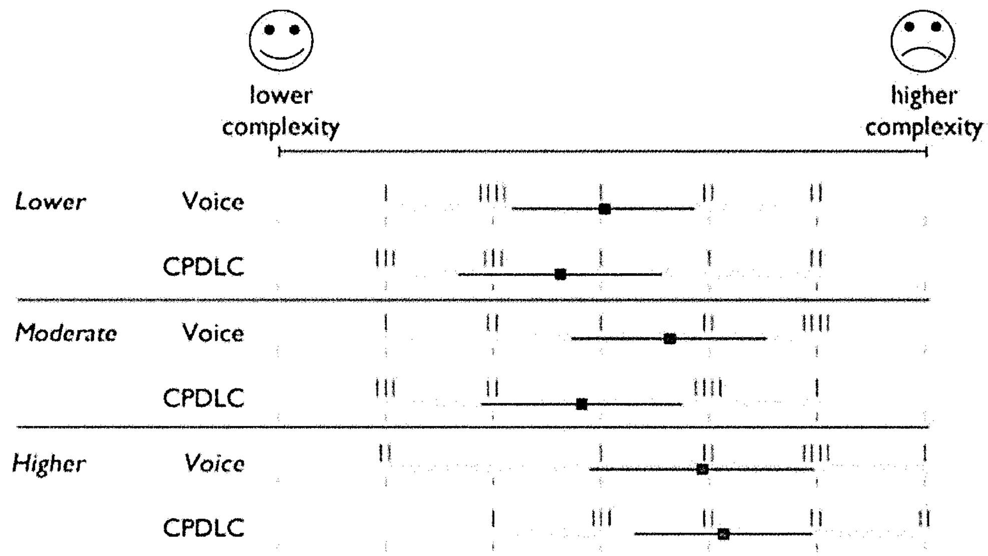


Figure 4-9. Controller Responses to "Rate the complexity of the [IM] Clearance"

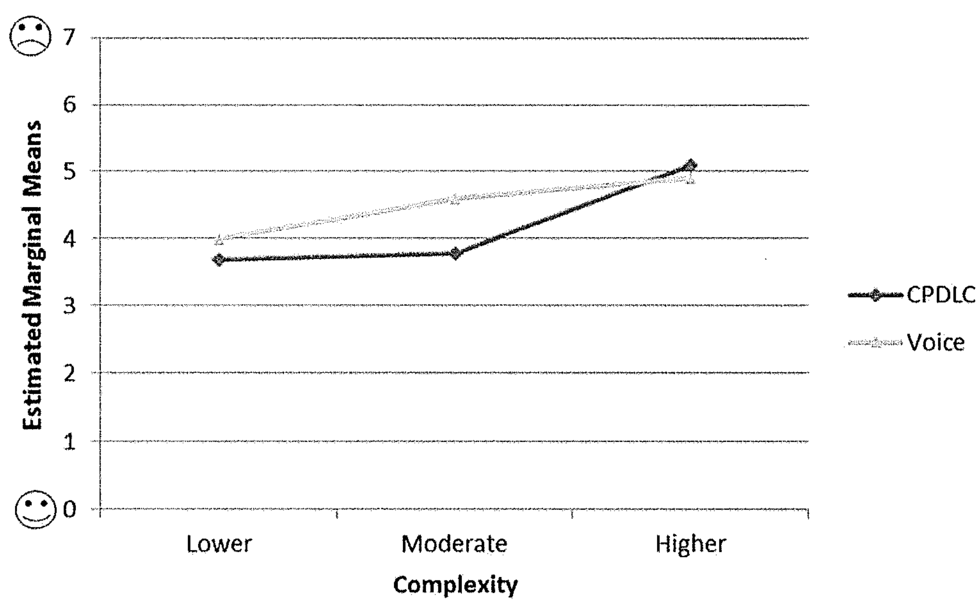


Figure 4-10. Relationship between Complexity and Communication Method for Controller Responses to "Rate the complexity of the [IM] clearance"

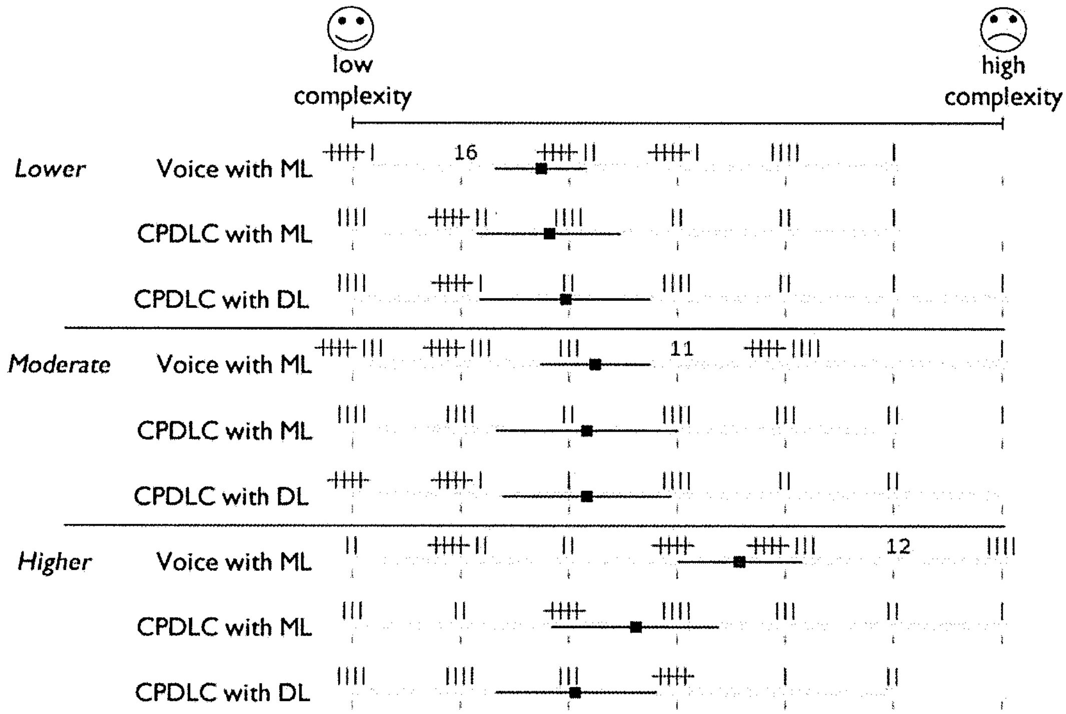


Figure 4-11. Pilot Responses to "Rate the complexity of the [IM] clearance"

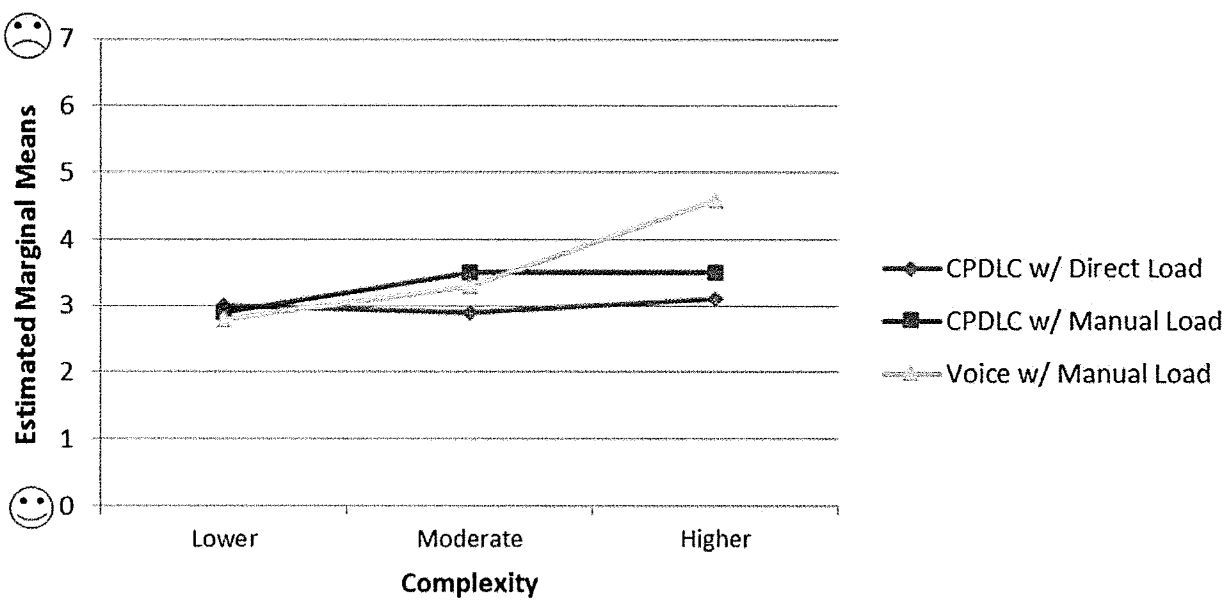


Figure 4-12. Relationship between Complexity and Communication Method for Pilot Responses to "Rate the complexity of the [IM] clearance"

After using the IM clearances, pilots and controllers were asked in the post-scenario questionnaire whether "The [IM] clearance communication exchanges were clear." No significant results were found for the controller responses. Controller responses are shown in Figure 4-13. Figure 4-14 shows the relationship between complexity and communication method. Pilot responses revealed significant differences across scenarios. The repeated measures MANOVA revealed main effects for complexity [F(2,38)=8.593 p=.001], communication method [F(1.272,24.168)=13.782 p=.001] and the interaction of complexity and communication method [F(3.075,58.422)=4.022 p=.011]. The pairwise comparison revealed that pilots agreed significantly more in the Lower (M=6.583, SE=.127) and Moderate (M=6.575, SE=.119) complexity conditions than in the Higher (M=6.125, SE=.209) complexity condition. Pilots also agreed significantly more in the CPDLC with Direct Load (M=6.717, SE=.157) and CPDLC with Manual Load (M=6.733, SE=.101) conditions than they did in the Voice with Manual Load (M=5.833, SE=.248) condition. Pilot responses are shown in Figure 4-15. Figure 4-16 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load were less clear. Pilot results indicate that pilots thought the exchanges were less clear with the Higher complexity IM clearances, as compared to the Lower and Moderate complexity clearances for both voice and CPDLC. Results also indicate that exchanges were less clear when using voice with Manual Load than when using either CPDLC with Manual or Direct Load.

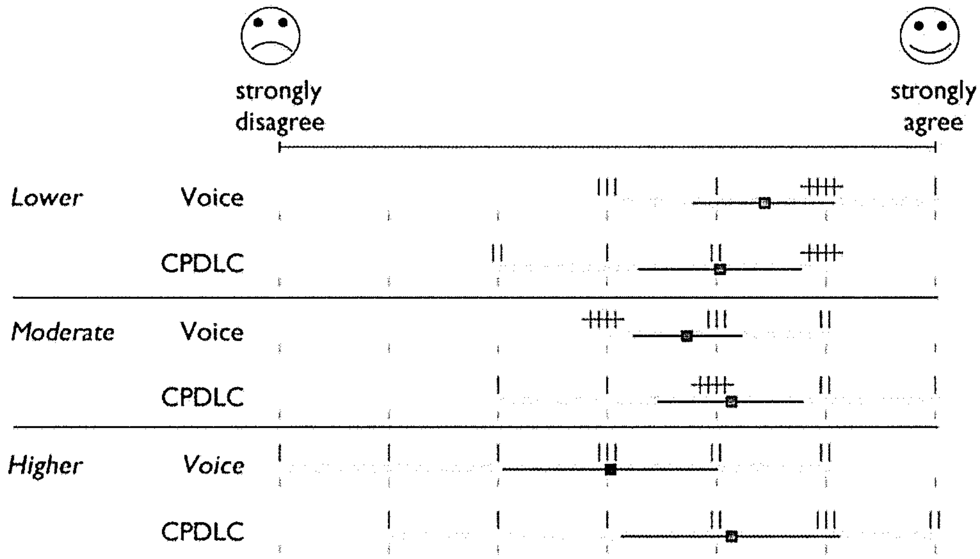


Figure 4-13. Controller Responses to "The [IM] clearance communication exchanges were clear"

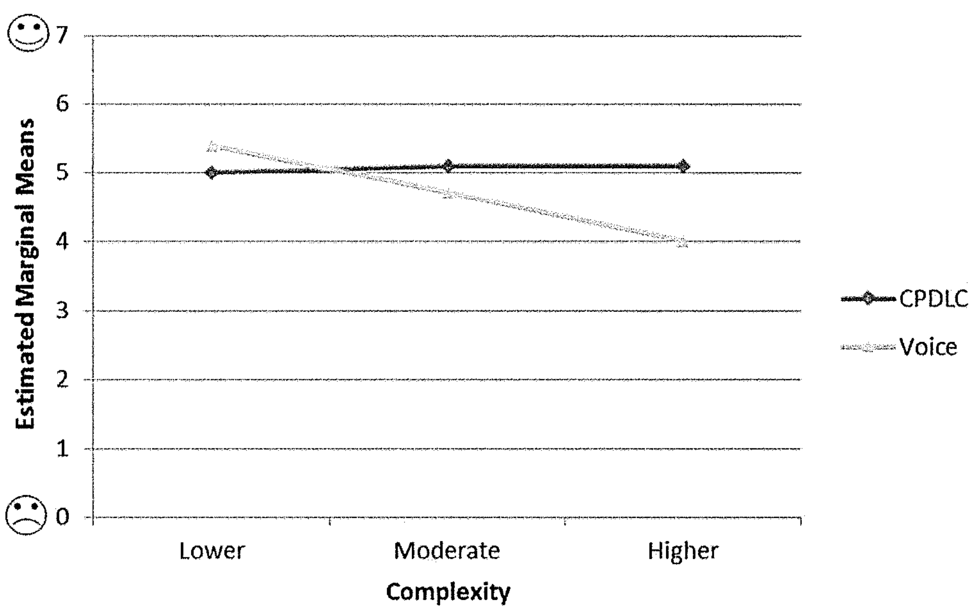


Figure 4-14. Relationship between Complexity and Communication Method for Controller Responses to "The [IM] clearance communication exchanges were clear"

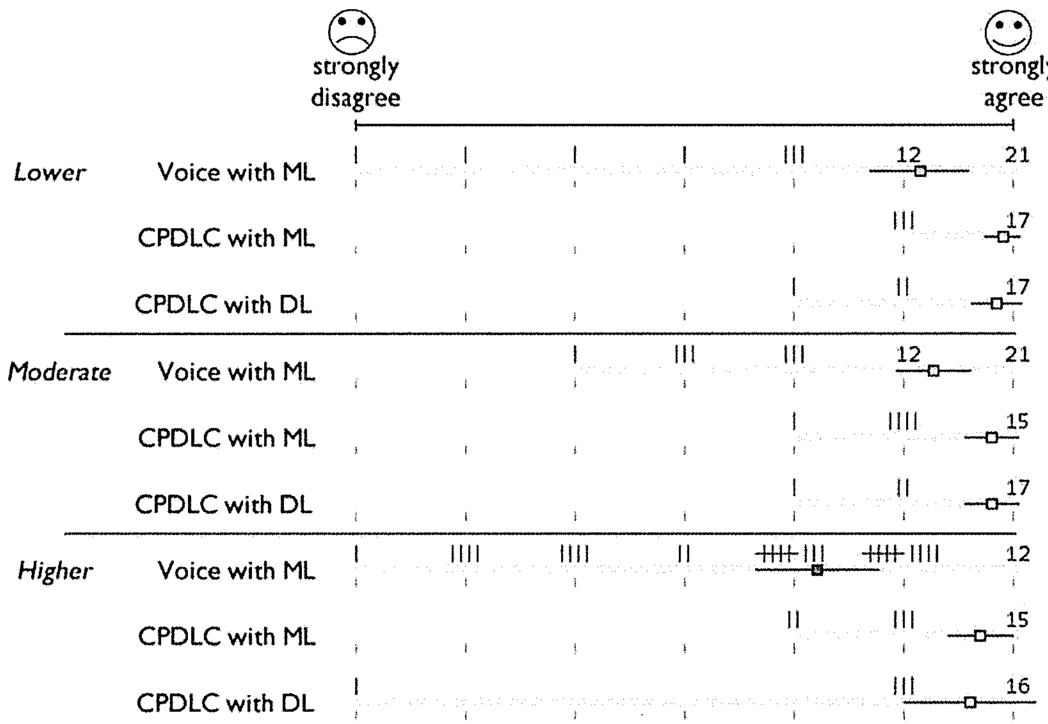


Figure 4-15. Pilot Responses to "The [IM] clearance communication exchanges were clear"

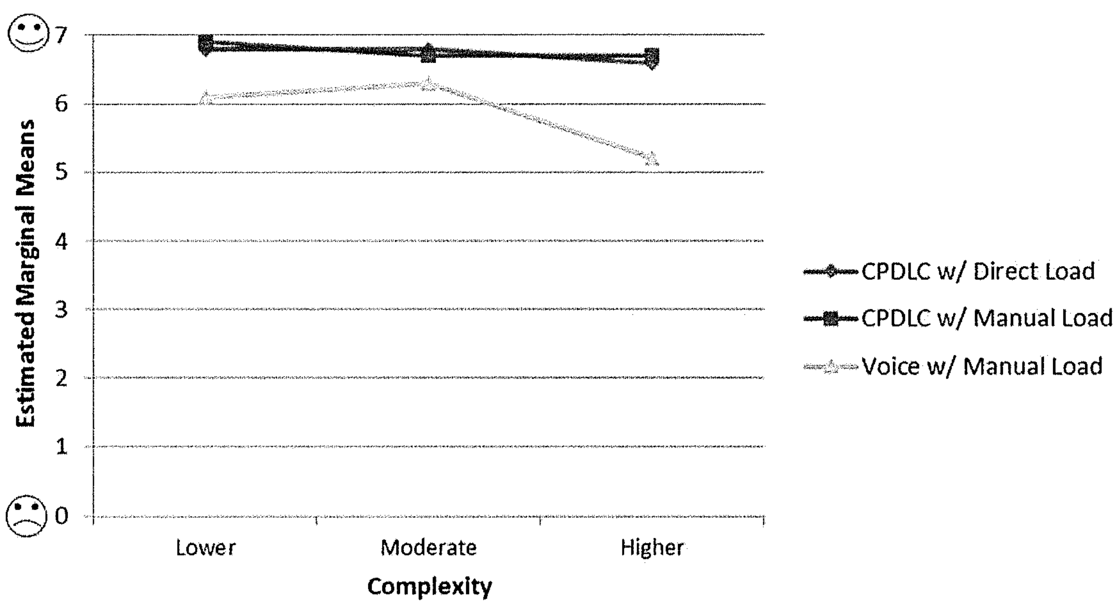


Figure 4-16. Relationship between Complexity and Communication Method for Pilot Responses to "The [IM] clearance communication exchanges were clear"

Pilots were asked if they were able to retain the IM clearance information. The repeated measures MANOVA revealed main effects for complexity [F(1.418,26.939)=5.104 p=.022], communication method [F(1.228,23.332)=16.225 p=.000] and the interaction of complexity and communication method [F(2.759,52.415)=4.725 p=.007]. The pairwise comparisons revealed that pilots agreed with the statement significantly more in the CPDLC with Direct Load (M=6.550, SE=.152) and CPDLC with Manual Load (M=6.417, SE=.189) conditions as compared to the Voice with Manual Load (M=5.700, SE=.271) condition. Responses are shown in Figure 4-17. Figure 4-18 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load were more difficult to retain.

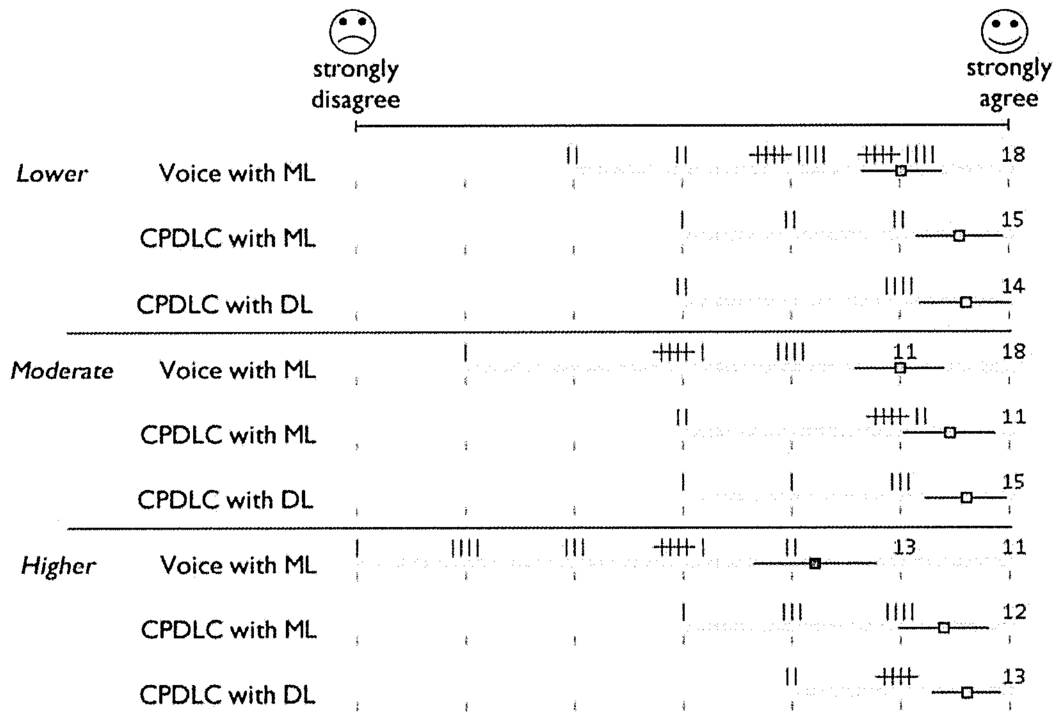


Figure 4-17. Pilot Responses to "I was able to retain the [IM] clearance information"

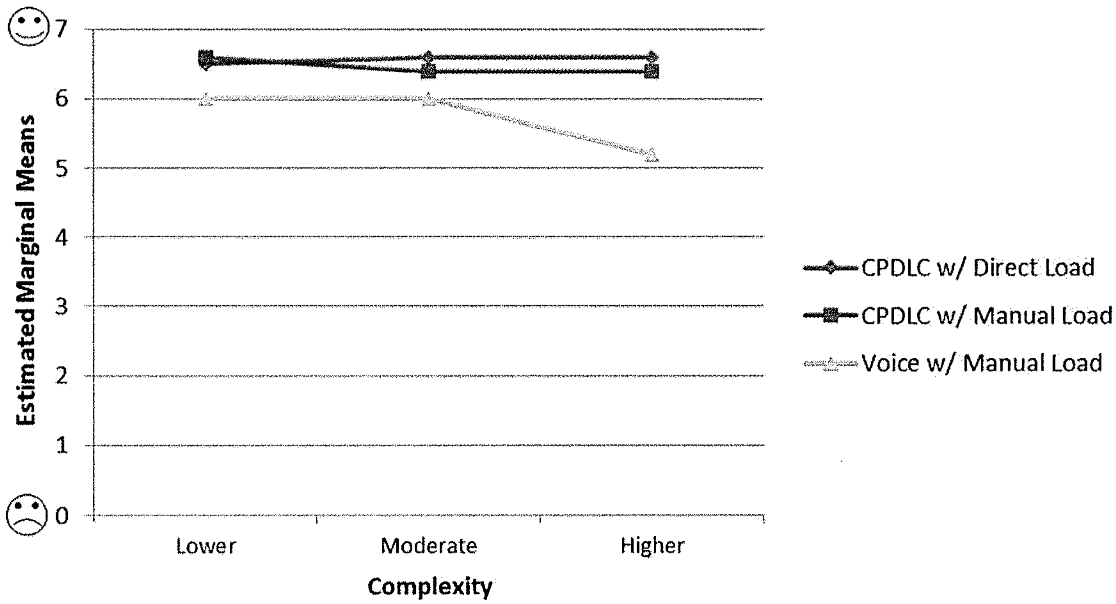


Figure 4-18. Relationship between Complexity and Communication Method for Pilot Responses to "I was able to retain the [IM] clearance information"

In the post-scenario questionnaire, controllers were asked if "The [IM] Clearance I issued to the pilots was acceptable." The repeated measures MANOVA did not reveal any significant differences. Controller responses are shown in Figure 4-19. Figure 4-20 shows the relationship between complexity and communication method.

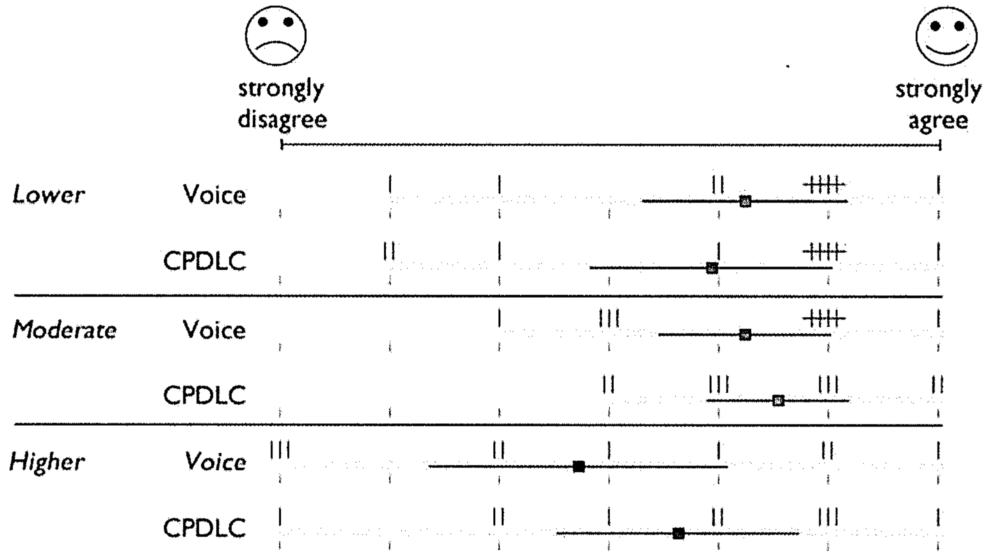


Figure 4-19. Controller Responses to "The [IM] clearance I issued to the pilots was acceptable"

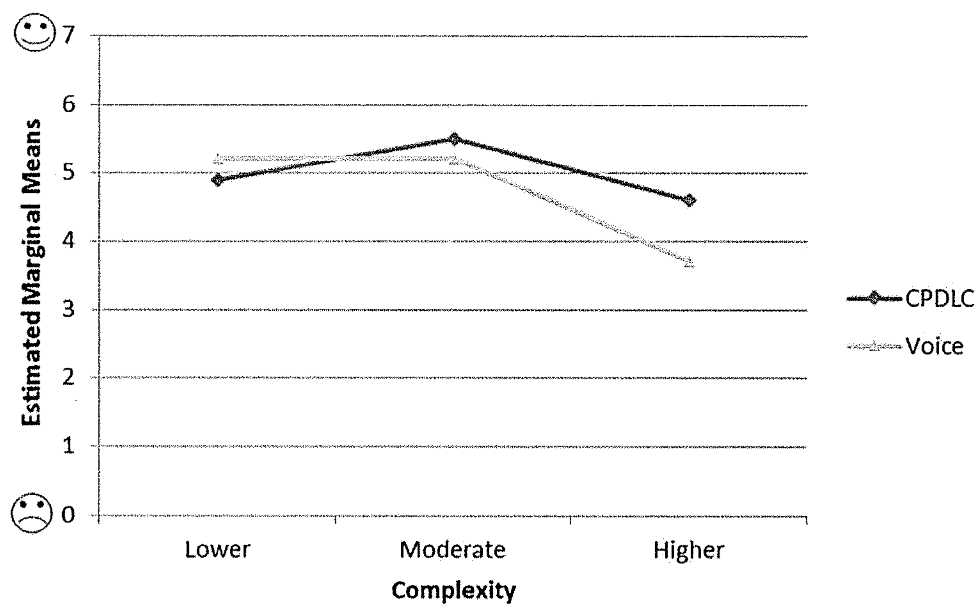


Figure 4-20. Relationship between Complexity and Communication Method for Controller Responses to "The [IM] clearance I issued to the pilots was acceptable"

Pilots were also asked whether they thought the IM clearance they received from the controllers was acceptable. The repeated measures MANOVA revealed main effects for complexity [F(2,38)=6.649 p=.003], communication method [F(1.221,23.191)=18.483 p=.000] and the interaction of complexity and communication method [F(2.715,51.584)=7.145 p=.001]. The pairwise comparisons for the conditions revealed that pilots agreed with the statement more in scenarios containing Lower complexity clearances (M=6.600, SE=.119) than in scenarios containing Higher (M=6.133, SE=.180) complexity clearances. Pilots also agreed with the statement significantly more in scenarios where CPDLC with Direct Load (M=6.817, SE=.082) and CPDLC with Manual Load (M=6.650, SE=.122) were utilized as compared to scenarios where Voice with Manual Load (M=5.725, SE=.239) was utilized. Figure 4-21 shows the pilot responses. Figure 4-22 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load had less acceptable IM clearances from the controller. Pilot results indicate that the clearances from the controller were more acceptable for the Lower than the higher complexity IM clearances for both voice and CPDLC. Results indicate that the clearances from the controller were less acceptable when using Voice with Manual Load than when using either CPDLC with Manual or Direct Load.

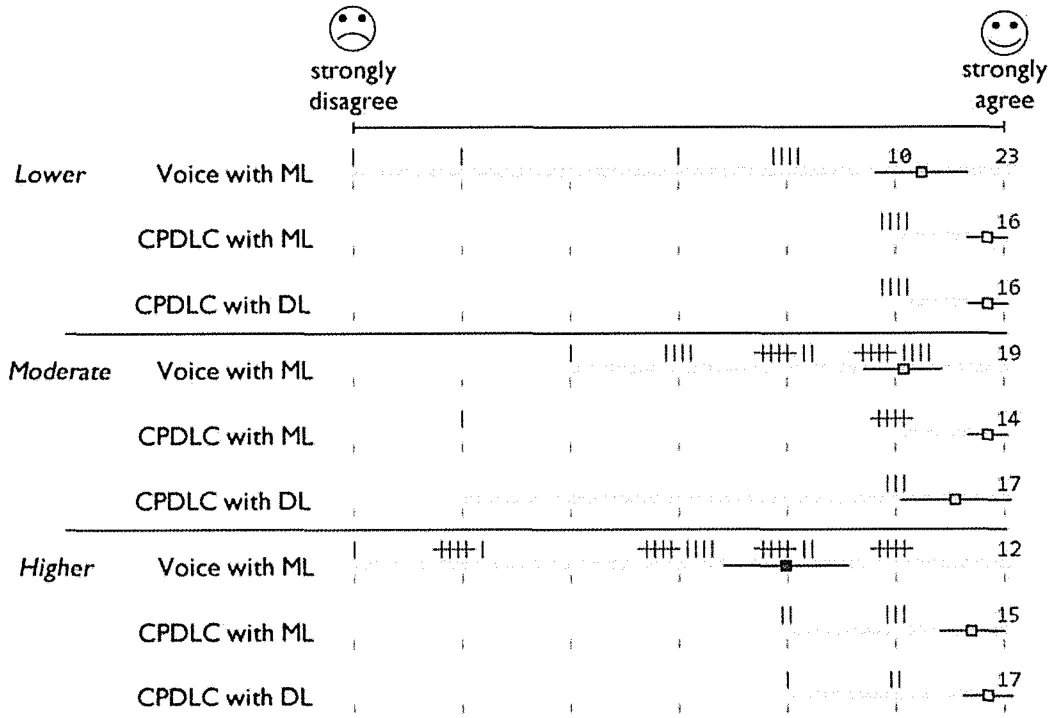


Figure 4-21. Pilot Responses to "The [IM] clearance I received from the controller was acceptable"

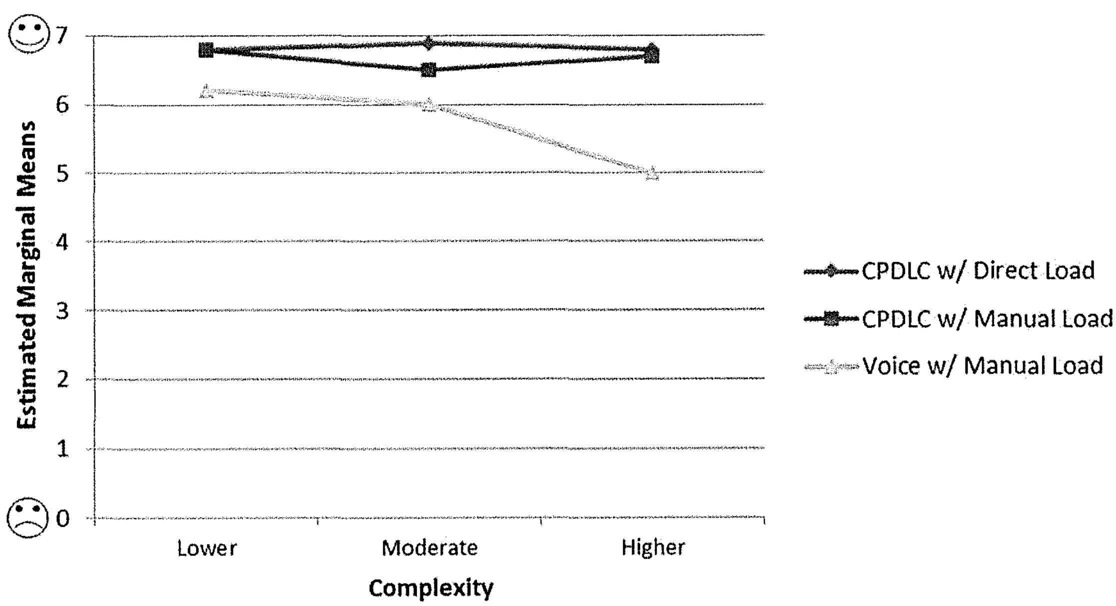


Figure 4-22. Relationship between Complexity and Communication Method for Pilot Responses to "The [IM] Clearance I received from the controller was acceptable"

In the post-scenario questionnaire, controllers were also asked whether the pilot readbacks of the IM clearances were acceptable. The repeated measures MANOVA did not reveal any significant differences. Controller responses are shown in Figure 4-23. Figure 4-24 shows the relationship between complexity and communication method.

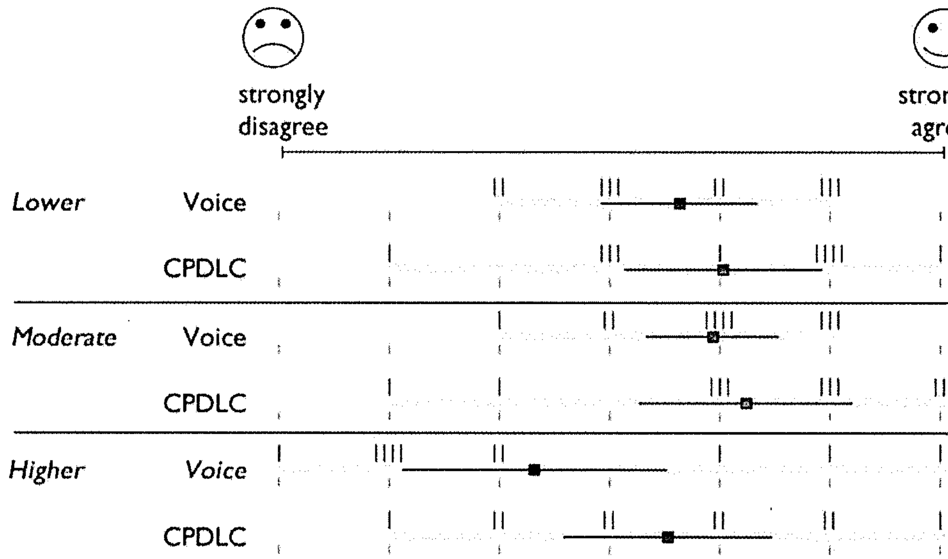


Figure 4-23. Controller Responses to "Pilot read backs of the [IM] clearance over voice were acceptable"

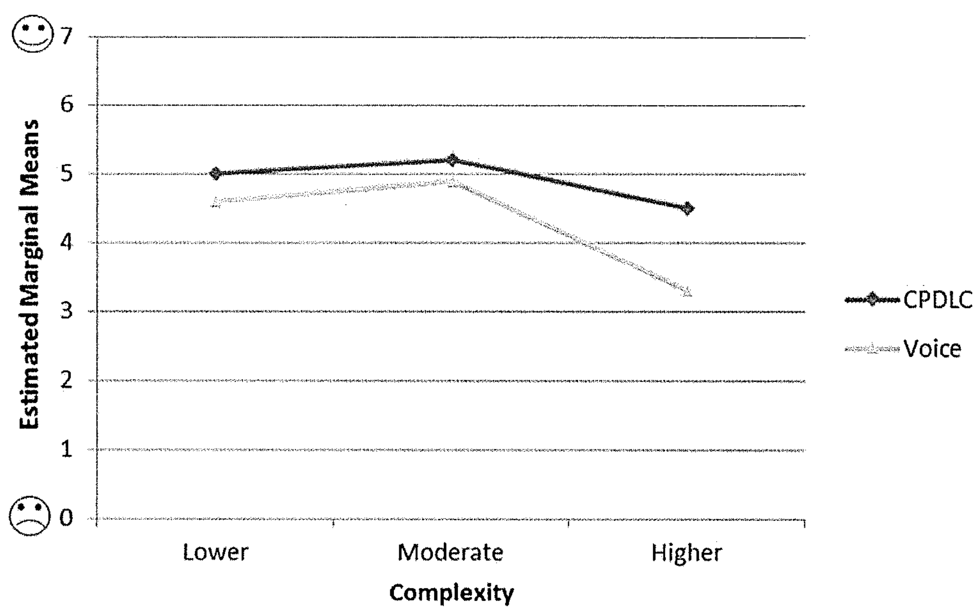


Figure 4-24. Relationship between Complexity and Communication Method for Controller Responses to "Pilot read backs of the [IM] clearance over voice were acceptable"

After each scenario, controllers and pilots whether "Overall, the [IM] clearance communications were acceptable." The repeated measures MANOVA for controllers revealed a main effect for communication method [F(1,9)=10.307 p=.011]. The pairwise comparisons for the communication method revealed that controllers found the scenarios where CPDLC (M=5.367, SE=.363) was utilized better than scenarios where voice (M=4.350, SE=.388) was utilized. Controller responses are shown in Figure 4-25. Figure 4-26 shows the relationship between complexity and communication method. The repeated measures MANOVA for pilots revealed main effects for complexity [F(1.246,23.675)=10.139 p=.002] and communication method [F(1.213,23.039)=16.235 p=.000]. The pairwise comparisons revealed that pilots agreed significantly more in the Lower (M=6.567, SE=.133) and Moderate (M=6.533, SE=.113) complexity conditions than in the Higher (M=5.900, SE=.267) complexity condition. Also, pilots agreed significantly more in the CPDLC with Auto Load (M=6.700, SE=.130) and CPDLC with Manual Load (M=6.600, SE=.127) conditions than in the Voice with Manual Load (M=5.700, SE=.280) condition. Pilot responses are shown in Figure 4-27. Figure 4-28 shows the relationship between complexity and communication method. Overall, controllers and pilots showed a preference for CPDLC. Pilot results indicated that the Lower and Moderate IM clearances were more acceptable than the Higher complexity IM clearance.

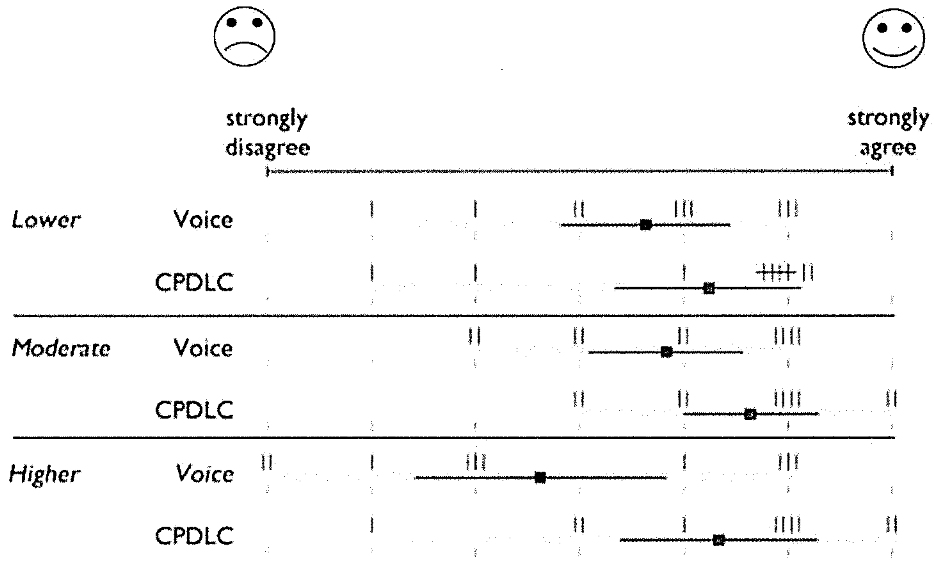


Figure 4-25. Controller Responses to "Overall, the [IM] clearance communications were acceptable"

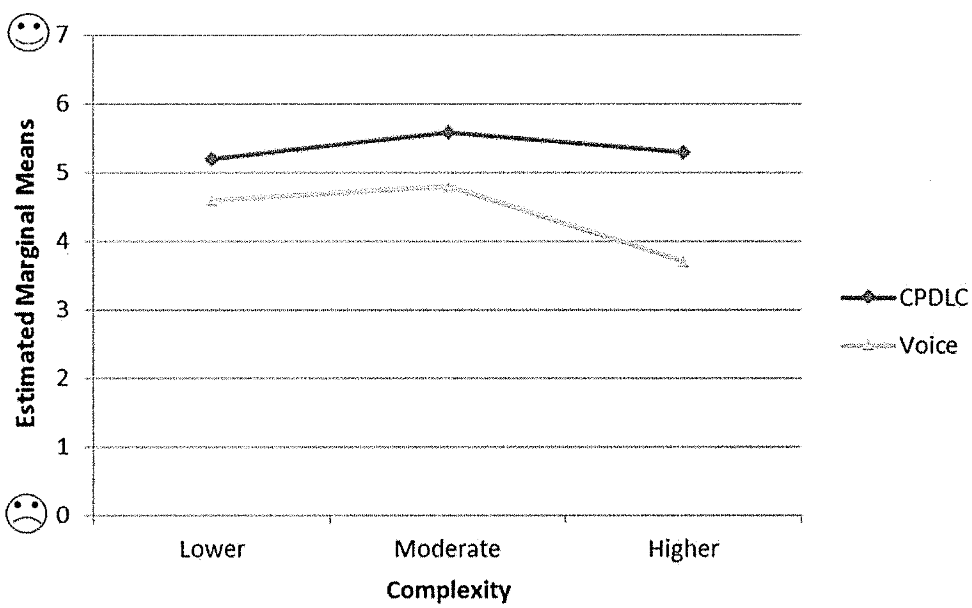


Figure 4-26. Relationship between Complexity and Communication Method for Controller Responses to "Overall, the [IM] clearance communications were acceptable"

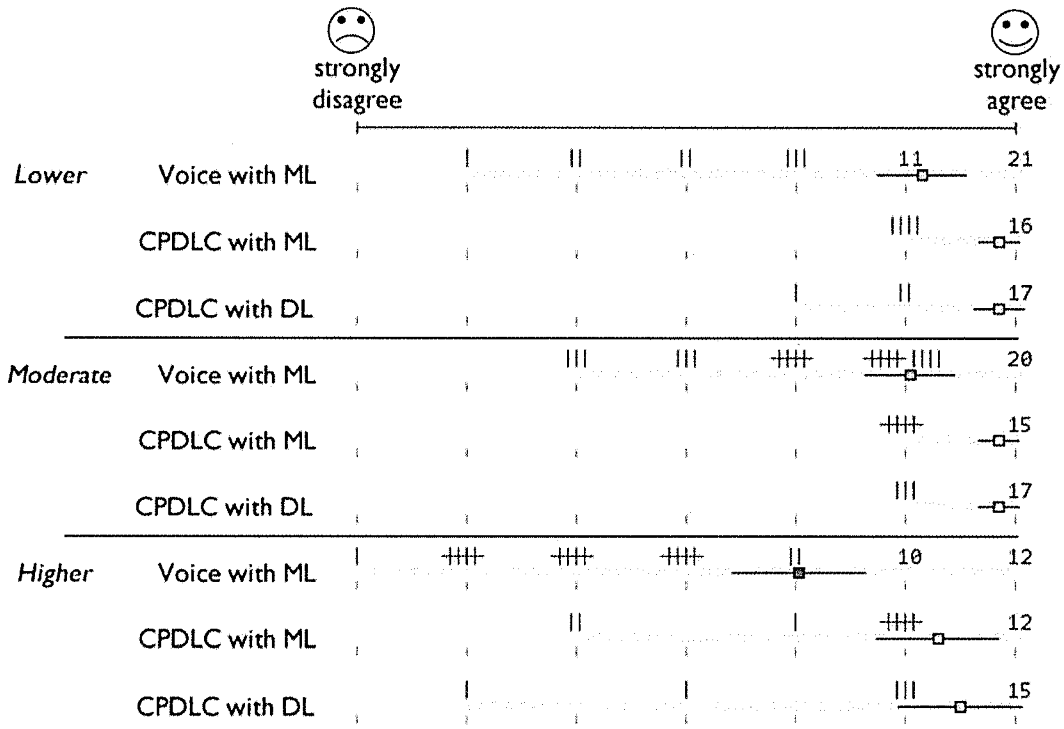


Figure 4-27. Pilot Responses to "Overall, the [IM] clearance communications were acceptable"

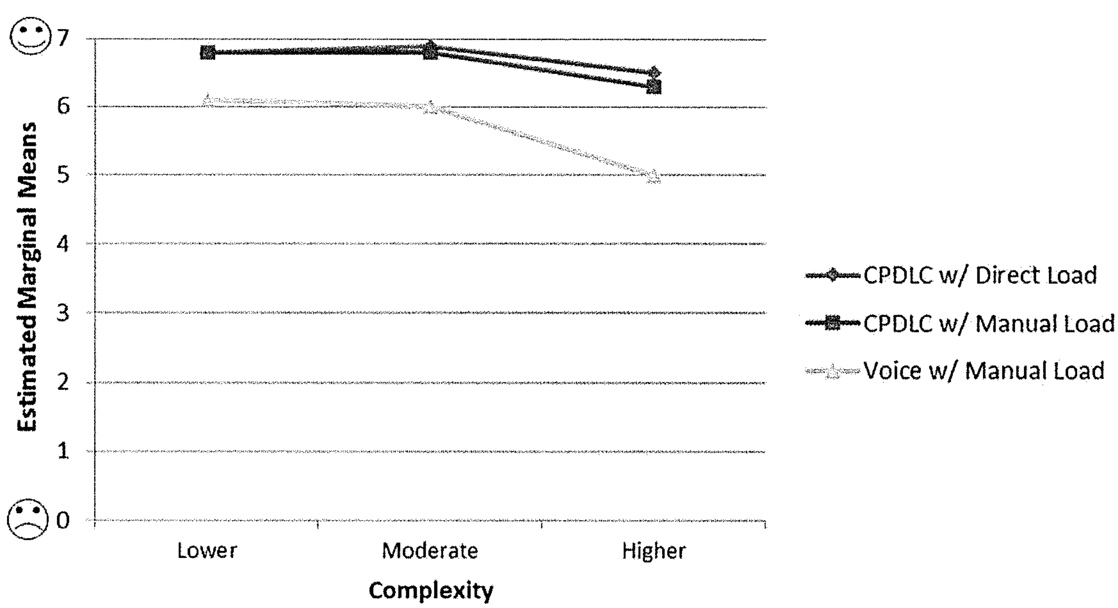


Figure 4-28. Relationship between Complexity and Communication Method for Pilot Responses to "Overall, the [IM] clearance communications were acceptable"

Controllers were asked about the acceptability of the length of the IM clearances after each scenario. The repeated measures MANOVA revealed no statistical significance. A great deal of variance was found across all scenarios. Controller responses are shown in Figure 4-29. Figure 4-30 shows the relationship between complexity and communication method.

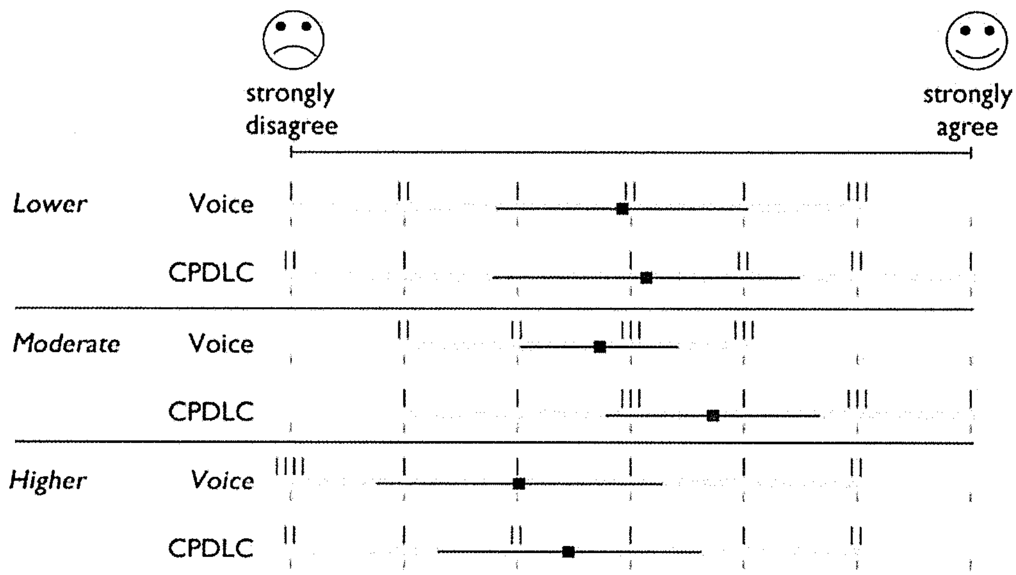


Figure 4-29. Controller Responses to "The length of the [IM] clearance communications was acceptable"

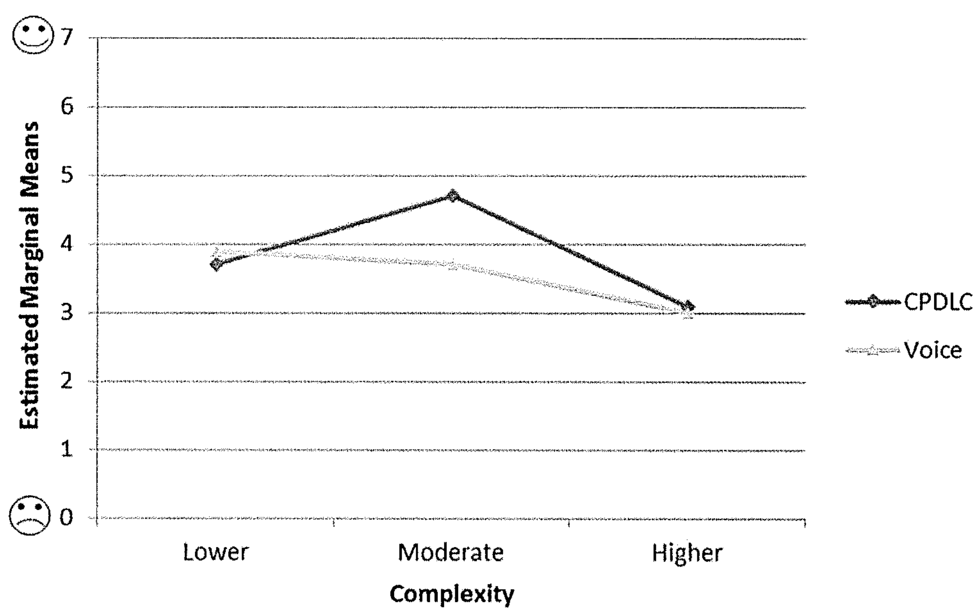


Figure 4-30. Relationship between Complexity and Communication Method for Controller Responses to "The length of the [IM] clearance communications was acceptable"

When pilots were also asked about the acceptability of the length of IM clearances, responses differed. The repeated measures MANOVA revealed main effects for complexity [F(1.489,31.273)=14.861 p=.000], communication method [F(1.306,24.823)=16.723 p=.000] and the interaction of complexity and communication method [F(2.255,42.844)=9.164 p=.000]. The pairwise comparisons revealed that pilots agreed with the statement significantly more when the clearance complexity was Lower (M=6.633, SE=.122) and Moderate (M=6.583, SE=.124) when compared to Higher complexity (M=6.092, SE=.201) clearances. Also, pilots agreed with the statement significantly more when CPDLC with Direct Load (M=6.833, SE=.092) and CPDLC with Manual Load (M=6.700, SE=.113) was used when compared to Voice with Manual Load (M=5.775, SE=.277). Pilot responses show general agreement across all scenarios, with the exception of the Higher complexity, voice communications scenario which showed a great deal of variance in pilot responses. Pilot responses are shown in Figure 4-31. Figure 4-32 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load had a less acceptable length. Pilot results indicate that pilots thought the Higher complexity clearance had less acceptable length as compared to the Lower and Moderate complexity clearances for both voice and CPDLC. Results also indicate that the clearances had less acceptable lengths when using Voice with Manual Load than when using either CPDLC with Manual or Direct Load.

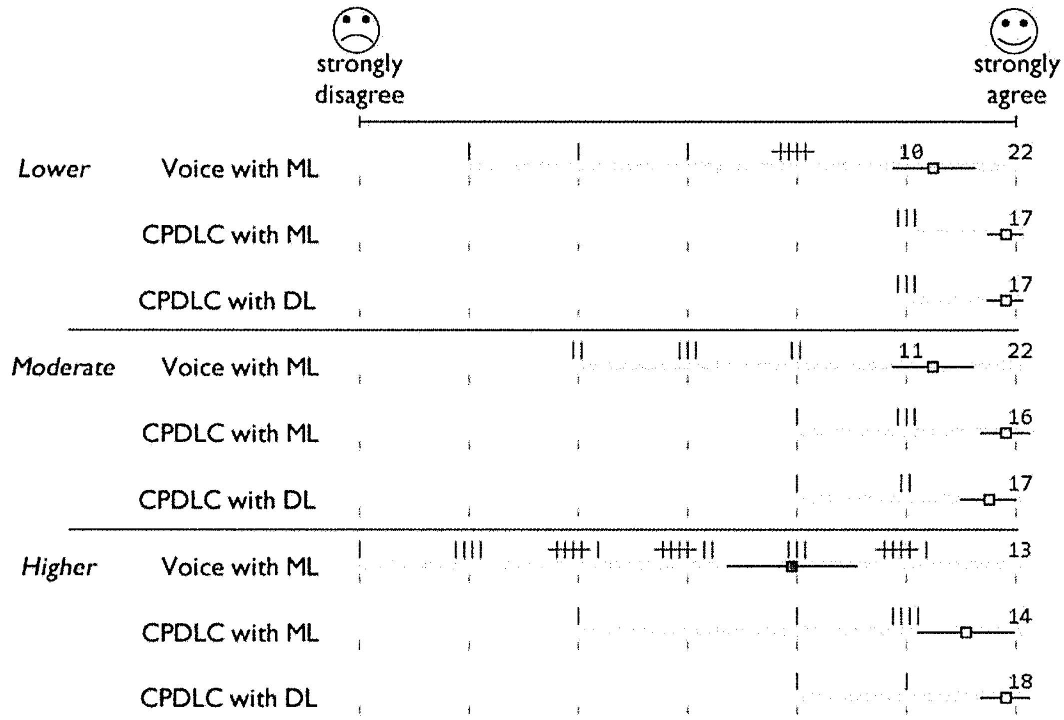


Figure 4-31. Pilot Responses to "The length of the [IM] clearance communications was acceptable"

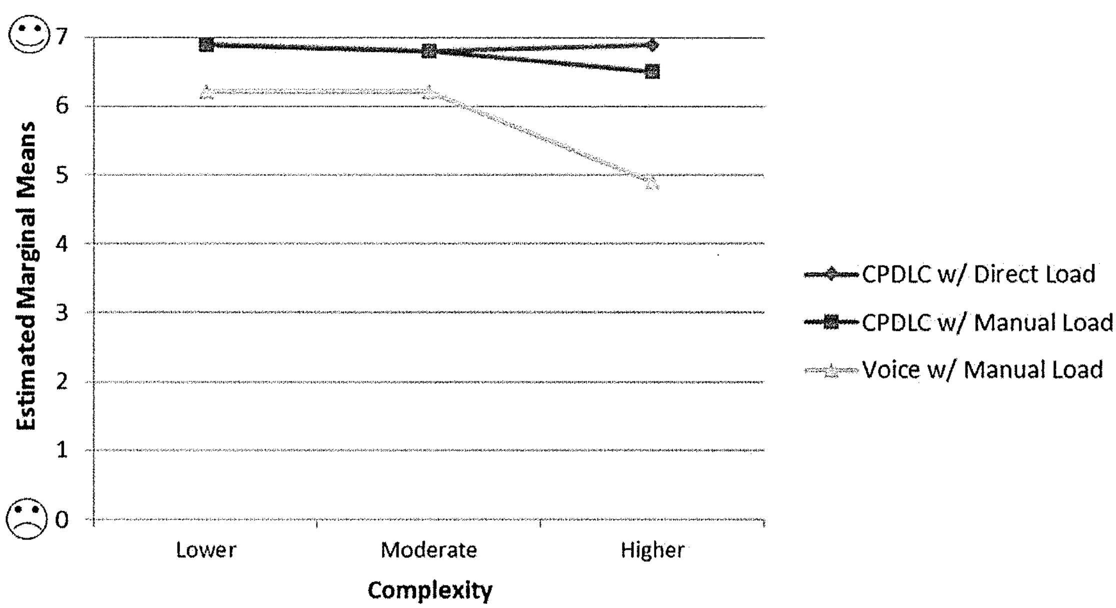


Figure 4-32. Relationship between Complexity and Communication Method for Pilot Responses to "The length of the [IM] clearance communications was acceptable"

The controllers were also asked about the acceptability of the complexity of the IM clearances after each scenario. The repeated measures MANOVA revealed no statistical significance. Controller responses are shown in Figure 4-33. Figure 4-34 shows the relationship between complexity and communication method.

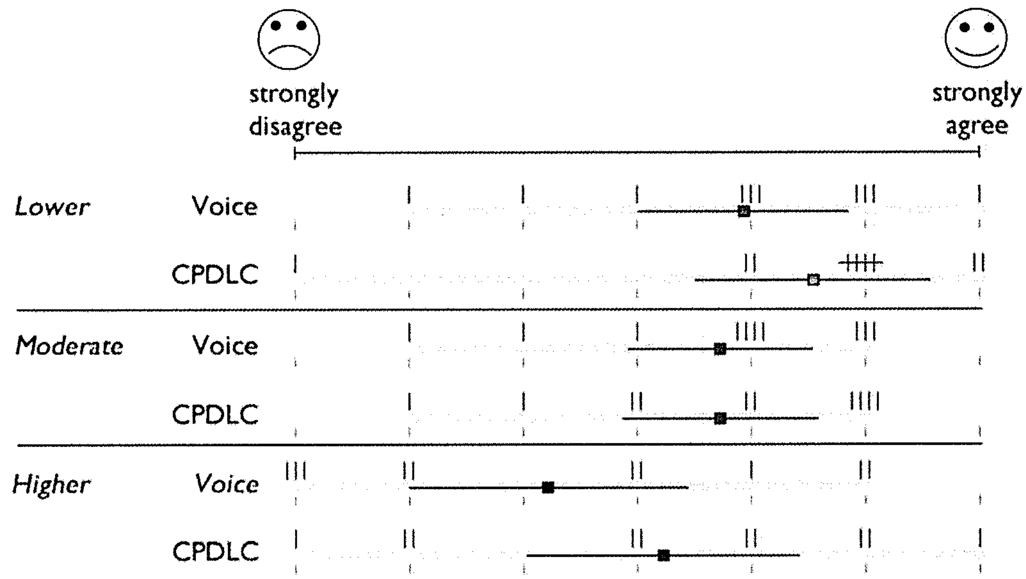


Figure 4-33. Controller Responses to "The complexity of the [IM] clearance communications was acceptable"

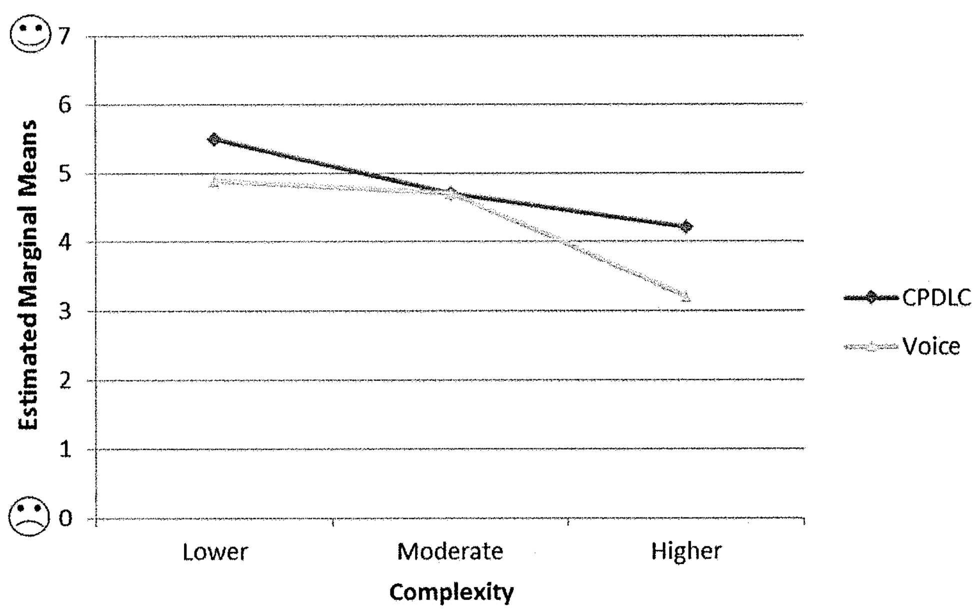


Figure 4-34. Relationship between Complexity and Communication Method for Controller Responses to "The complexity of the [IM] clearance communications was acceptable"

Pilot responses differed when asked about the acceptability of the complexity of the IM clearance. The repeated measures MANOVA revealed main effects for complexity [F(2,38)=12.776 p=.000], communication method [F(1.398,26.567)=14.478 p=.000] and the interaction of complexity and communication method [F(2.425,46.084)=4.284 p=.014]. The pairwise comparison revealed that pilots felt the complexity of the IM clearance was more acceptable in the Lower (M=6.533, SE=.148) and Moderate (M=6.450, SE=.158) complexity conditions than in the Higher complexity (M=5.892, SE=.246) conditions. Further, pilots significantly agreed that the complexity of the IM clearance was more acceptable in the CPDLC with Direct Load (M=6.650, SE=.146) and CPDLC with Manual Load (M=6.550, SE=.146) conditions than the Voice with Manual Load (M=5.675, SE=.293) condition. Responses are shown in Figure 4-35. Figure 4-36 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load had a less acceptable complexity. Pilot results indicate that pilots thought the Higher complexity clearance had less acceptable complexity as compared to the Lower and Moderate complexity clearances for both voice and CPDLC. Results also indicate that the clearances had less acceptable complexities when using voice with manual load than when using either CPDLC with manual or direct load.

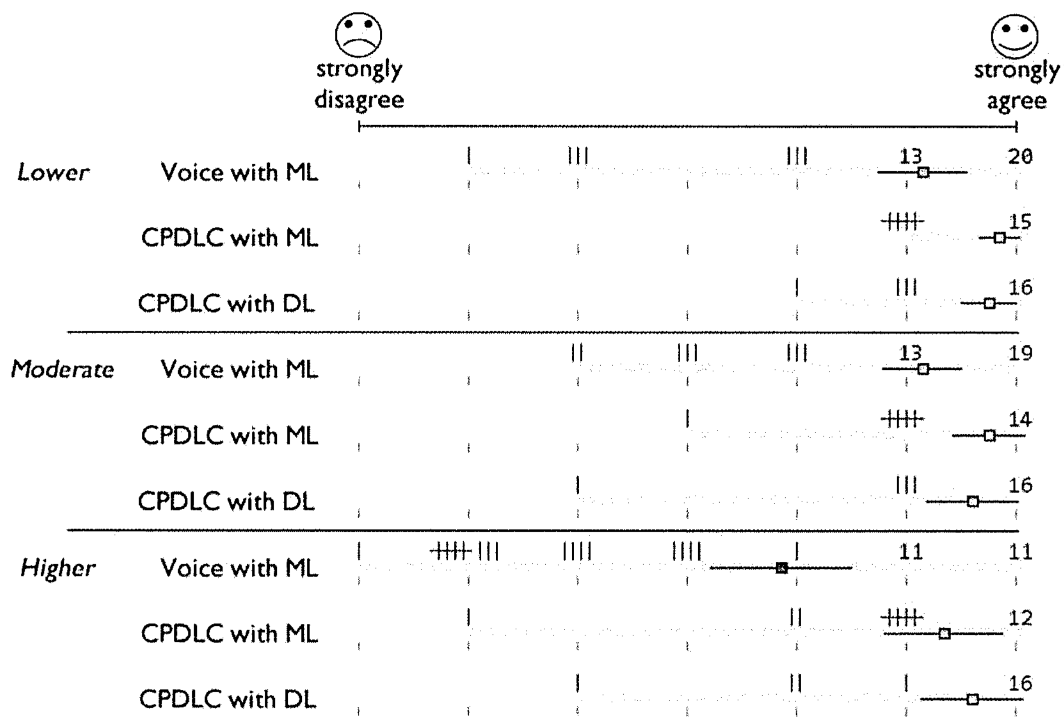


Figure 4-35. Pilot Responses to "The complexity of the [IM] clearance communications was acceptable"

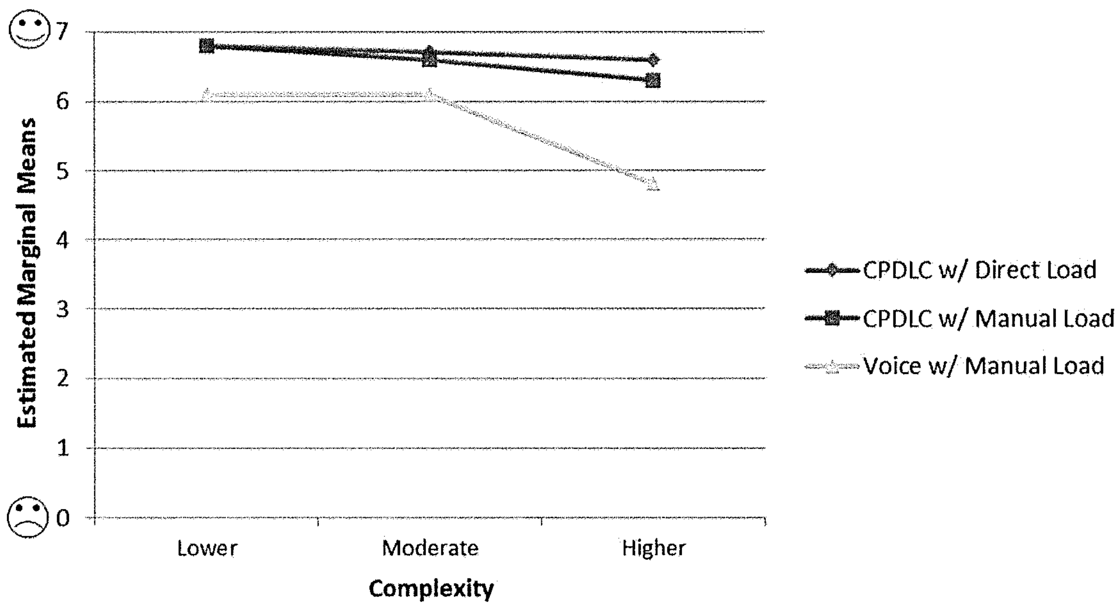


Figure 4-36. Relationship between Complexity and Communication Method for Pilot Responses to "The complexity of the [IM] clearance communications was acceptable"

Across all scenarios, the majority (55/60; 92%) of controller responses indicate that the controllers would be willing to issue the same IM clearance with a lower traffic load. The repeated measures MANOVA revealed main effects for communication method [F(1,9)=7.200 p=.025]. The pairwise comparisons for the conditions revealed that controllers agreed with the statement more for scenarios where CPDLC (M=6.333, SE=.268) was utilized than scenarios where voice (M=5.667, SE=.430) was utilized. Figure 4-37 shows controller responses. Figure 4-38 shows the relationship between complexity and communication method. Overall, results indicate that controllers thought the clearances had less acceptability in lower traffic environments when using voice than when using CPDLC.

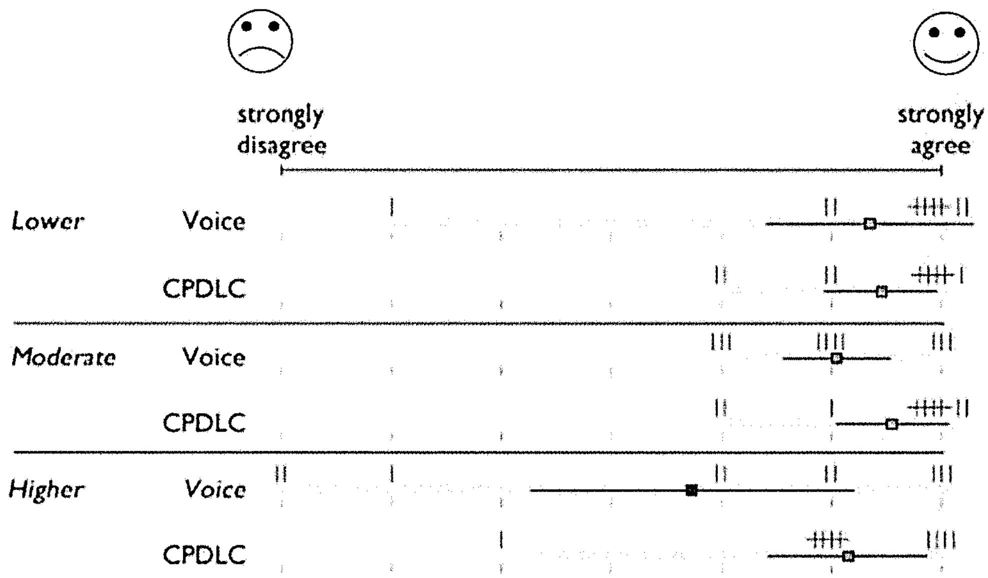


Figure 4-37. Controller Responses to "I would be willing to issue the same [IM] clearance in a lower workload environment"

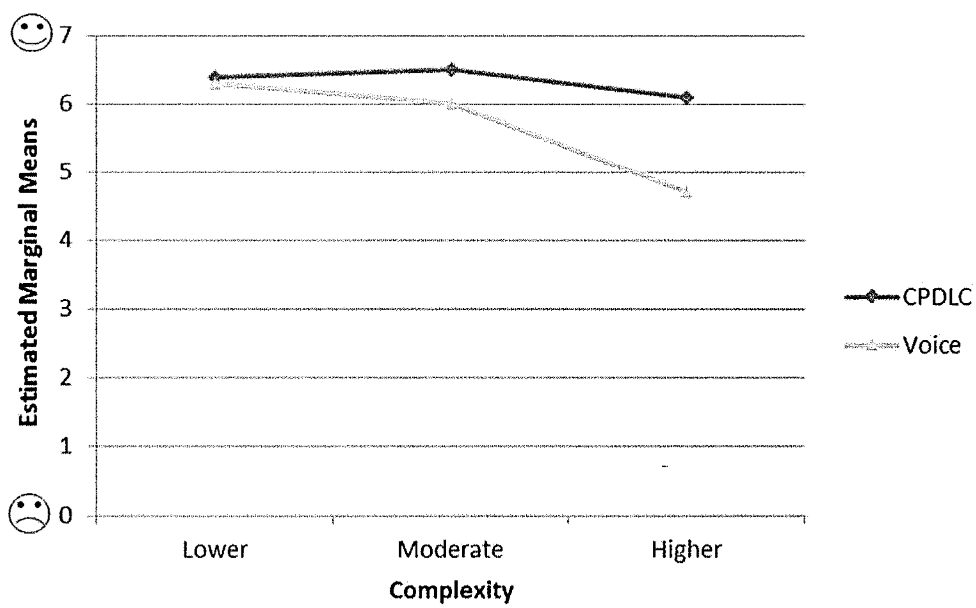


Figure 4-38. Relationship between Complexity and Communication Method for Controller Responses to "I would be willing to issue the same [IM] clearance in a lower workload environment"

Pilot responses to whether they would be willing to receive the same IM clearance in a lower workload environment differed across scenarios. The repeated measures MANOVA revealed main effects for complexity [F(1.505,28.590)=11.805 p=.001], communication method [F(1.131,21.485)=15.766 p=.000] and the interaction of complexity and communication method [F(2.131,40.497)=5.203 p=.009]. The pairwise comparison for complexity revealed that pilots agreed with the statement significantly more when clearance complexity was Lower (M=6.767, SE=.078) and Moderate (M=6.783, SE=.078) than when clearance complexity was Higher (M=6.508, SE=.104). Further, pilots agreed significantly more when they used CPDLC with Direct Load (M=6.933, SE=.039) and CPDLC with Manual Load (M=6.867, SE=.066) than when they used Voice with Manual Load (M=6.258, SE=.175). Despite the differences shown here, the majority of pilot responses across all scenarios show general agreement with this statement. The pilot responses are shown in Figure 4-39. Figure 4-40 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load had less acceptability in lower workload environments. Results also indicate that the clearances had less acceptability in lower workload environments when using Voice with Manual Load than when using either CPDLC with Manual or Direct Load.

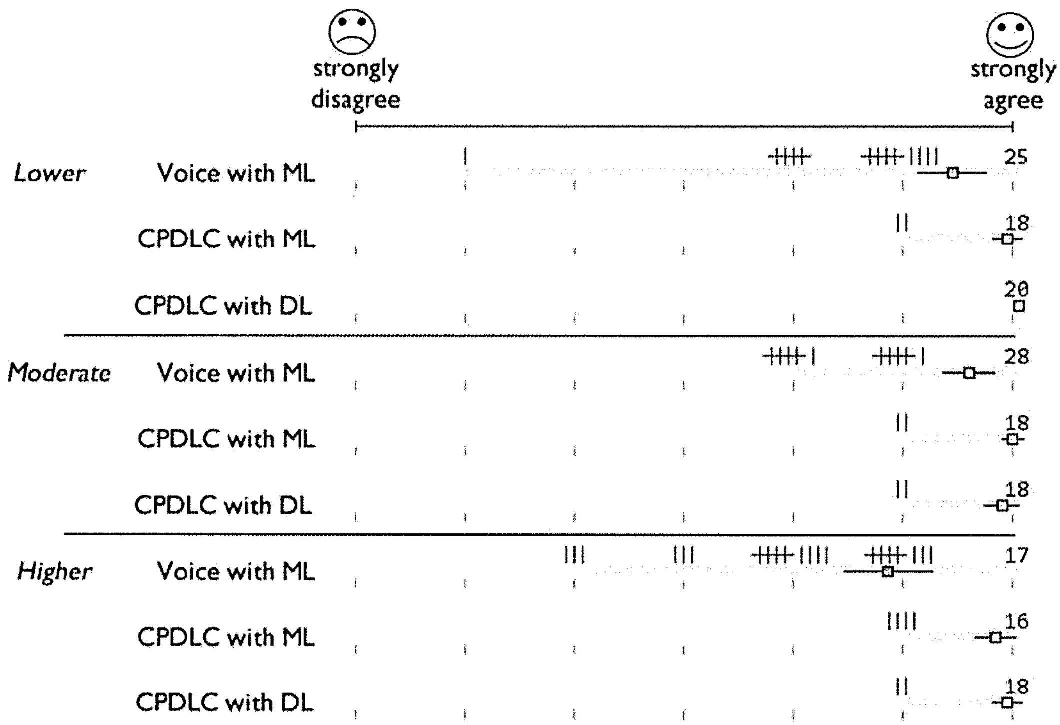


Figure 4-39. Pilot Responses to "I would be willing to receive the same [IM] clearance in a lower workload environment"

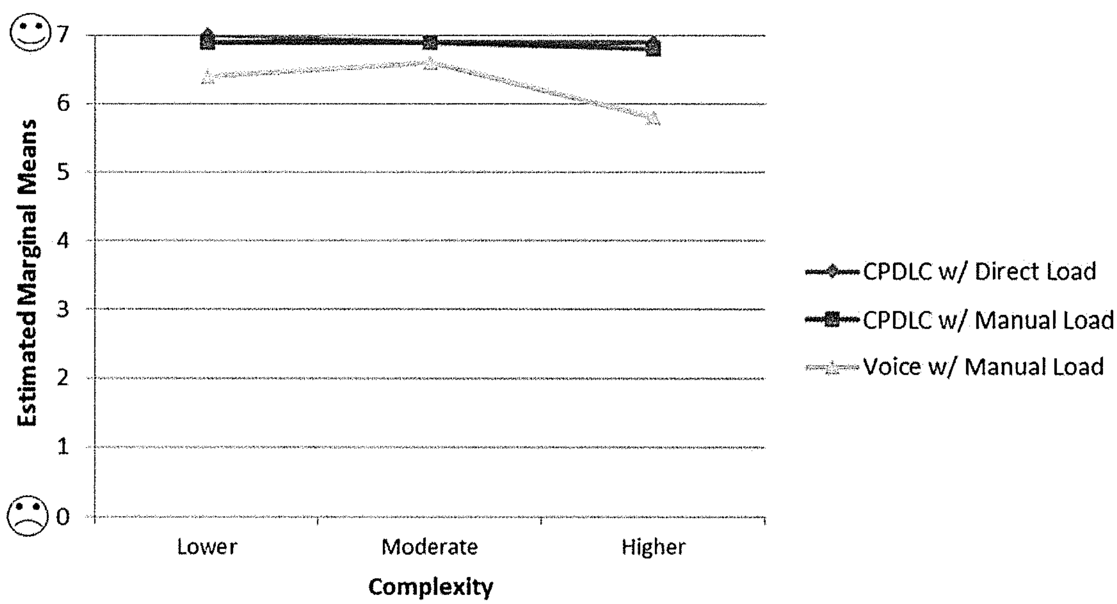


Figure 4-40. Relationship between Complexity and Communication Method for Pilot Responses to "I would be willing to receive the same [IM] clearance in a lower workload environment"

Across all scenarios, about half (33/60; 55%) of controller responses indicate that the controllers would be willing to issue the same IM clearance with a higher traffic load. The repeated measures MANOVA revealed a main effects for communication method [F(1,9)=8.938 p=.015]. The pairwise comparisons for the conditions revealed that controllers agreed with this statement more for scenarios where CPDLC (M=4.767, SE=.439) was utilized than scenarios where voice (M=3.633, SE=.308) was utilized. Controllers responses are shown in Figure 4-41. Figure 4-42 shows the relationship between complexity and communication method. Overall, results indicate that controllers thought the clearances had less acceptability in higher traffic environments when using voice than when using CPDLC.

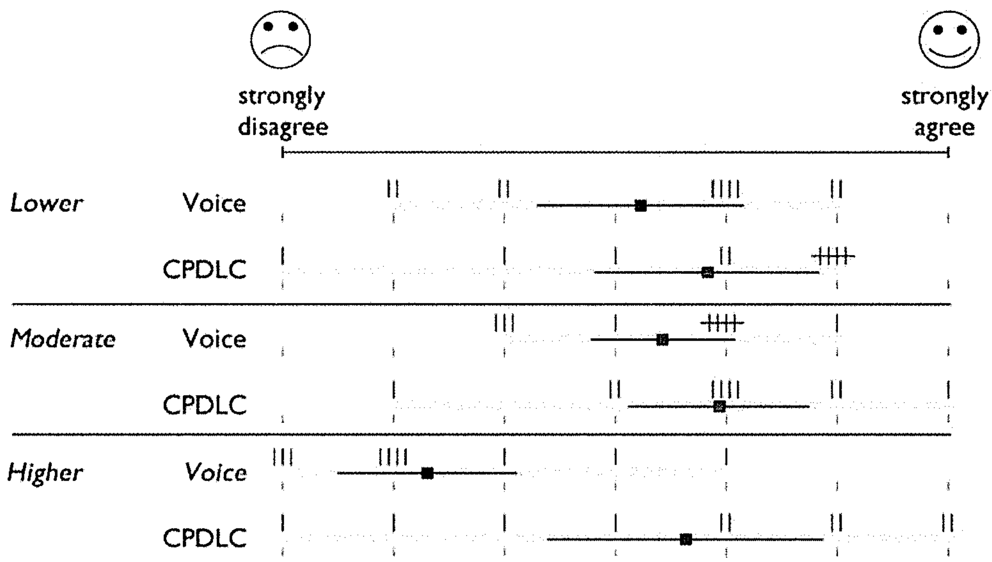


Figure 4-41. Controller Responses to "I would be willing to issue the same [IM] clearance with a higher traffic load"

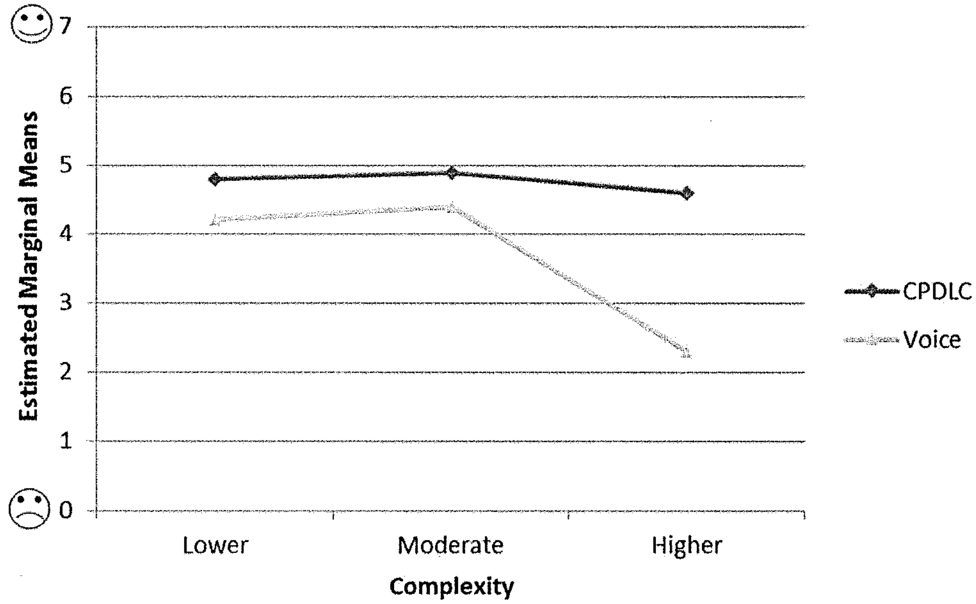


Figure 4-42. Relationship between Complexity and Communication Method for Controller Responses to "I would be willing to issue the same [IM] clearance with a higher traffic load"

Differences were found between scenarios when pilots were asked about receiving the same IM clearance in a higher workload environment. The repeated measures MANOVA revealed main effects for complexity [$F(2,38)=9.458$ $p=.000$], communication method [$F(1.387,26.183)=18.470$ $p=.000$] and the interaction of complexity and communication method [$F(4,76)=4.291$ $p=.003$]. The pairwise comparisons revealed that pilots agreed significantly more when they would receive Lower (M=6.117, SE=.227) and Moderate (M=5.883, SE=.213) complexity clearances than when they would receive Higher Complexity (M=5.300, SE=.270) clearances. Additionally, pilots agreed significantly more when they used CPDLC with Direct Load (M=6.350, SE=.178) and CPDLC with Manual Load (M=6.100, SE=.236) than when they used Voice with Manual Load (M=4.850, SE=.339). Again, the majority of pilot responses across all scenarios show general agreement with this statement, with the exception of the Higher complexity, voice communications scenario which showed quite a bit of variance in responses. Pilot responses are shown in Figure 4-43. Figure 4-44 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load had less acceptability in higher workload environments. Results indicate that pilots thought the Higher complexity clearance had less acceptability in higher workload environments as compared to the Lower and Moderate complexity clearances for both voice and CPDLC. Results also indicate that the clearances had less acceptability in higher workload environments when using Voice with Manual Load than when using either CPDLC with Manual or Direct Load.

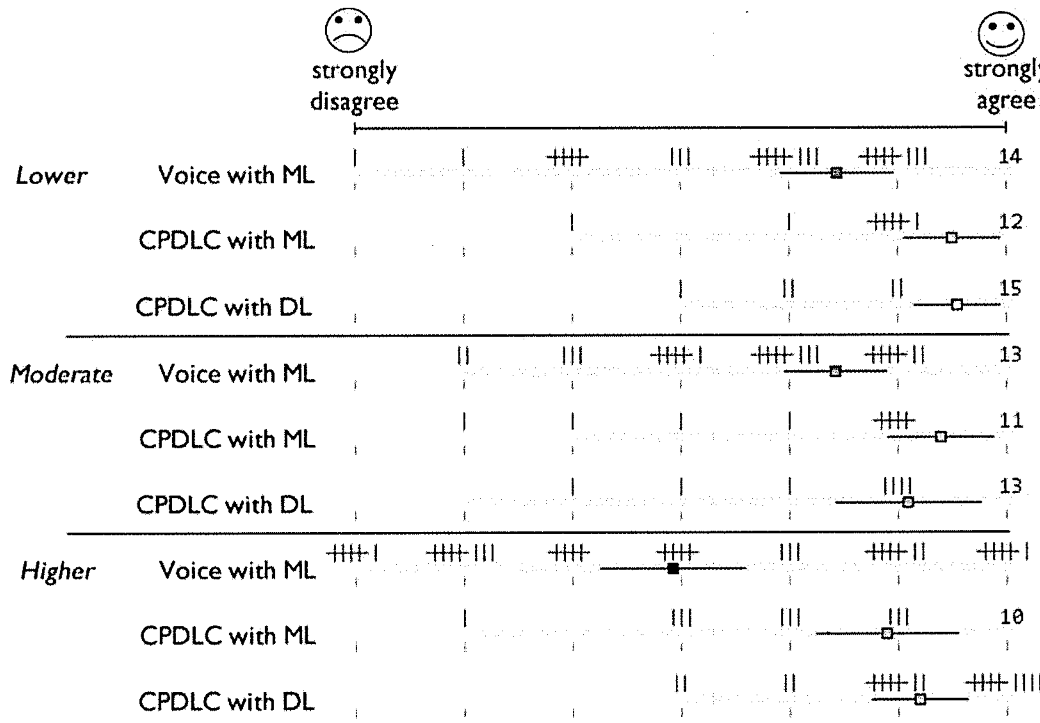


Figure 4-43. Pilot Responses to "I would be willing to receive the same [IM] clearance in a higher workload environment"

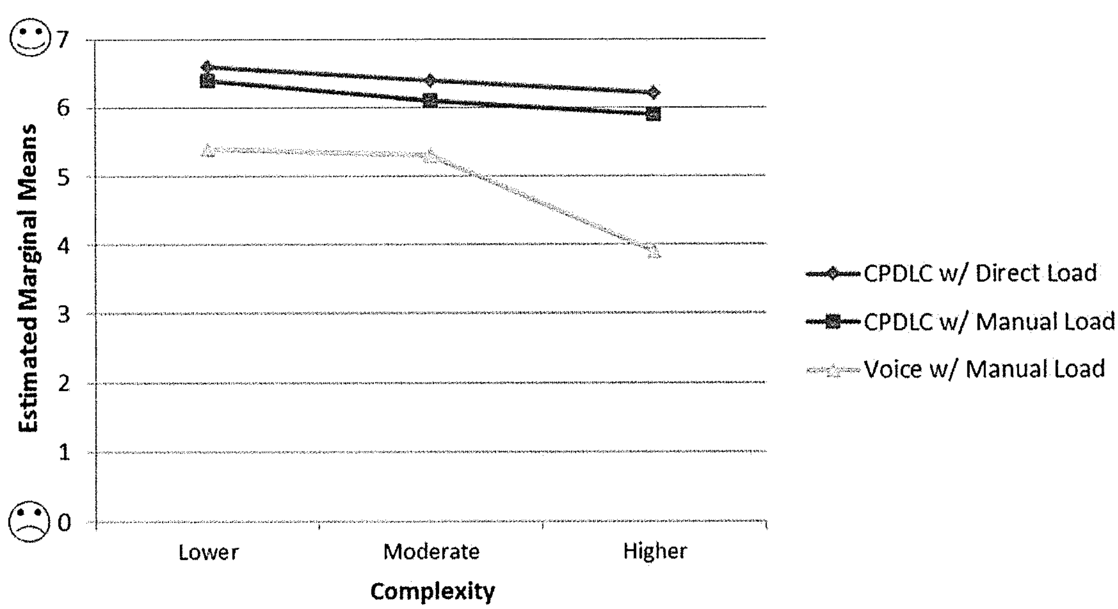


Figure 4-44. Relationship between Complexity and Communication Method for Pilot Responses to "I would be willing to receive the same [IM] clearance in a higher workload environment"

When pilots and controllers were asked to report acceptability on the statement "I can imagine at least one environment where this [IM] clearance would be acceptable," the majority of both controller (53/60; 88%) and pilot (201/208; 97%) responses indicated that across all scenarios they could imagine at least one environment. The repeated measures MANOVA for controllers and the repeated measures MANOVA for pilots revealed no significant results.

After completing the scenarios, the controllers were asked whether the different complexities of IM clearances had different levels of acceptability. The majority (8/10; 80%) replied "yes,"and two stated that the length of the IM clearances made the difference in acceptability while three others indicated that the communications containing waypoints were unacceptable over voice communications. When pilot were asked the same question, the majority (13/20; 65%) replied "yes." The most (7) comments were with issues related to the IFPI.

Controller responses were mixed on the open-ended question of which of the IM clearance complexity levels were acceptable. Four controllers commented that the lowest level of complexity message, which had routing information of "merging at KEEEN" was the only acceptable message. Three other controllers commented that the messages that contained published arrivals as the routing portion of the communication were also acceptable and one controller simply indicated that all clearances communicated over CPDLC were acceptable. During the debrief, participants reiterated that the most complex messages were difficult over voice but even the most complex messages would be acceptable over CPDLC.

All but one controller (9/10; 90%) agreed that they preferred using CPDLC rather than voice communications for IM clearances (M=6.5, SD=1.1). The one controller that did not agree was neutral and commented that it was preferred, but it took a long time to get a response over CPDLC. One of the controllers who strongly agreed said that CPDLC was especially preferred for longer route clearances. All (20/20; 100%) pilots responded that they would prefer the use of CPDLC rather than voice when receiving IM clearances (M=6.9, SD=0.3).

Pilots and controllers were asked for suggestions on improving the IM clearance. Pilot comments related to how to improve the IM clearances included 4 suggestions to only use CPDLC and 4 reporting issues related to the IFPI. Controllers were found to utilize strategies in an attempt to alleviate some of the confusion associated with the IFPI. One strategy included preemptively spelling the waypoints letter-by-letter phonetically instead of simply pronouncing the names as spelled (e.g., for the KEEEN waypoint, saying Kilo Echo Echo Echo November instead of "kēn" which can be spelled many ways). Another strategy involved splitting the IM clearance into two parts: one containing the basic IM information and a second communication containing the reference aircraft IFPI. Both methods appeared to help.

The most common suggestion from controllers was to not say "for interval spacing" in voice communications when issuing the actual clearance. Controllers were asked to use this phrase after issuing the advanced organizer "Interval spacing clearance available. Advise when ready to copy." Some controllers reported repeating "interval spacing" was unnecessary based on setting the context with the advanced organizer. In regards to the advanced organizer, half of the controllers (5/10; 50%) did not rate it as necessary. However, all pilots (20/20; 100%) rated this communication as necessary. During the debrief, most (15/20; 75%) pilots mentioned that the advanced organizer communication was helpful in managing their workload when initiating IM.

4.4.1.3 Other Interval Management (IM) Messages

Controllers were asked if there was a need for additional IM CPDLC messages that were not available in the simulation, and all but one (9/10; 90%) responded "no." The one that responded "yes" indicated that altimeter setting messages were needed, which are not actually IM messages. Pilots were asked the same question and the majority (14/20; 70%) replied, "no." Of the 5 comments, 2 were not related to IM. 2 were related to wanting confirmation messages from ATC.

As noted previously, the extra scenario was designed to examine the IM messages other than the IM clearance. Four additional messages were utilized. The responses on a question by question basis will be provided first in this section. Following those summaries, comments from participants on a message by message basis will be reviewed.

Controllers and pilots were asked whether "The time required to ("receive a response for the messages" / "reply to communications") over CPDLC is acceptable." The responses are shown in Table 4-2. As can be seen there was general agreement across the messages. However, controllers seemed to have concerns about the time required to receive a response for the pilot termination message "unable to continue interval spacing."

Table 4-2. Controller and Pilot Responses to "The time required to ("receive a response for the messages" / "reply to communications") over CPDLC is acceptable"

	Controller			Pilot		
Message	Mean	SD	N	Mean	SD	N
"Cancel interval spacing"	5.3	0.95	10	6.8	0.42	19
"Unable to continue interval spacing"	3.8	2.32	6	6.6	0.62	16
"Report starting interval spacing"	5.2	1.75	10	6.4	0.72	24
"Report assigned spacing interval behind [reference aircraft]"	5.2	1.40	10	6.4	0.83	24

Controllers and pilots were asked whether "The message exchange was acceptable." The responses are shown in Table 4-3. As can be seen there was general agreement across the messages. However, controllers seemed to have concerns about the message exchanges for the pilot termination message "unable to continue interval spacing."

Table 4-3. Controller and Pilot Responses to "The message exchange was acceptable"

	Controller			Pilot		
Message	Mean	SD	N	Mean	SD	N
"Cancel interval spacing"	5.0	1.76	10	6.6	1.0	20
"Unable to continue interval spacing"	3.0	2.00	7	5.6	1.68	25
"Report starting interval spacing"	4.9	1.85	10	6.2	1.20	16
"Report assigned spacing interval behind [reference aircraft]"	4.8	1.75	10	6.3	1.40	16

Controllers and pilots were asked whether "The [IM] communications were properly phrased." The responses are shown in Table 4-4. As can be seen there was general agreement across the messages. However, controllers seemed to have concerns about the phrasing of the pilot termination message.

Table 4-4. Controller and Pilot Responses to "The [IM] communications were properly phrased"

	Controller			Pilot		
Message	Mean	SD	N	Mean	SD	N
"Cancel interval spacing"	5.6	0.73	9	6.9	0.24	18
"Unable to continue interval spacing"	4.2	2.14	6	6.4	0.96	16
"Report starting interval spacing"	5.0	1.73	9	6.4	0.94	26
"Report assigned spacing interval behind [reference aircraft]"	5.6	0.74	9	6.6	0.84	28

Controllers and pilots were asked whether "The communication exchanges were clear." The responses are shown in Table 4-5. As can be seen there was general agreement across the messages. However, controllers seemed to have concerns about the clarity of communications related to the pilot termination message. Pilot responses also show a lower rating and higher variability for the pilot termination message, as compared to the other messages.

Table 4-5. Controller and Pilot Responses to "The communication exchanges were clear"

	Controller			Pilot		
Message	Mean	SD	N	Mean	SD	N
"Cancel interval spacing"	5.9	0.6	9	6.8	0.71	19
"Unable to continue interval spacing"	4.0	2.24	7	5.6	1.60	16
"Report starting interval spacing"	6.0	0.71	9	6.4	1.10	24
"Report assigned spacing interval behind [reference aircraft]"	5.8	0.67	9	6.5	0.81	26

Controllers and pilots were asked whether "Overall, the communications were acceptable." The responses are shown in Table 4-6. As can be seen there was general agreement across the messages. However, controllers seemed to have concerns about the clarity of communications related to the pilot termination message. Pilot responses also show a lower rating and higher variability for the pilot termination message, as compared to the other messages.

Table 4-6. Controller and Pilot Responses to "Overall, the communications were acceptable"

	Controller			Pilot		
Message	Mean	SD	N	Mean	SD	N
"Cancel interval spacing"	5.6	1.07	10	6.6	0.96	19
"Unable to continue interval spacing"	3.2	1.94	6	5.2	1.72	16
"Report starting interval spacing"	5.0	1.6	10	6.3	1.15	24
"Report assigned spacing interval behind [reference aircraft]"	5.0	1.4	2	6.5	0.87	25

Overall, responses indicate general acceptability of the additional IM messages. Very few comments were received for the "Report starting interval spacing" and "Report assigned spacing interval behind [reference aircraft]" messages. For the controller termination message "Cancel interval spacing" and the pilot termination message "Unable to continue interval spacing," both sets of participants suggested that this is better handled over voice communications (versus over CPDLC). Additionally, for the pilot termination message, several pilots reported confusion about whether controllers received the "unable" message. Pilots reported wanting a clear acknowledgement from the controllers. For all downlink messages, controllers reported missing new messages and wanted better notification that a message was received from the flight deck.

4.4.1.4 Communication Transaction Time

Two RCP-related measures were gathered (as specified in Figure 2-4).

- "Initiator performance" (from A to D in Figure 2-4)
- "Monitored performance" (from D to P in Figure 2-4)

Initiator performance was recorded for both voice and CPDLC for the controller (note: 14 of 60 values were unavailable for the Voice conditions for unknown reasons). A repeated measures ANOVA was run and revealed no significant results. Table 4-7 shows the mean times in seconds for the conditions. Figure 4-45 shows the relationship between complexity and communication method.

Table 4-7. Mean Time for Initiator (Controller) Performance (seconds)

IM Clearance Complexity	Voice	CPDLC
Lower	24.9	3.0
Moderate	22.8	4.5
Higher	25.5	6.3

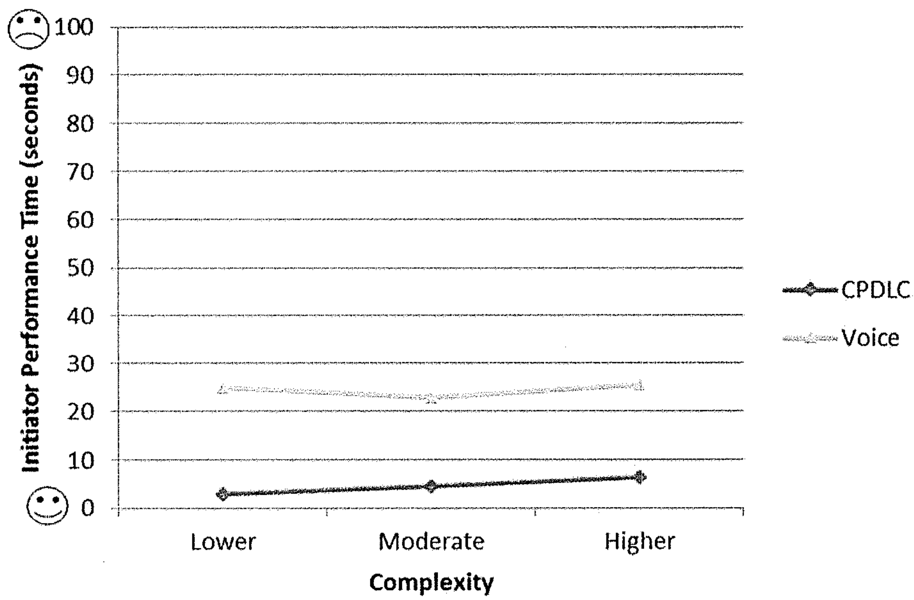


Figure 4-45. Relationship between Complexity and Communication Method for Mean Time for Initiator (Controller) Performance

Since the initiator performance is mainly of interest for CPDLC and RCP, the CPLDC data is detailed further. Figure 4-46 shows the initiator performance times for just the CPDLC conditions (M=4.6, SD=8.2). As can be seen, the vast majority (56/60; 93%) of cases were under 10 seconds. Additionally, 95% (57/60) were under 13 seconds (RCP130 nominal time) and 98% (59/60) were under 30 seconds. One outlier exists at 58 seconds (for unknown reasons).

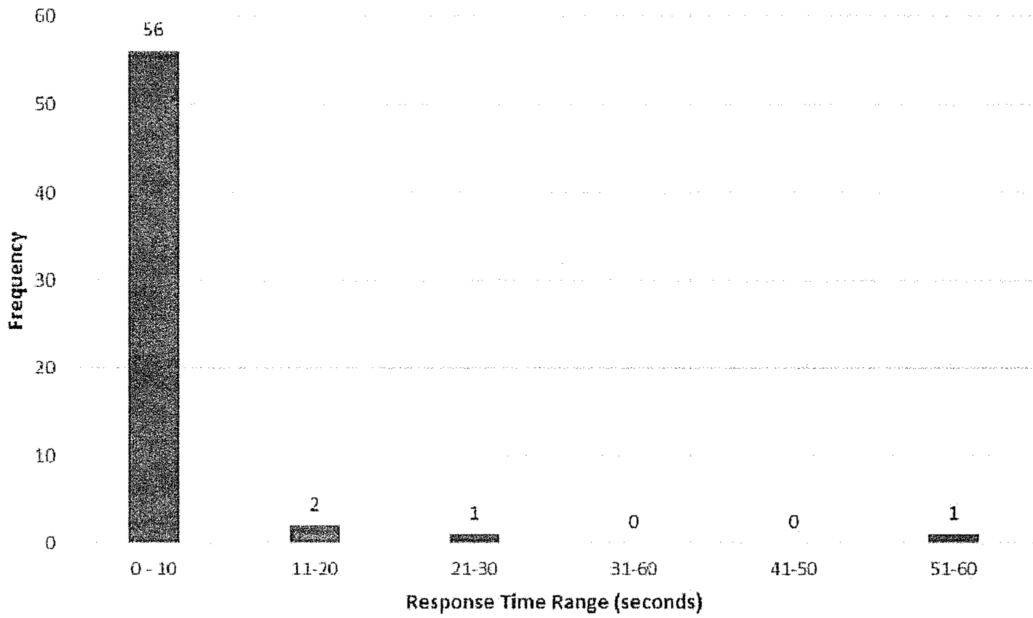


Figure 4-46. Initiator (Controller) Performance Times for CPDLC

Monitored performance was also recorded for both voice and CPDLC. The technical performance (from D to G and M to P in Figure 2-4) was not manipulated in this simulation. The technical time was based on message transit time in the lab and was under a second. Past work shows the average number in the real world to be around 5 seconds roundtrip (Matyas, 2013). For both voice and CPDLC, the time started when the message was issued and ended when the dialog was closed (as described in section 2.2.4). For voice, this meant that the time ended / the dialog was considered closed when any clarification communications were completed.

Monitored performance was measured in the three communication method conditions and the three levels of complexity. A repeated measures ANOVA revealed main effects for both complexity, $F(1.15,10.389)=5.113$, $p=.017$ and communication method, $F(2,18)=9.424$, $p=.01$. The test also revealed a significant interaction between communication method and complexity, $F(1.864,16.777)=6.518$, $p=.009$. The pairwise comparisons revealed that monitored performance was significantly lower in scenarios containing the Lower (M=25.580, SE=5.825) and Moderate (M=25.408, SE=3.425) complexity clearances when compared to the scenario containing the Higher (M=49.117, SE=6.672) complexity clearances. The pairwise comparisons also revealed that monitored performance was significantly lower in the CPDLC with Direct Load (M=21.400, SE=2.172) and CPDLC with Manual Load (M=26.200, SE=2.917) conditions when compared to the Voice with Manual Load (M=52.505, SE=7.982) condition. Table 4-8 shows the mean times in seconds for the conditions. Figure 4-47 shows the relationship between complexity and communication method. Overall, results indicate that the Higher and Lower complexity clearances done over Voice with Manual Load had greater monitored performance time than the other conditions. The Higher complexity messages appear to drive much higher monitored performance time when conducted via voice. Results indicate that the monitored performance time was greater for the Higher complexity messages as compared to the Lower and Moderate complexity clearances for both voice and CPDLC. Results also indicate that the monitored performance time was greater when using Voice with Manual Load than when using either CPDLC with Manual or Direct Load.

Table 4-8. Mean Time for Monitored Performance (seconds)

IM Clearance Complexity	Voice	CPDLC with Manual Load	CPDLC with Direct Load
Lower	44.0	16.7	16.0
Moderate	19.2	36.3	20.7
Higher	94.3	25.6	27.5

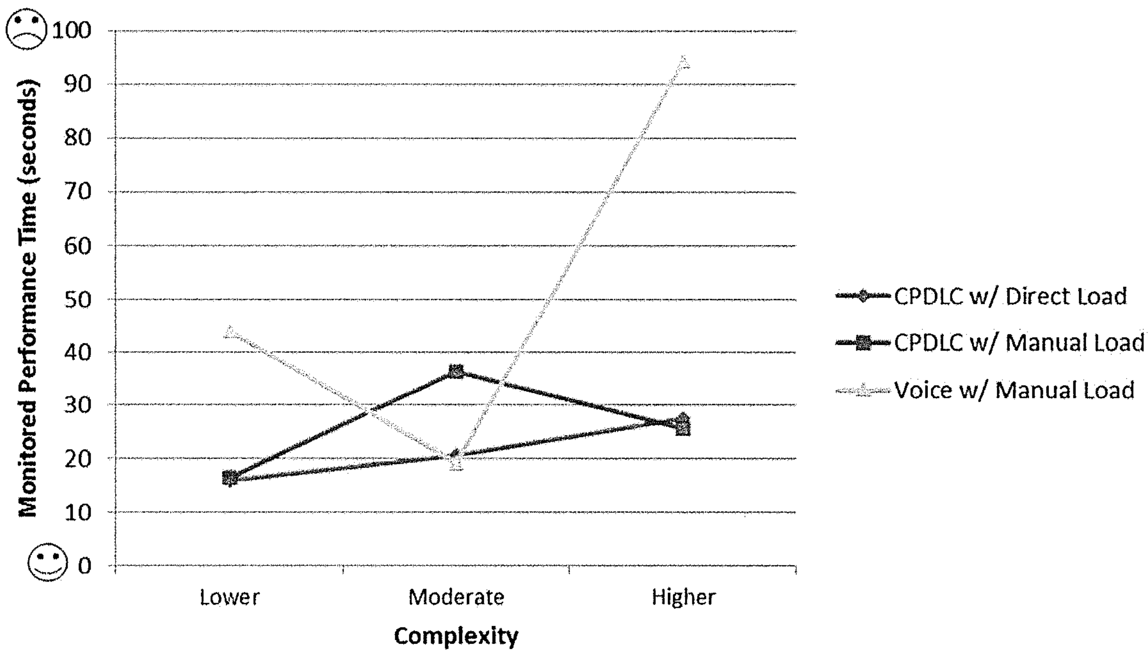


Figure 4-47. Relationship between Complexity and Communication Method for Monitored Performance Time

Figure 4-48 shows the monitored performance times for just the CPDLC conditions (CPDLC with Manual Load: M=26.2, SD=19.2; CPDLC with Direct Load: M=21.4, SD=8.9).

When considering these numbers for RCP, the figure shows the vast majority (57/60; 95%) of times were under 60 seconds. Additionally, 93% (56/60) were under 44 seconds (RCP130 nominal time). Three (3/60; 5%) outliers exist (for unknown reasons) in the 71 to 80 second range. All three were in the CPDLC with Manual Load Moderate complexity clearance condition and led to the higher mean seen for that condition.

If the initiator performance and monitored performance data are combined with data from Matyas (2013), the average transaction time (from A to Z in Figure 2-4) can be calculated. Note the time from P to Z in Figure 2-4 was basically zero since no controller action was required to display the message. The following equation uses rounded numbers to derive the average transaction time: 5 seconds (A to D) + 2.5 seconds (D to G) + 24 seconds (G to M) + 2.5 seconds (M to P) + 0 seconds (P to Z) = 34 seconds (A to Z / transaction time).

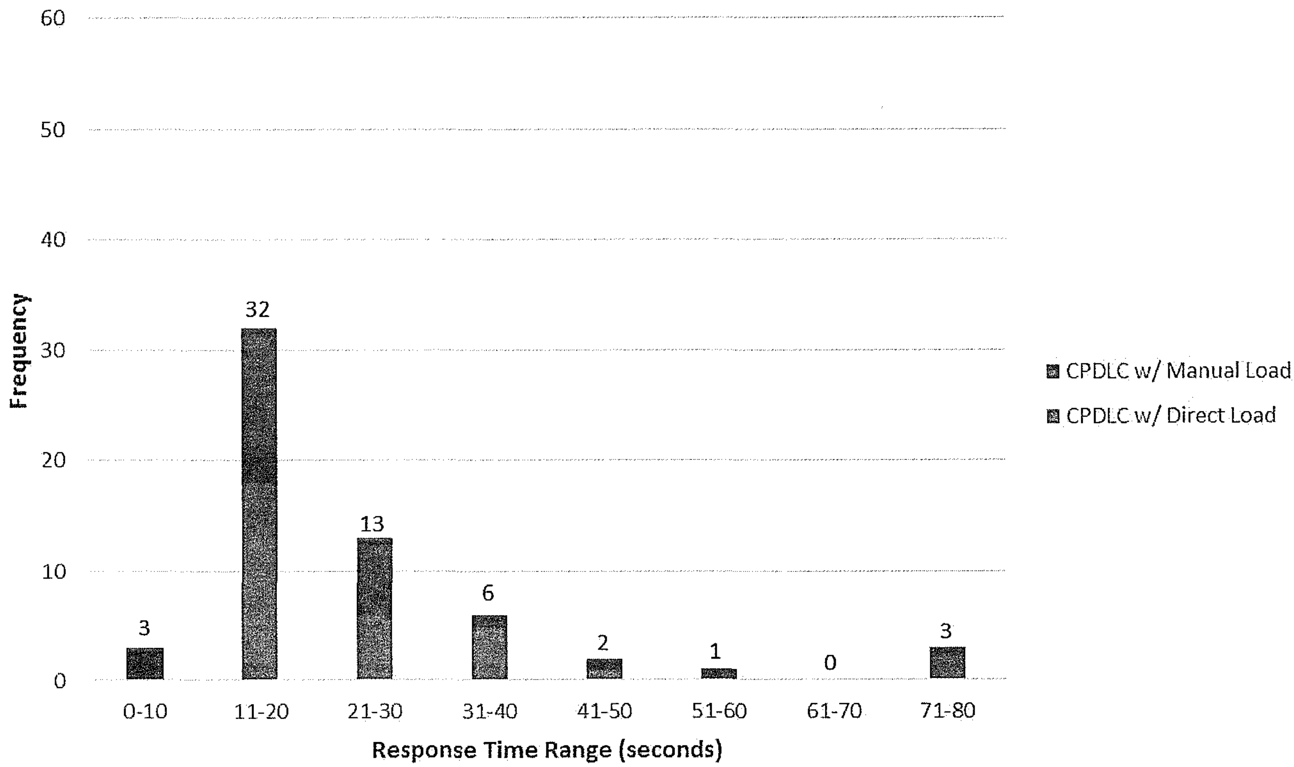


Figure 4-48. Monitored Performance Times for CPDLC

Pilots and controllers were asked about the message exchange times. All pilots agreed that the time available to respond to IM clearances over CPDLC was acceptable. When controllers were asked whether the time required to receive a response for the individual IM clearances over CPDLC was acceptable, the majority (8/10; 80%) agreed. Two controllers disagreed. One that disagreed commented and said he was waiting on pilots and that it was quicker to use voice. One controller that agreed said the response time would need to be less than 120 seconds. Another controller that agreed said there was never a delay.

In addition to examining the time required for exchanges between the controller and flight deck, the time required for the flight crew to start IM after replying to the clearance was also examined. The flight deck process time was defined as the time it takes the flight deck to input the clearance and configure the onboard automation to begin conducting the IM operation. During CPDLC conditions, flight deck process time began when the flight deck selected the "ACCEPT" button in response to a clearance. During voice conditions, flight deck process time began once the clearance was successfully read back to ATC. For both CPDLC and voice conditions, the flight deck process time ended when the flight deck selected "ARM" on the CDTI.

Flight deck process time was measured in the three communication method conditions and the three levels of complexity. A repeated measures ANOVA revealed a main effect only for communication method [F(2,14)=19.547 p=.000]. The pairwise comparisons revealed that CPDLC with Direct Load (M=55.195, SE=6.488) resulted in significantly faster flight deck process times when compared to flight deck process times for the CPDLC with Manual Load (M=112.801, SE=11.335) and Voice with Manual Load (M=136.193, SE=12.052) conditions. Figure 4-49 shows the relationship between complexity and communication method. As would be expected, the ability to directly load a message yielded a lower time between acknowledging a message and being able to engage the operation.

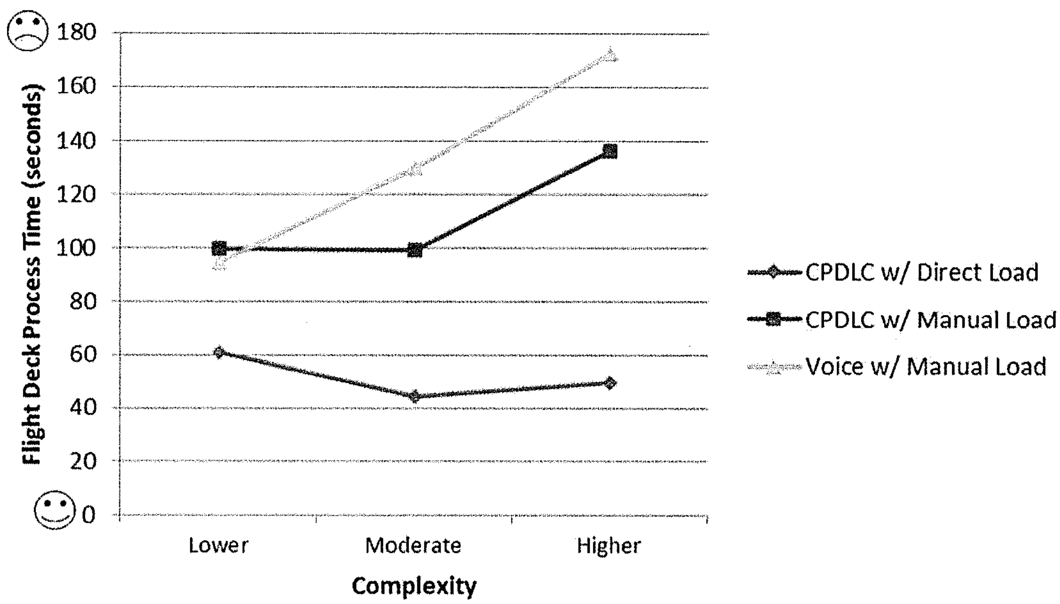


Figure 4-49. Relationship between Complexity and Communication Method for Flight Deck Process Time

4.4.1.5 Time on Frequency

The time on which the subjects (ATC and Flight Deck) were on the frequency (from PTT down to PTT up) was recorded during each scenario for all communications. Table 4-9 depicts the mean time on frequency for the combination of complexity (Lower, Moderate, and Higher) and the primary communication mode for the frequency (CPDLC and Voice).

Table 4-9. Mean Time on Frequency (seconds)

	ATC		Flight Deck	
IM Clearance Complexity	Voice	CPDLC	Voice	CPDLC
Lower	534	271	52	12
Moderate	550	227	50	6
Higher	557	270	82	17

The data were analyzed using a repeated measures ANOVA. The analysis revealed a main effect of complexity [F(2,18)=8.426 p=.003] for the pilot time on frequency and a main effect of communication method for both the pilot [F(1,9)=166.094 p=.000] and controller [F(1,9)=132.172 p=.000]. Additionally, the test revealed a main effect for the interaction of complexity and communication mode for the pilot, $F(2,18)=4.868$ $p=.020$. The pairwise comparisons revealed that time on frequency was significantly longer for the pilot in the Higher complexity (M=49.587, SE=6.354) than in the Lower (M=32.056, SE=3.545) and Moderate (M=28.117, SE=1.050) complexity conditions. The pairwise comparisons also revealed that time on frequency was significantly higher for both ATC and Flight Crew in scenarios when voice was the only communication mode (controller M=547.086, SE=32.426; pilot M=61.318, SE=3.950) than scenarios which contained CPDLC (controller M=253.127, SE=12.913; pilot M=11.855, SE=2.668). The relationship between complexity and communication method for time on frequency is shown in Figure 4-50 for controllers and in Figure 4-51 for pilots. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load yielded significantly more time on frequency. As would be expected, less time is spent on the voice frequency for both pilots and controllers when using CPDLC, even in a 50/50 split of voice and CPDLC communications.

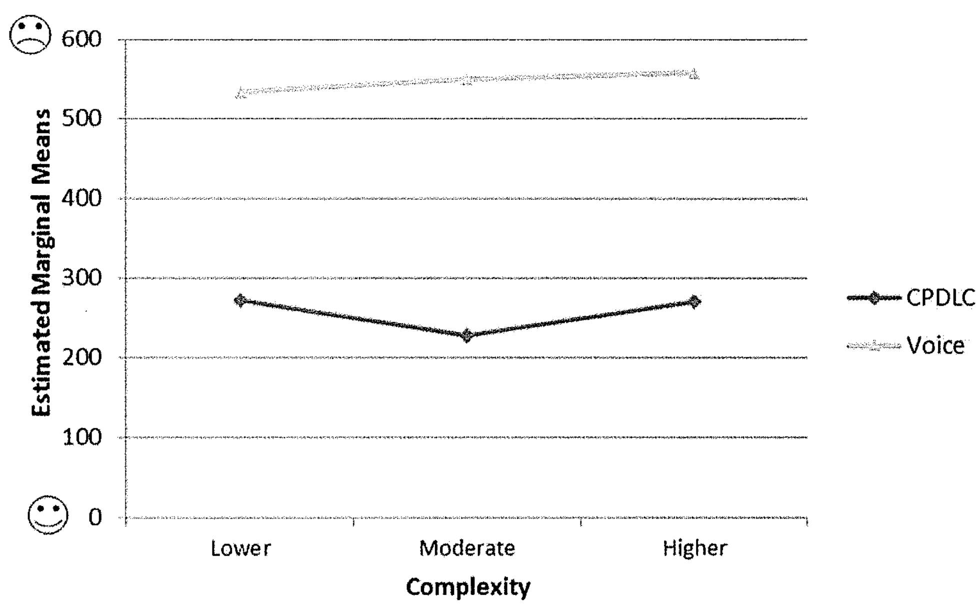


Figure 4-50. Relationship between Complexity and Communication Method for Time on Frequency for Controllers

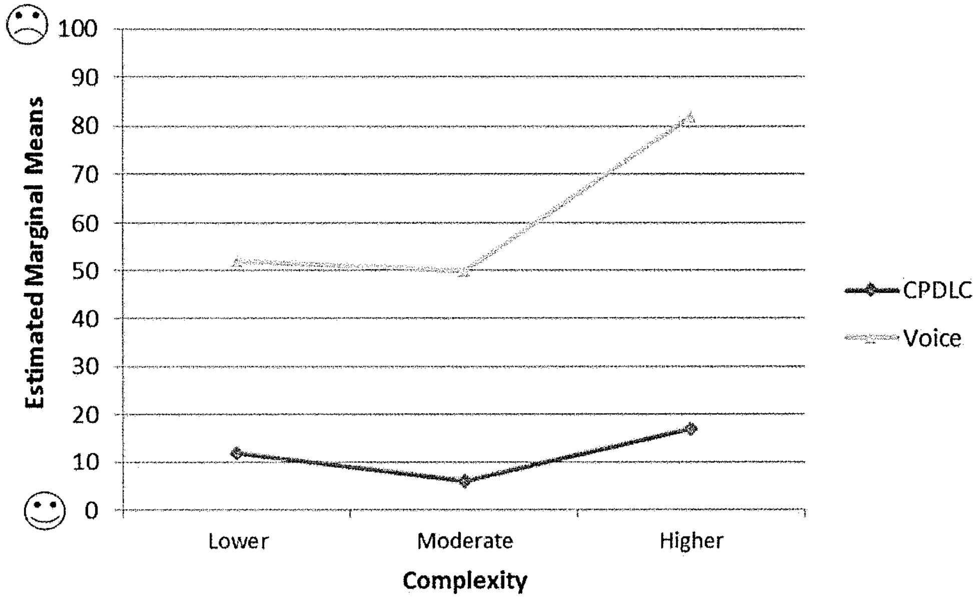


Figure 4-51. Relationship between Complexity and Communication Method for Time on Frequency for Pilots

4.4.2 Procedures

During the simulation, pilots were asked to accept the IM clearances before entering the information into their CDTI and receiving the first IM speed (i.e., follow A-P procedures). Controllers were asked if these procedures for initiating IM were acceptable. Figure 4-52 shows the controller responses for voice and CPDLC. As can be seen, the majority (9/10; 90%) of the controllers found the procedures acceptable with CPDLC while 40% (4/10) found the procedures acceptable with voice communications. Pilot the responses were similar. Figure 4-53 shows the pilot responses for voice and CPDLC. For CPDLC, all of the pilots (20/20; 100%) agreed. For voice communications, 50% (10/20) of the pilots agreed.

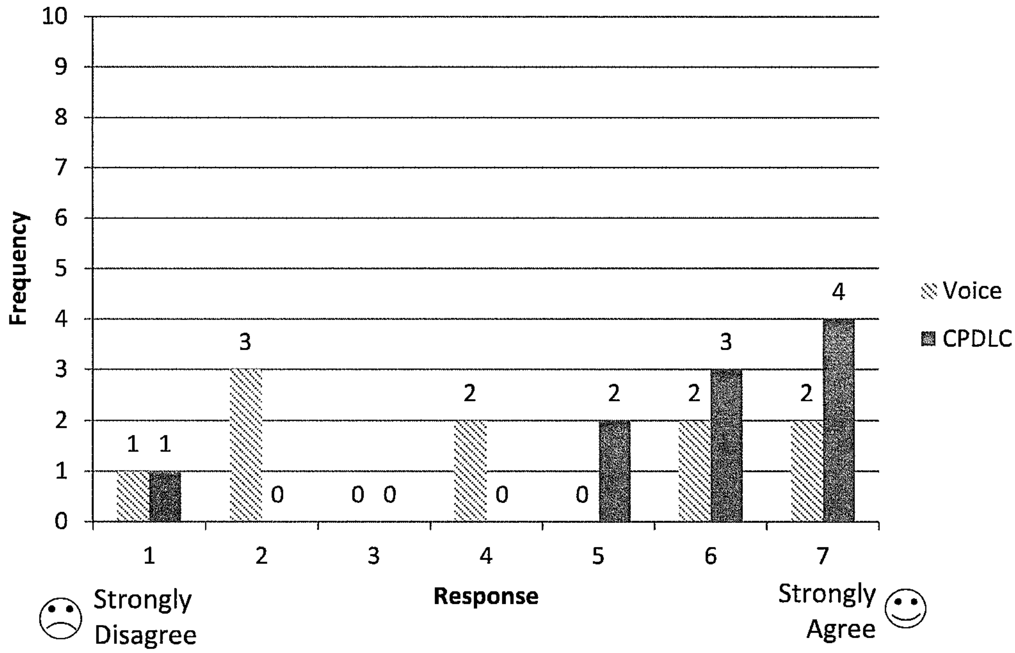


Figure 4-52. Controller Responses to "The procedures defined as the flight crew receiving an [IM] Clearance, responding to the clearance, entering it into the FIM equipment, and then ensuring they can fly the first [IM] speed was acceptable"

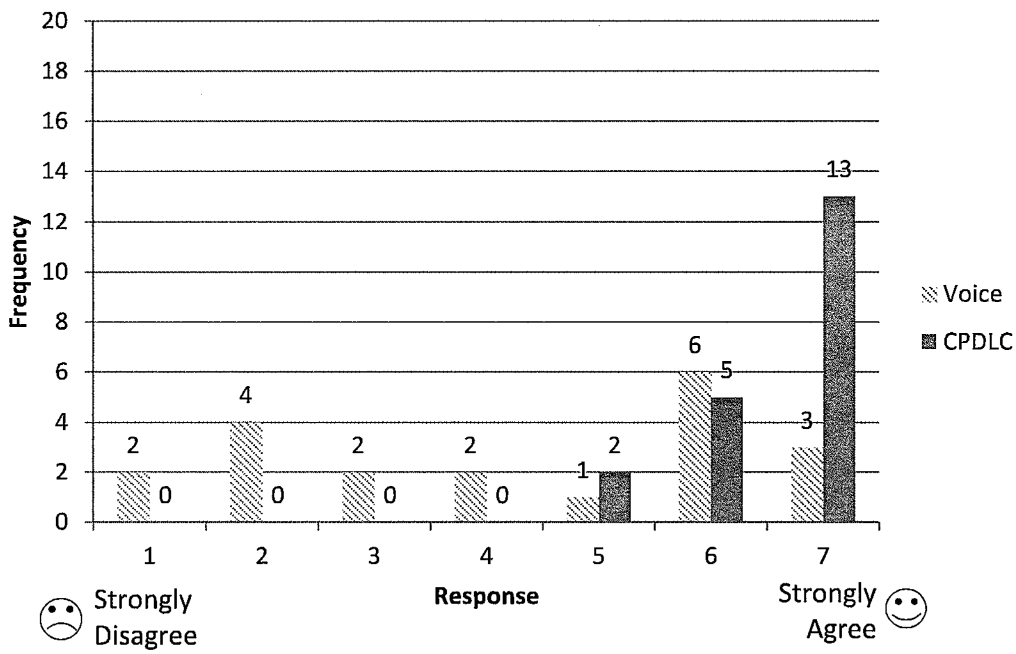


Figure 4-53. Pilot Responses to "The procedures defined as receiving a [IM] clearance, reading it back to ATC, entering it into the FIM equipment, and then receiving the First [IM] speed was acceptable"

Pilots and controllers were also asked to speculate whether it would be preferable for the flight crew to accept the IM clearance only after ensuring they could fly the first IM speed (i.e., follow P-A procedures). Controller results were mixed for both voice and CPDLC (Figure 4-54). Two controller comments indicated that there would be some concern with the amount of time it would take to receive a response. One controller commented that it was not a concern whether or not the aircraft could fly the IM speeds because it was rare for the aircraft to be unable. Pilot results were also mixed (Figure 4-55). Two pilots that agreed commented that they would feel more comfortable ensuring the operation is possible before accepting the clearance, and one pilot that disagreed commented that the time it would take to respond would cause issues and if an unacceptable IM speed were presented, they could simply terminate the operation later. Two pilots recommended accepting the clearance to let ATC know they received it, then providing an additional communication to let ATC know they are commencing spacing when the first IM speed is presented.

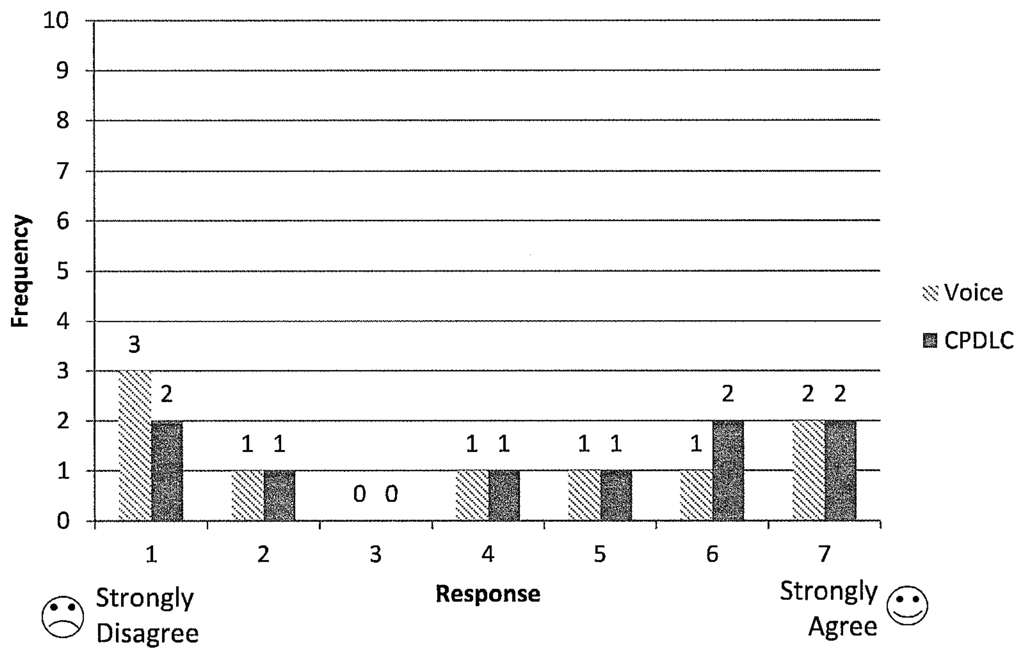


Figure 4-54. Controller Responses to "It would be preferable for the flight crew to accept the [IM] Clearance only after ensuring they can fly the first [IM] speed"

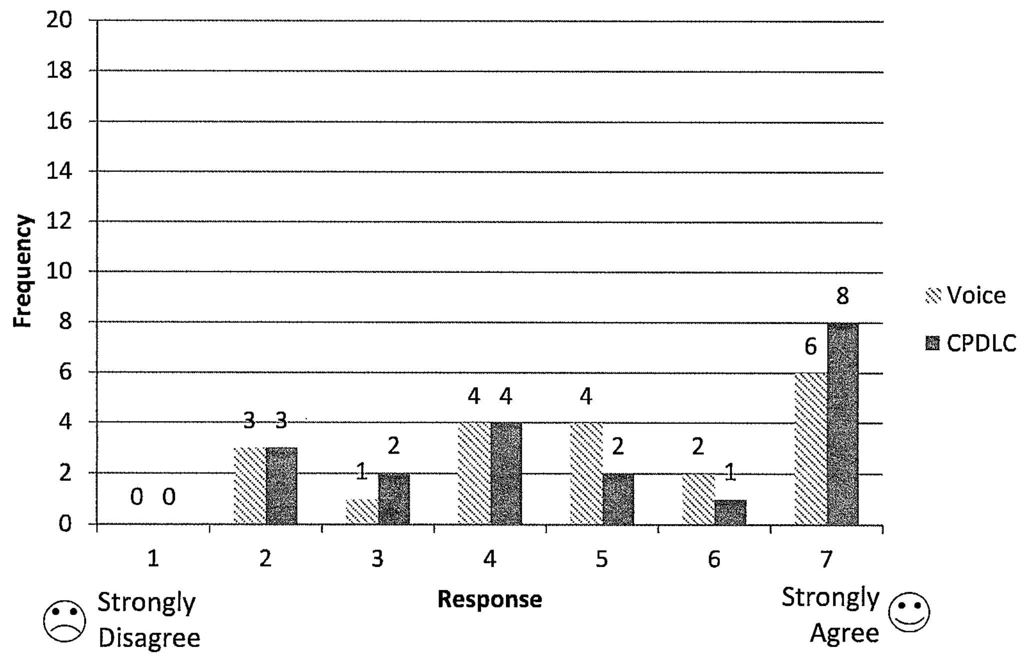


Figure 4-55. Pilot responses using Voice Communications to "It would be preferable to accept the [IM] clearance only after entering it into the FIM equipment and then receiving the first [IM] speed"

4.4.3 Workload

After each scenario, controllers and pilots were asked to rate their workload on the BWRS. A repeated measures ANOVA was run to assess whether significant differences were present (test 2 noted in Section 4.1.1). Controller responses demonstrate a low level of workload across all scenarios. The repeated measures ANOVA revealed no statistical significance. However, the Higher complexity IM clearance over voice shows the most variability. Figure 4-56 shows controllers responses. Figure 4-57 shows the relationship between complexity and communication method.

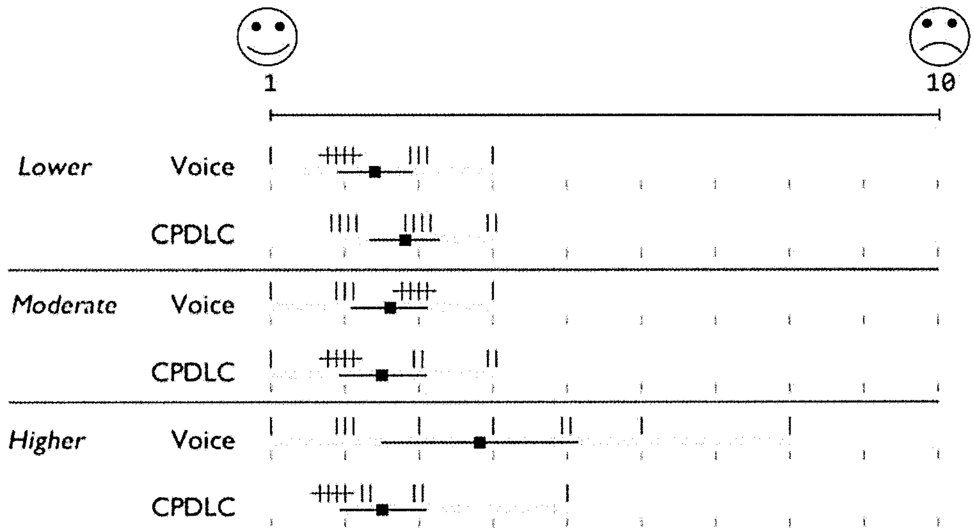


Figure 4-56. Controller Responses to Bedford Workload Rating Scale

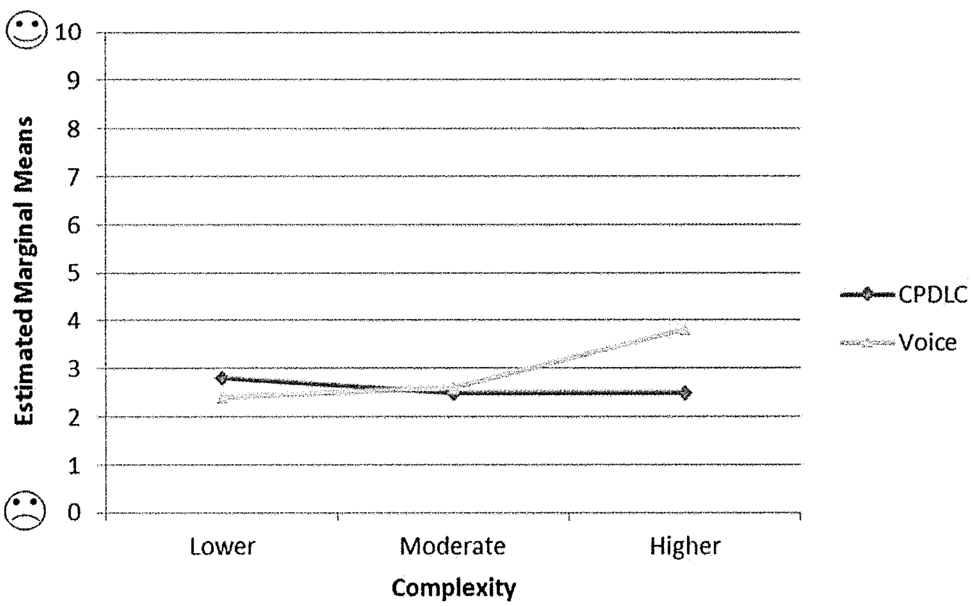


Figure 4-57. Relationship between Complexity and Communication Method for Controller Responses to Bedford Workload Rating Scale

Pilots were also asked to rate their perceived workload using the BWRS after each run. The ANOVA revealed a main effect of complexity [F(1.529,29.042)=7.002 p=.006], communication method [F(2,38)=21.556 p=.000], and an interaction of complexity and communication method [F(4,76)=8.932 p=.000]. A pairwise analysis of the data revealed that workload was rated significantly higher in the Higher IM clearance complexity scenarios (M=2.408, SE=.194) when compared to the Lower IM clearance complexity (M=1.992, SE=.140) and Moderate IM clearance complexity scenarios (M=2.017, SE=.153). Additionally, a pairwise comparison revealed that workload ratings were significantly different for each level of the communication method condition, with CPDLC with Direct Load (M=1.767, SE=.130) being significantly lower than Voice with Manual Load (M=2.617, SE=.205) and CPDLC with Manual Load (M=2.033, SE=.153). Figure 4-58 shows the pilot responses. Figure 4-59 shows the relationship between complexity and communication method. Overall, the pilot results indicate that the Higher complexity clearances done over Voice with Manual Load drive up pilot workload.

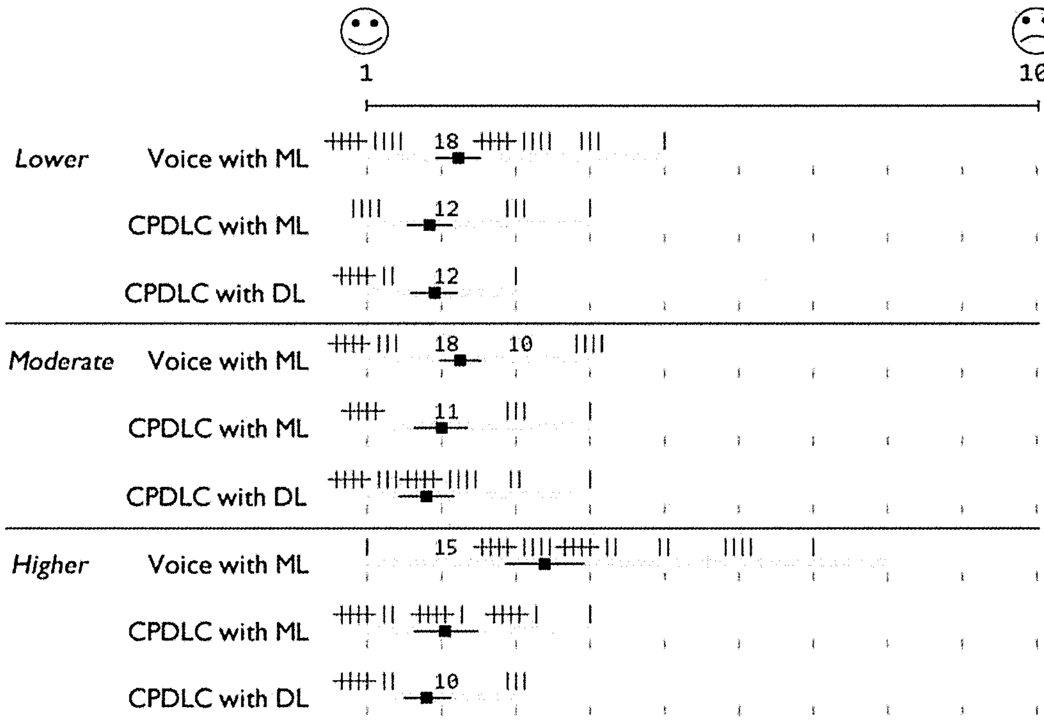


Figure 4-58. Pilot Responses to the Bedford Workload Rating Scale

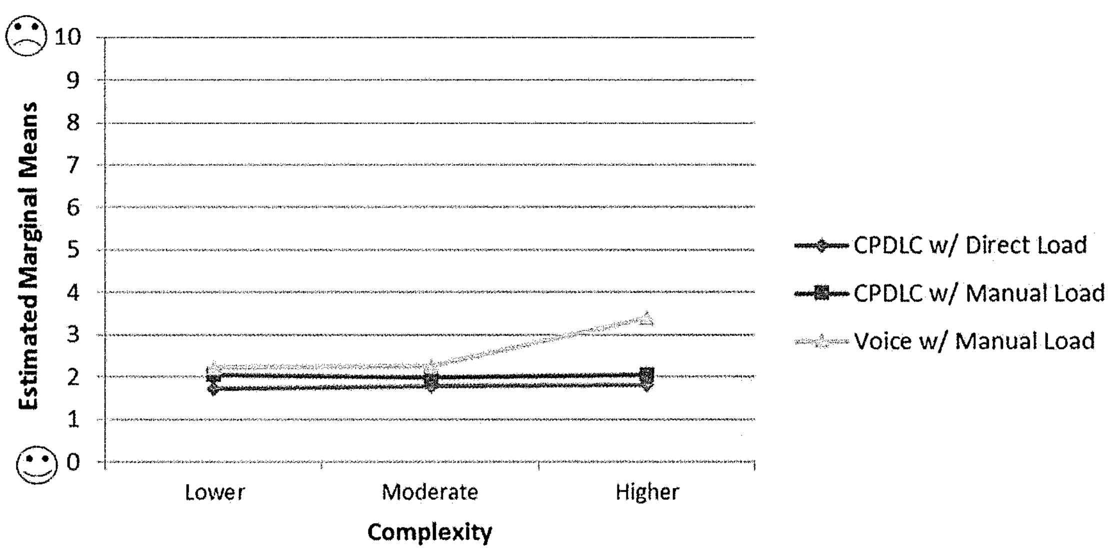


Figure 4-59. Relationship between Complexity and Communication Method for Pilot Responses to the Bedford Workload Rating Scale

To further examine controller workload when using CPDLC, the average number of open messages (i.e., open dialogs) and the peak number of messages in the queue were tracked. Table 4-10 shows the average number of CPDLC messages open at any given moment. As can be seen, controllers did not have more than one message, on average, open awaiting action at any given moment. Table 4-11 shows the peak number of messages in the queue. The queue length was often very short and very rarely reached 4 messages.

Table 4-10. Average Number of Open CPDLC Dialogs

IM Clearance Complexity	Average Open Dialogs
Lower	0.26
Moderate	0.24
Higher	0.51

Table 4-11. Percentage of Scenario Time at a Given Queue Length

	Queue Length				
IM Clearance Complexity	0	1	2	3	4
Lower	79.1	15.9	4.6	0.4	0.0
Moderate	80.2	16.1	3.4	0.3	0.0
Higher	61.0	27.5	10.0	1.4	0.1

4.4.4 Interfaces

Controllers were asked about the interface used for IM during this simulation, and the majority (9/10; 90%) reported that they would be willing to perform IM with the displays used (M=5.7, SD=1.6). One controller commented that they did not like the amount of display space the extra windows (Spacing List and Clearance Template) took up on the scope, and two others commented on the lack of use of color to indicate different steps in the IM procedures, and the fact that all IM information disappeared upon the passing of the data block to the next sector but before the communications were transferred. The majority (7/10; 70%) also reported not having any difficulties using the interface for IM, and that the presentation of the IM clearance in the Clearance Template was acceptable (M=5.4, SD=1.3). When asked whether the direct loading of the IM clearance into the CPDLC interface was acceptable, the majority (9/10; 90%) agreed and one was neutral (M=6.1, SD=1.0).

The majority of controllers (7/10; 70%) reported not having any difficulties with the interface for CPDLC, although some comments indicate that the procedures for sending a CPDLC message contained too many steps. This seemed to be an artifact of the interface design used solely for this simulation, as controllers were required to select an aircraft, select the message to construct, then send the message by clicking the "uplink" button. The majority of controllers (8/10) commented that this was too many clicks of the mouse to send a simple message.

All pilots (20/20; 100%) rated their head down time during the simulation as acceptable (M=5.4, SD=1.8). When asked if the manual loading of the IM clearance into the CDTI was acceptable, responses were mixed for voice communications (Figure 4-60) (M=4.1, SD=1.7). Four pilot comments indicated that the reference aircraft IFPI and TPCS caused the most problems. They also mentioned that manual loading created more opportunities to make errors. One pilot commented that feedback from the system when fixes or TPCSs were spelled wrong would be helpful. All pilots (20/20; 100%) agreed that the manual loading of the IM clearance into the CDTI was acceptable for CPDLC communications (M=6.1, SD=0.8), and all pilots (20/20; 100%) agreed that the direct loading of the IM clearance into CDTI was acceptable (M=6.8, SD=0.5). The direct loading feature was used 100% of the time by the pilots.

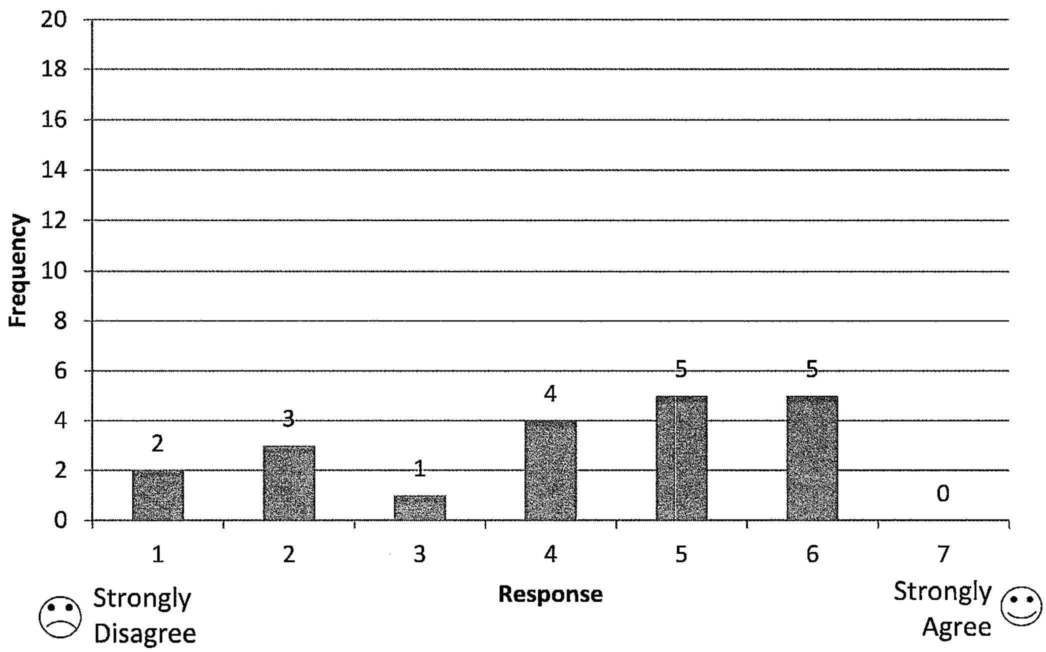


Figure 4-60. Pilot Responses to "The manual loading of the [IM] clearance into the FIM system was acceptable" when using voice communications

The majority of pilots (18/20; 90%) agreed that the presentation format of the IM clearance message on the CDU was acceptable, although some indicated difficulties when having to scroll through multiple pages to review the longer IM clearances (M=6.4, SD=1.0). One flight crew commented that it was not always clear that there was further detail on the next page.

4.5 Simulation

Participants were asked to indicate their level of agreement with the following statement: "The overall simulation was effective as a context for evaluating [IM] and CPDLC." The majority (9/10; 90%) of the controller agreed (M=6.1, SD=1.0). One was neutral. The majority (19/20; 95%) of pilots also agreed (M=6.2, SD=1.0). One disagreed and wondered how it would work where clearances are assigned later in the arrival. Participants were also asked if they received an adequate amount of training. All (10/10; 100%) of the controllers reported getting an adequate amount of training. The majority (18/20; 90%) of pilots reported getting an adequate amount of training. The two that replied "no" commented. One wanted material prior to arriving and the other wanted more training on when an IM clearance overrides an ATC clearance.

4.6 Statistical Results Summary

Figure 4-61 Figure 4-62 and on the following pages provides a summary of the statistical test outcomes.

ATC		Complexity Level			Comm method	Interaction
		L v M	L v H	M v H	CPDLC v V	
MANOVA (Subjective)	The [IM] Clearance I issued to the pilots was acceptable					
	Pilot read backs of the [IM] Clearance over voice were acceptable					
	I would be willing to issue the same [IM] clearance in a *higher* workload environment					
	I would be willing to issue the same [IM] clearance with a *lower* traffic load					
	I can imagine at least one environment where this [IM] clearance would be					
	The *length* of the [IM] Clearance communications was acceptable					
	The complexity of the [IM] Clearance communications was acceptable					
	The [IM] Clearance communication exchanges were clear					
	Overall, the [IM] Clearance communications were acceptable					
ANOVA (Subjective)	Bedford Worlkload Rating Scale					
ANOVA (Subjective)	Rate the *complexity* of the [IM] Clearance					

Pilot		Complexity Level			Comm method			Interaction
		L v M	L v H	M v H	C-D v C-M	C-D v V-M	C-M v V-M	
MANOVA (Subjective)	The [IM] Clearance I received from ATC was acceptable							
	I would be willing to receive the same [IM] clearance in a *higher* workload environment							
	I would be willing to receive the same [IM] clearance with a *lower* workload							
	I can imagine at least one environment where this [IM] clearance would be acceptable							
	The *length* of the [IM] Clearance communications was acceptable							
	The *complexity* of the [IM] Clearance communications was acceptable							
	The [IM] Clearance communication exchanges were clear							
	I was able to retain the [IM] Clearance info							
	Overall, the [IM] Clearance communications were acceptable							
ANOVA (Subjective)	Bedford Workload Rating Scale							
ANOVA (Subjective)	Rate the *complexity* of the [IM] Clearance							

Not significant
Significant. First better

Key
C-D: CPDLC with Direct Load
C-M: CPDLC with Manual Load
H: Higher
L: Lower
M: Moderate
V: Voice
V-M: Voice with Manual Load

Figure 4-61. Subjective Statistical Test Outcome Summary

		Complexity Level			Comm method			Interaction
		L v M	L v H	M v H	C-D v C-M	C-D v V-M	C-M v V-M	
ANOVA (Objective)	RCP - Monitored performance							
ANOVA (Objective)	RCP - Flight deck process time							

		Complexity Level			Comm method	Interaction
		L v M	L v H	M v H	CPDLC v voice	
ANOVA (Objective)	Time on frequency - ATC					
ANOVA (Objective)	Time on frequency - Pilot					
ANOVA (Objective)	Communication Issues					

	Not significant
	Significant. First better

Key
C-D: CPDLC with Direct Load
C-M: CPDLC with Manual Load
H: Higher
L: Lower
M: Moderate
V: Voice
V-M: Voice with Manual Load

Figure 4-62. Objective Statistical Test Outcome Summary

5 Discussion

Three main topic areas were examined during this simulation, along with additional results regarding the IM and CPDLC concepts in general. The three main areas were: communications, procedures, and interfaces. These are discussed below. Following a discussion statement, support for the relevant hypotheses (from Section 3.6) is shown.

5.1 Interval Management (IM) and Controller Pilot Data Link Communications (CPDLC)

When examining the union of two capabilities, it is important to understand the acceptability of the concepts individually first. For the IM concept, the vast majority of controllers and pilots agreed that IM is operationally acceptable. The one controller who did not agree commented on the length and complexity of the IM clearance, which is one of the main topics of examination for the simulation. A couple of pilot comments related to acceptability were related to the complexity of the IM clearance and the need for CPDLC. The simulation was testing the boundaries of acceptability so it is not surprising that this may have influenced the acceptability of the underlying concept(s). While the controllers found the concept acceptable, the majority did report issues with conducting IM in a mixed IM equipage environment, e.g., one in which not all aircraft are capable of IM. It may be that the 50% IM equipage examined in this simulation was insufficient equipage. However, 50% IM equipage showed benefits and feasibility for controllers in work such as Boursier, et al. (2006). Therefore, it could be that the IM clearance complexity had an impact on the acceptability of the equipage levels.

For CPDLC, the vast majority of pilots and controllers reported they preferred using CPDLC for the complex messages in the simulation and that all non-IM messages were acceptable. The level of 50% mixed CPDLC equipage appeared to be less of an issue for controllers (as seen in Hébraud and Cloërec, 2007 and Willems et al., 2010) than it was for IM. While liking CPDLC, both controllers and pilots reported wanting to and actually reverting to voice communications. The reversions to voice for the pilots were often for termination of IM or to get clarification on the reference aircraft IFPI or IM procedures. Confusion over termination procedures has been a source of confusion in past simulations (e.g., Bone et al., 2008). Controller reasons included reverting to voice for time critical messages such as the instruction to cancel the IM clearance. Others reported that voice was sometime easier due to habit or the longer times associated with CPDLC. The desire to revert to voice is expected and acceptable. It is allowed for in future environments with CPDLC (Gonda et al., 2006).

5.1.1 Communications

The simulation showed more communication issues when using voice as compared to when using CPDLC. This result is to be expected and is one of the claimed benefits of CPDLC. This simulation further validated that claim. The simulation also showed many more communication issues when conveying the Higher IM clearance (with 10 elements) over voice communications. These trends were further validated by the pilot reports of follow-on communications. They reported less follow-on communication with CPDLC than with voice. With voice, they reported needing more follow-on communications when communicating about the Higher IM clearance.

The simulation also revealed that CPDLC reduced the amount of time both controllers and pilots spend on the voice frequency. Pilot and controller time on the voice frequency was fairly consistent within either voice or CPDLC across the IM clearance complexity levels. However, the one outlier is when pilots were using voice communications for the Higher complexity IM clearances. In that case, the pilots spent significantly more time on the voice frequency relative to the other conditions.

TPCS was a specific topic of interest because of the potential confusion introduced by its use. The TPCS use can be an issue for pilots when the airline telephony designator (e.g., "Brickyard") does not closely match the airline three letter designator (e.g., "RPA") on the CDTI traffic display (Bone, 2013). TPCS can also be an issue for the reference aircraft whose call sign is being used. The flight crew may think the communication is for them and query the controller or actually act upon an instruction intended for another aircraft. Most controller and pilot responses indicated general acceptability of TPCS use. Most problems were related to the reference aircraft call sign spoken in the voice communication (the airline telephony designator) not matching the reference aircraft call sign shown on the CDTI traffic display (the airline three letter designator). A slight majority of controllers reported that it would be acceptable to use the airline three letter designator rather than the airline telephony designator.

5.1.1.1 Interval Management (IM) Message Set

The IM message set includes several different messages as defined in RTCA and EUROCAE (2013). The IM clearance will be discussed separately from the rest of the communications as it was a focus of the simulation due to the expectation of more issues related to its complexity.

5.1.1.1.1 Interval Management (IM) clearance

The IM clearances used in the simulation were constructed based on the draft IM CPDLC message set established for CPDLC in RTCA and EUROCAE (2013). The majority of the scenarios examined variations in the IM clearance since it is expected to be the most complex IM message. The most complex IM clearances may be problematic over voice communications. Specific IM clearances were developed to represent the complexity desired for each scenario. The final set of IM clearances chosen were relatively complex but were still believed to be possible over CPDLC and potentially over voice communications. The IM clearance elements used in this simulation across all scenarios were the reference aircraft call sign / TPCS, ASG, and achieve-by point. The reference aircraft IFPI was also used. It was varied across the scenarios to allow for additional complexity since it was cited as being most challenging element in the IM clearance in past work (e.g., Bone, 2014). Three levels of complexity were used. The IM clearances either had 6 (Lower), 7 (Moderate), or 10 (Higher) elements. These complexity levels were expected to have the potential to cause communication issues based on past research (e.g., Cardosi, 1993).

Numerous questions were asked about the acceptability of the IM clearance. While the following paragraphs will review those results, general trends can be summarized.

The pilots:

- Consistently found the Higher complexity IM clearances when using the Voice with Manual Load communication method to be the least favorable set of conditions (not supporting M-9 but pointing to a potential issue).
- Consistently showed a preference for the Lower and Moderate complexity IM clearances as compared to the Higher complexity IM clearances (supporting M-7, M-8, M-10, and M-11).
- Consistently showed a preference for CPDLC with Manual Load and CPDLC with Direct Load over Voice with Manual Load (supporting M-10, M-11, and M-12).
- Showed acceptability of all conditions (supporting M-7, M-8, M-10, M-11, and M-12; not supporting M-9) even though there were differences found among the conditions.

The controllers:

- Had fewer statistically significant results and had higher variability in their responses. The most variability in replies appears to have been with the Higher Complexity IM clearances under both Voice and CPDLC.
- Preferred CPDLC over voice communications although it seemed to be less of a factor when considering questions on the IM clearance.

Across both pilots and controllers, the Higher complexity IM clearances over voice condition seemed to be the least favorable, and it had significantly more communication related issues when compared to the other conditions.

Pilots and controller responses indicated that the IM clearance was well phrased but that shortening it would improve acceptability. Reference aircraft IFPI came up as the most problematic element of the IM clearance (as with Bone, 2014; Baxley et al., 2013). Pilots found the IM clearance exchanges to be clearer for the Lower and Moderate clearance complexities as compared to the Higher clearance complexities. While the tests on controller replies for the question of IM clearance clarity did not reveal significance, the Voice condition results had high variability. Pilots reported being able to retain the IM clearance information better under both CPDLC conditions than under the Voice with Manual Load condition.

When asked if overall, the IM clearance communications were acceptable, controller responses showed a preference for CPDLC but no difference for the complexities. Pilots preferred both CPDLC conditions over the Voice with Manual Load condition as well as the Lower and Moderate complexity conditions over the Higher complexity condition. The Higher complexity IM clearances when using the Voice with Manual Load communication method stood out as being the least favorable set of conditions.

When asked about the length of the IM clearances, controllers showed high variability. Pilots again preferred both CPDLC conditions over the Voice with Manual Load condition and the Lower and Moderate complexity conditions over the Higher complexity conditions. Again, the Higher complexity IM clearances when using the Voice with Manual Load communication method stood out as being the least favorable set of conditions.

While differences existed when asked about using the same IM clearance in lower workload conditions, both pilot and controller responses indicated that they would. When asked the same thing for higher workload conditions, controller replies indicated that they would be less willing to issue the Higher complexity IM clearances under higher traffic loads. Issuing the Higher complexity IM clearance appeared to be more problematic for the Voice condition. Pilot replies showed general acceptability, but the Higher complexity IM clearances when using the Voice with Manual Load communication method stood out as being the least favorable set of conditions for higher workload environments.

When pilots and controllers were asked how to improve the IM clearance, pilots brought up the reference aircraft IFPI most often. Most controller comments were related to the removal of a phrase when issuing the IM clearance over voice. Controllers issued the advanced organizer "Interval spacing clearance available. Advise when ready to copy" prior to issuing the IM clearance when using voice communications. The intent was to alert the pilot that a lengthy clearance was going to be issued and that they may want to prepare to write it down. The most common suggestion from controllers was to not say "for interval spacing" in the follow-up IM clearance. Some controllers reported repeating "interval spacing" was unnecessary based on setting the context with the advanced organizer. In regards to the advanced organizer, all pilots (20/20) rated this communication as necessary while only half of the controllers found it necessary.

Overall, CPDLC use seemed to improve pilot acceptability of the complex clearances. The differences in acceptability between the CPDLC with Direct Load and CPDLC with Manual Load for the Higher complexity IM clearances appeared minimal. This may not be the case as the IM clearances increase in complexity beyond that of the Higher condition with 10 elements tested in this simulation. At some point, direct loading from the CPDLC system to the flight deck IM equipment may be necessary, especially when the number of elements in the clearance is over 25 like those seen in Baxley et al. (2013).

Based on past research and literature, the following includes some thoughts on the acceptable number of elements / level of complexity of the IM clearances. Past research in a voice environment found around 4 - 7 elements in an IM clearance to be acceptable (e.g., Mercer et al., 2005; Hassa, et al., 2005). Past research has also found 6 elements in an IM clearance acceptable in a flight deck CPDLC with manual load environment (i.e., Nyberg, 2006). Finally, past research found both 9 and 27 elements in an IM clearance to be acceptable in a flight deck CPDLC direct load environment (Prevot et al., 2007; Baxley et al., 2013). The simulation described in this paper examined 6, 7, and 10 elements in each of the three environments.

Based on this simulation and past research, the 4 - 7 element range appears to be acceptable for the IM clearance over voice communications in an en route environment. However, caution should be exercised at and above 4 - 5 elements based on issues noted for non-IM clearance communications in past research (e.g., Cardosi, 1993; Cardosi, 1994; Burki-Cohen, 1995). Eight to 10 elements may be reaching the limitations of voice communications for the IM clearance. At these levels of complexity, it may still be necessary or desirable to take other measures to reduce complexity such as using two communications, where the second communication includes only the reference aircraft IFPI. It should be noted that the acceptability of the complexity of the IM clearance over voice communications in this simulation may have been impacted by the use of the advanced organizer "Interval spacing clearance available. Advise when ready to copy." This communication informed the flight crew that a complex IM clearance was going to be issued and prepared them to write it down. This likely increased the acceptability of the IM clearance as all of the pilots reported this communication as necessary. It should also be noted that the simulation was conducted in an en route environment where pilot workload may be lower than other environments like during final approach in the TRACON. The number of elements may need to be fewer in high workload environments, based not only on the demands of communications and other flight deck tasks, but the need for the flight crew to enter the IM clearance information into the flight deck IM equipment.

If the IM clearance needs, at a minimum, the term "for interval spacing," the achieve-by point (may be optional for some implementations), the time interval and units, as well as the reference aircraft call sign, five elements are already utilized. That implies that the reference aircraft IFPI should be limited to around 2 - 5 elements during voice communications. That number would need to be reduced if other elements such as a termination point or IM turn were utilized.

The following thoughts for the acceptability of CPDLC IM clearance complexity assume support for the controller for IM clearance generation. For CPDLC with the ability to directly load the IM clearance into the flight deck IM equipment, ten to 27 elements may be acceptable. An exact upper limit is unknown, but 27 may be near that limit. For CPDLC with only a manual load option, ten (or maybe more) elements appear acceptable. Again, an upper limit is unknown. For CPDLC with manual load, the message content will be available for the pilot to view, which improves acceptability. However, the effort and time required to enter all the information into the flight deck IM equipment will likely be the issues that determine the acceptable upper limit on the number of elements / level of complexity.

5.1.1.1.2 Other Interval Management (IM) messages

One of the goals of the simulation was to determine whether the necessary set of messages was available in the international CPDLC standards community (now reflected in the draft document RTCA and EUROCAE, 2013). While those messages are defined for CPDLC, they are also expected to be very similar, if not the same, as those that will be used over voice communications. The IM clearance was discussed in the previous section. The additional messages that were examined in the extra scenario are the topic of this section. Not all the messages were able to be examined but key messages were examined. Additional uplink and downlink message were examined. The following messages were examined in the extra scenario.

- **ATC clearance with "when able…report starting spacing"** – "When able, for interval spacing, cross KEEEN 120 seconds behind United 123, merging at KEEEN. Report starting interval spacing."
    - Flight crew reply – "Interval spacing behind United 123"
- **ATC request to report ASG** – "Report assigned spacing interval behind United 123."
    - Flight crew reply – "Assigned spacing interval 120 seconds behind United 123"
- **ATC termination** – "Cancel interval spacing."
- **Flight crew termination** – "Unable to continue interval spacing"

Controller and pilot responses to several questions after using these messages indicate that the messages are necessary. The messages also appear to be well phrased and allow for acceptable and clear communication exchanges in both voice and CPDLC (supporting M-5 and M-6). Pilots and controllers did not identify the need for any additional messages under the conditions simulated (supporting M-1, M-2, M-3 and M-4). The main comments related to these messages were about termination messages and were more about procedures versus the messages themselves. Both pilots and controllers reported that termination is likely best done over voice communications due to the delay in CPDLC. Pilots also reported that they were unsure whether the controller received their "unable" (termination) message. Pilots wanted clearer acknowledgement from the controllers upon receipt of the "unable" (termination) message.

5.1.1.2 Communication Transaction Times

The RCP concept exists "to ensure the acceptable performance of communications within a complete ATM system" (ICAO, 2013, p. 2-2). An RCP type is defined as the point from which the controller starts to generate a message to the point when the controller receives a response to that message. The human is likely the main contributor to the allocated time. For ACARS over VDL Mode 2, the technical performance has been found to be 4.8 seconds on average, 11.0 seconds for 95%, and 90.3 seconds for 99.9% (Matyas, 2013). At the time of the simulation, RCP180 was derived for IM. However, after completion of the simulation RCP180 was no longer specified. RCP130 was the next closest RCP type and was chosen for IM (RTCA and EUROCAE, 2014). Select time requirements for RCP130 are shown in section 2.2.4.1.

The vast majority (95%) of the monitored performance times (mainly the pilot reaction time) were under 60 seconds (supporting RCP-1). This is in line with ICAO (2013, section 5.3.2.4) which states that one minute is expected to be sufficient time to read and respond to a CPDLC message. It is similar to that seen by Pepitone et al. (2013) who showed mean response times of 44.5 seconds for non-IM messages. It is also less than the approximately 60 seconds seen in Baxley et al. (2013) for more complicated IM clearances for CPDLC with direct loading. Additionally, 93% of the monitored performance times were under 44 seconds, which is the RCP130 95% nominal time requirement. The monitored performance time seen in the simulation was very close to the 95% requirement. For the initiator (controller) performance time, 95% of the times were under the RCP130 95% nominal time requirement of 13 seconds. While not a specific RCP measurement / requirement, the average total transaction time in this simulation was 34 seconds when adding mean times seen in the simulation and mean times defined in other bodies of work (i.e., Matyas, 2013).

In this current study, both CPDLC with Manual Load and CPDLC with Direct Load had faster pilot responder performance times than the Voice with Manual Load method. These positive results counter those seen by Pepitone et al. (2013) where they did not see differences in response times for manual versus direct loading. The lack of a difference in that work appears to be, in part, due to the flight crew having to follow the P-A procedure.

The majority of pilots and controllers agreed that the times seen in the simulation were acceptable. Controllers had very few messages / dialogs open and rarely got above a peak of 3 message in the queue. Controllers reported acceptable workload for CPDLC with Manual Load and CPDLC with Direct Load (supporting RCP-2). The results from the simulation closely align with the RCP130 specifications detailed in RTCA and EUROCAE (2014).

5.1.2 Procedures

Flight crews can use two methods to accept a clearance: A-P and P-A (Gonda et al., 2013). A-P and is typically followed in voice communications. For IM it is applied in the following manner: the controller issues an IM clearance, the flight crew accepts the clearance after doing a reasonableness check, enters the IM clearance information into the CDTI, conducts a cross-flight deck verification, and then arms the flight deck IM equipment. The flight crew only needs to come back to the controller and report an issue if they are not able to conduct IM (e.g., the IM speed cannot be flown). The second method is termed Process-then-Accept (P-A). In this situation, the flight crew does not accept the clearance until after reading, loading, and executing the clearance information. The P-A method obviously will take longer for the controller to receive a reply to close the dialog.

Both pilots and controllers found the A-P acceptable for both CDPLC with Direct Loading and Manual Loading. The IM clearance complexity did not seem to be an issue for A-P (supporting P-1). However, both also expressed concerns about using A-P in a voice environment. The reasons were unclear as to why they were not concerned about the process for CPDLC but showed some concern for voice communications. The pilot reply variability may be related more to concerns about making errors over voice communications than the actual A-P procedure or it could be the interrelationship between the two. While both groups expressed concerns about A-P use during voice communications, they did not seem to think P-A was better. Pilot and controller results were mixed when asked whether P-A should be used for CPDLC and for voice. It should be noted that the time it took for the pilots to start IM after acknowledging the clearance was on average around two minutes for the manual loading conditions (i.e., voice and CPDLC). That would be additional time the controller would have to wait for final dialog closure. This lengthy amount of time would have an impact on RCP. Additionally, past research (e.g., Hebraud et al., 2004; Barmore, Abbott, and Capron, 2005) has not indicated the P-A was required for IM. It should be noted that the CPDLC with Direct Load reduced that time to less than half. Controllers had very limited messages / dialogs open and reported acceptable workload for CPDLC with Manual Load and CPDLC with Direct Load (supporting P-2).

The majority of controllers reported not having issues working in a mix communication environment of 50% voice and 50% CPDLC (supporting P-4). When considering voice for non-routine and urgent messages, it seemed to work well in the simulation. The procedure of transitioning to voice communications mainly seemed to occur when either (1) attempting to gain clarity about confusing IM clearance elements such as reference aircraft IFPI or TPCS or (2) terminating IM. These transitions appeared to work well even if they were undesirable (supporting P-3).

5.1.3 Interfaces

Controllers and pilots had new interfaces for both CPDLC and IM. Controller displays were based on previous work done independently for both IM and CPDLC (Peterson et al., 2012; National User Team FAA ATO ERAM, 2012; and FAA, 2010). Pilot interfaces were based on work done in past simulations and fielded equipment (Bone et al., 2008; Penhallegon and Bone, 2014). The interfaces used in the simulation were notional implementations and were not intended to be the final design / implementation.

The majority of controllers reported finding both the IM and CPDLC interfaces individually acceptable (supporting I-10). The few suggestions that were made for improvements are reflected in the recommendations in the next section.

The majority of pilots also reported finding both the IM and CPDLC interfaces individually acceptable. Some pilots expressed confusion when messages spanned multiple pages on the CDU. Some reported missing information when not realizing additional detail was on another page.

The main area of interest for this simulation was the interaction between the IM and CPDLC equipment. The important need to consider the integration of ground and flight deck systems in new operations has been noted as an area that is often neglected (Weiner, 1989; Kerns, 2010). For controllers, the IM clearance messages were sent from the IM system to the CPDLC system and were automatically generated for the controller's confirmation prior to sending. The vast majority of controllers reported that the direct loading of the IM clearance into their IM system was acceptable. For pilots, two CPDLC conditions were tested: one where the messages were presented on the CPDLC display and then manually loaded into the flight deck IM equipment and another where the messages were presented on the CPDLC display and then could be directly loaded into the flight deck IM equipment for flight crew confirmation prior to IM engagement.

Across complexities, pilot responses were mixed on the acceptability of manually entering the voice-issued IM clearances into the flight deck IM system. The Voice with Manual Load was consistently rated poorer then both CPDLC with Manual Load and CPDLC with Direct Load (supporting I-4, I-5, I-6, I-7, I-8, and I-9). However, the Lower and Moderate complexity IM clearances were regularly reported as more acceptable than the Higher complexity IM clearances (supporting I-1, I-2). This indicates that the Higher complexity messages are the problematic ones over voice (not supporting I-3 but pointing to a potential issue).

The direct loading feature was used 100% of the time by the pilots. This might be explained by the pilots being asked to use the direct load feature, but there were no reports of pilots stating they did not want to use it. This is in line with Baxley et al. (2013) where it was the required procedure. However, it is higher usage than reported by Pepitone et al. (2013). The lower usage seen by Pepitone et al. (2013) was stated as being related to some messages being easier to manually enter and pilots missing the "load" option. It also appears that it could be related to not all elements in their simulated messages being loadable, which lead to flight crew confusion. All elements in the IM clearances tested in this simulation were loadable.

6 Conclusions and Recommendations

The goal of this research was to conduct a human-in-the-loop simulation to investigate the integration of two advanced NextGen capabilities across both the air and ground domains in order to uncover any complications that could arise from capabilities that have been developed separately. In addition, the findings from this research are intended to support answering outstanding questions for IM and CPDLC such as the validity and acceptability of currently defined IM CPDLC messages as well as their performance parameters and procedures. The simulation focused on three levels of IM clearance complexity (Lower, Moderate, and Higher) and different modes of communication (i.e., voice only versus CPDLC and voice). Flight crew communications were further examined by allowing for the CPDLC message to either be manually loaded or directly loaded from the CPDLC equipment into the flight deck IM equipment.

The majority of pilots and controllers found the integration of the NextGen capabilities of IM and CPDLC acceptable. Controllers seemed to have more difficulty with traffic with a mix of aircraft equipage for IM than they did for a mix of aircraft equipage for CPDLC. Both pilots and controllers found the A-P procedures acceptable for both CDPLC with Direct Loading and CPDLC with Manual Loading. Both pilots and controllers expressed concerns about A-P use during voice communications; however, they did not seem to think P-A was better.

Both pilots and controller preferred CPDLC over voice communications. However, both recognized that voice is still necessary for urgent instructions, such as some IM terminations. CPDLC messages have an associated RCP concept that exists "to ensure the acceptable performance of communications within a complete ATM system" (ICAO, 2013, p. 2-2). The vast majority of times associated with the CPDCL communications aligned with the RCP130 requirements. CPDLC also reduced the time both controllers and pilots spent on the voice frequency.

Overall, pilot and controller responses indicated that the IM clearance was well phrased but that shortening it would improve acceptability. Reference aircraft IFPI came up as the most problematic element of the IM clearance (as with Bone, 2013; Baxley et al., 2013). TPCS was mainly an issue for voice communications based on the fact that the call sign used in CPDLC communications matches that available on the CDTI. Pilots consistently showed a preference for the Lower and Moderate complexity IM clearances as compared to the Higher complexity IM clearances. Pilots also consistently found the Higher complexity IM clearances when using the Voice with Manual Load communication method to be the least favorable set of conditions. Controllers had the most variability in their replies with the Higher Complexity IM clearances under both Voice and CPDLC. The Higher complexity IM clearance conditions also had more communication issues than any of the other conditions. While the Higher complexity IM clearances were less acceptable over voice, the use of CPDLC for pilots improved the acceptability of the most complex clearances.

The simulation also examined additional IM messages in an extra scenario. Controller and pilot responses to several questions indicated that the additional IM messages are necessary, well phrased, and allow for acceptable and clear communication exchanges in both voice and CPDLC.

The following are recommendations / considerations based on the results of this simulation.

Communications / IM Message Set

- Retain, as is, the IM messages tested in this simulation.
- Since a RCP180 option (that was specified for IM at the time of the simulation) may no longer exist per current standards (RTCA and EUROCAE, 2014), consider these results to support the RCP130 type. The results from the simulation closely align with the RCP130 specifications detailed in RTCA and EUROCAE (2014).
- Keep the IM controller and pilot termination CPDLC messages, even if voice communications may be a better option under most conditions. The messages can be used in non-time critical situations and may help update flight deck or ground automation.
- Require / allow controllers to use the advanced organizer "Interval spacing clearance available. Advise when ready to copy" when using voice communications for complex IM clearances. Pilots reported wanting this communication. It will allow them to prepare for the complex clearance. Controllers currently use this type of communication for complex navigation clearances. This would be an extension of that.
  - When the advanced organizer is used, consider not saying "for interval spacing" in the follow-up IM clearance as the context would have been set with the advanced organizer.
- Conduct further research to determine how to manage complex IM clearances over voice communications. For example, certain clearance elements could be included in published arrival procedures or the IM clearance could be broken into two separate messages (one with the basic information and another with the reference aircraft IFPI).
- Determine how to best provide flight crews the necessary information to manage disconnects between the reference aircraft call sign spoken in the voice communication (the airline telephony designator) and the reference aircraft call sign shown on the CDTI traffic display (the airline three letter designator), especially for non-intuitive cases.
- Consider 8 – 10 elements the potential maximum number of elements / level of complexity for IM clearances over voice communications in the en route environment. Four to 7 elements may be a more reasonable number of elements based on past IM research (e.g., Mercer et al., 2005; Hassa, et al., 2005) but may still have some potential for communication issues (e.g., Cardosi, 1993; Cardosi, 1994; Bürki-Cohen, 1995).
- Ensure the reference aircraft trajectory information (i.e., IFPI) is kept to a minimum, especially for voice communications. IM clearances with 10 elements proved challenging in this simulation. The IFPI was often cited as the problematic element. Consider limiting the IFPI to 2 – 5 elements or less during voice communications.
- Determine whether there is a point when the number of elements in the IM clearance require the direct loading of the IM clearance from the CPDLC system to the flight deck IM system (e.g., when the number of elements in the clearance is over 25 like those seen in Baxley et al. [2013]).
- Consider additional research that examines communication error rates when using the different IM clearance complexities and different communication methods. Additional research testing objective measures in more detail may reveal issues in communications that were not fully revealed in this simulation.

Procedures

- Retain the planned A-P method of IM clearance acceptance when using CPDLC communications (as specified in RTCA, 2011).
- Continue to explore and determine whether there are issues with the A-P method of IM clearance acceptance when using voice communications, even though past research has not shown it to be necessary.
- Continue to explore and determine whether there are issues with termination procedures in IM.
- Explore the appropriate acceptable mix of IM equipped and non-IM equipped aircraft operating in the same airspace.
- Ensure pilot termination CPDLC messages are answered with clear controller acknowledgements.

Interfaces

- Consider direct loading from the CPDLC system to the flight deck IM equipment to reduce errors and reduce initiation time, especially for the higher complexity IM clearances (likely those with 10 or more elements).
- Consider options for minimizing the number of actions required to accept automation suggestions for IM pairing and then send a CPDLC message.
- Ensure IM related information remains visible to the controller up until the transfer of communications.
- Ensure CPDLC interfaces on CDUs make it clear to pilots when messages span multiple pages.

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Appendix A Demographics Forms

A.1 Controller Demographics Form

1. How many years of experience do you have actively controlling air traffic?
   _________ Years
2. How many months out of the past 12 have you actively controlled air traffic?
   __________ Months
3. At which facility do you now (or did you last) work?
   ____
4. At what other types of facilities have you worked? ____ Tower _____ TRACON
   ______ Center______ Other
5. What is your current position?
   ____
6. What other positions have you held within the FAA (e.g., TMC, airspace operations, etc.)?
7. Have you ever been a controller at Atlanta Hartsfield International Airport (ATL)? (circle one)

   YES **NO**

If yes, approximately how many months / years:
____

8. Do you have any experience with concepts where aircraft are using cockpit tools to space from another aircraft (e.g., Interval Management [IM], Merging and Spacing), such as demos, other simulations, etc.? (circle one)

   YES **NO**

   If yes, please describe your previous experience:
9. Can we contact you after the simulation if we have any questions on the data you provided? (circle one)

   YES **NO**

A.2 Pilot Demographics Form

Crew Code: _______ Participant Role: CAPTAIN / FIRST OFFICER

DATE: _____ /_____ /_____

Please complete the following background questionnaire. Your identity will be kept completely confidential and will not be included in any of the reports or documents that will be produced as a result of this study.

Employer Type: ☐Airline ☐Corporate Flying ☐Other

1. Age: ____Years Sex: ____Male ____Female

2. Approximately how long have you been a pilot? ____ Years ____Months

3. With what aircraft type do you have the most experience? ______________________

4. Estimated total flight hours logged: ______
   Estimated hours logged in the past 90 days: ______

5. Current Position (circle one): Captain First Officer

6. Type of flying you do most often: (check all that apply)

   ____ Local area, pleasure only ____ Personal & business, cross country
   ____ Mostly business flying ____ Professional pilot or full-time CFI

7. FAA Pilot Certificate Held:

   ____ Recreational ____Private ____Commercial ____ATP ____CFI

8. Ratings Held: (check all that apply)

   ____ Instrument ____ Multi-engine ____Glider

   ____ Rotorcraft Other: _____________

9. Type of aircraft currently flown most often:

   ____ Light Single ____ Complex Single ____ Light Twin

   ____ Turboprop ____ Jet

10. Approximately how many hours have you logged in multi-engine aircraft? ____________

11. What aircraft type do you currently fly? _______________

12. Approximately how many hours of sleep did you get last night?

DAY 1: __________ **DAY 2:** __________

13. How long did it take you to get here today?

DAY 1: __________ **DAY 2:** __________

14. Did you eat breakfast today?

DAY 1: YES NO **DAY 2:** YES NO

15. Have you ever experienced simulator sickness?

YES **NO**

16. Do you have experience with, or are you familiar with Controller Pilot Datalink Communications (CPDLC)?

YES **NO**

If yes, please explain:

17. Do you have experience with, or are you familiar with Flight-Deck Based or Ground Based Interval Management (FIM and GIM)?

FIM: **YES** **NO**

GIM: **YES** **NO**

If yes, please explain:

18. Please list the type ratings listed on your license:

Aircraft	Hours

Appendix B Post Scenario Questionnaires

B.1 Controller Post Scenario Questionnaire

IM CPDLC Post Scenario ATC Questionnaire

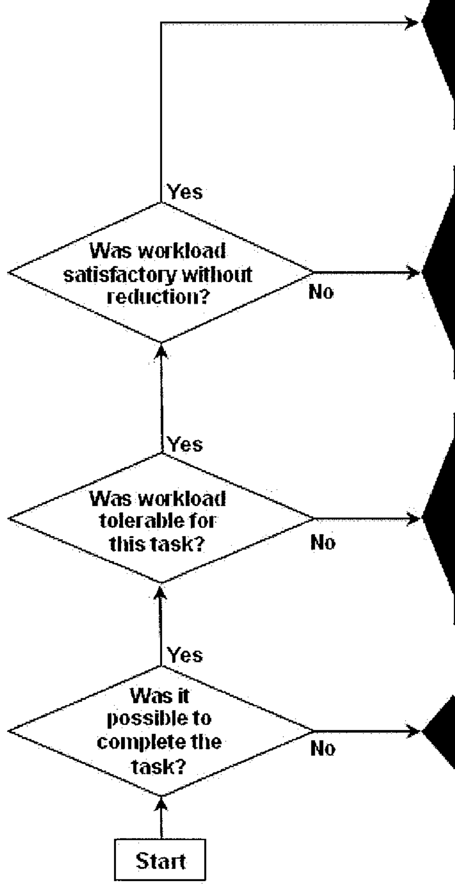
Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. **Using the chart below, how would you rate your *average* level of workload?**

(a) Working up from the bottom, answer each yes/no question.

(b) Select the numerical rating that best reflects your experience.



Difficulty Level	Operator Demand Level	Rating
Very Easy	Workload insignificant.	1
Easy	Workload low.	2
Fair	Enough spare capacity for all desirable additional tasks.	3
Minor, Annoying	Insufficient spare capacity for easy attention to additional tasks.	4
Moderately Objectionable	Reduced spare capacity. Additional tasks cannot be given the desired amount of attention.	5
Very Objectionable	Little spare capacity. Level of effort allows little attention to additional tasks.	6
Major Difficulty	Very little spare capacity, but the maintenance of the *primary* task is still possible.	7
Major Difficulty	Very high workload with almost no spare capacity. Difficulty in maintaining level of effort.	8
Major Difficulty	Extremely high workload, no spare capacity. Ability to maintain effort on primary task doubtful.	9
Impossible	Task abandoned. Unable to apply sufficient effort.	10

CPDLC

2. The time required to receive a response for the FIM clearances over CPDLC is acceptable. (circle one)

1	2	3	4	5	6	7	NA
Strongly Disagree						Strongly Agree	

Comments:

3. The non-FIM clearance messages (e.g., crossing restrictions, speeds, altitudes) were acceptable. (circle one)

1	2	3	4	5	6	7	NA
Strongly Disagree						Strongly Agree	

Comments:

FIM Clearance Messages – Excluding Third Party Flight Identification

4. The FIM Clearance I issued to the pilots was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

5. Pilot read backs of the FIM Clearance over voice were acceptable.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

6. I would be willing to issue the same FIM clearance with a *higher* traffic load. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

7. I would be willing to issue the same FIM clearance with a *lower* traffic load. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

8. I can imagine at least one environment where this FIM clearance would be acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

9. The *length* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

10. The *complexity* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

11. Rate the *complexity* of the FIM Clearance. (circle one)

1	2	3	4	5	6	7
Very Low Complexity						Very High Complexity

Comments:

12. The FIM Clearance communication exchanges were clear. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

13. Did any particular elements of the FIM Clearance cause difficulties? (circle one)

Yes **No**

If yes, describe:

14. Did you notice any errors during the communications? (circle one)

Yes **No**

If yes, explain:

15. Overall, the FIM Clearance communications were acceptable. (circle one)

1	2	3	4	5	6	7

Strongly Disagree — Strongly Agree

Comments:

a) If any were unacceptable, please describe.

16. Where there any follow-up communications necessary for the FIM clearance? (circle one)

Yes **No**

If yes, explain:

17. During CPDLC communications, did you ever want to revert to voice communications? (circle one)

Yes **No** **NA**

If yes, explain:

FIM Clearance Messages – Third Party Flight Identification

18. Did you have any issues during communications with flight crews when third party flight identification was used? (circle one)

Yes **No**

If yes, describe:

B.2 Controller Post Extra Scenario Questionnaire

IM CPDLC POST CPDLC EXTRA SCENARIO ATC QUESTIONNAIRE

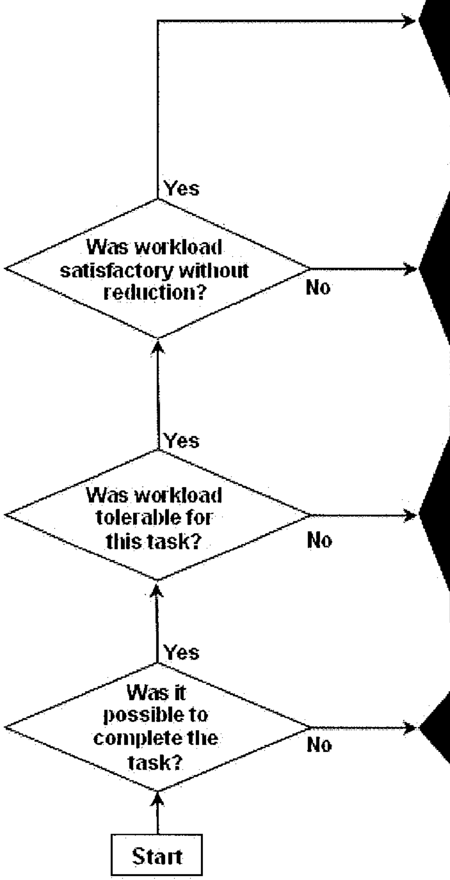
Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. Using the chart below, how would you rate your *average* level of workload?

(a) Working up from the bottom, answer each yes/no question.

(b) Select the numerical rating that best reflects your experience.



DIFFICULTY LEVEL	OPERATOR DEMAND LEVEL	RATING
Very Easy	Workload insignificant.	1
Easy	Workload low.	2
Fair	Enough spare capacity for all desirable additional tasks.	3
Minor, Annoying	Insufficient spare capacity for easy attention to additional tasks.	4
Moderately Objectionable	Reduced spare capacity. Additional tasks cannot be given the desired amount of attention.	5
Very Objectionable	Little spare capacity. Level of effort allows little attention to additional tasks.	6
Major Difficulty	Very little spare capacity, but the maintenance of the *primary* task is still possible.	7
Major Difficulty	Very high workload with almost no spare capacity. Difficulty in maintaining level of effort.	8
Major Difficulty	Extremely high workload, no spare capacity. Ability to maintain effort on primary task doubtful.	9
Impossible	Task abandoned. Unable to apply sufficient effort.	10

CPDLC

2. The time required to receive a response for the messages over CPDLC is acceptable. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

3. The non-FIM clearance messages (e.g., crossing restrictions, speeds, altitudes) were acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

Messages – Excluding Third Party Flight Identification

4. The message exchange was acceptable. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

5. I would be willing to issue the same FIM clearance with a *higher* traffic load. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

6. I would be willing to issue the same FIM clearance with a *lower* traffic load. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

7. I can imagine at least one environment where this FIM clearance would be acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

8. The *length* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

9. The *complexity* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

10. The FIM communications were properly phrased. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

11. The communication exchanges were clear. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

12. Did any particular elements of the FIM communications cause difficulties? (circle one per row)

FIM Clearance	Yes	No
ATC FIM Termination	Yes	No
Pilot FIM Termination	Yes	No
FIM Report starting spacing	Yes	No
FIM Report Assigned Spacing	Yes	No

If yes, describe:

13. Did you notice any errors during the communications? (circle one per row)

FIM Clearance	Yes	No
ATC FIM Termination	Yes	No
Pilot FIM Termination	Yes	No
FIM Report starting spacing	Yes	No
FIM Report Assigned Spacing	Yes	No
Non-FIM instruction	Yes	No

If yes, describe:

14. Overall, the communications were acceptable. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

a) If any were unacceptable, please describe.

15. Where there any follow-up communications necessary for the FIM clearance? (circle one)

Yes **No**

If yes, explain:

16. During CPDLC communications, did you ever want to revert to voice communications? (circle one)

Yes **No**

If yes, explain:

FIM Clearance Messages – Third Party Flight Identification

17. Did you have any issues during communications with flight crews when third party flight identification was used? (circle one)

Yes **No**

If yes, describe:

B.3 Pilot Post Scenario Questionnaire

IM CPDLC Post Scenario PILOT Questionnaire

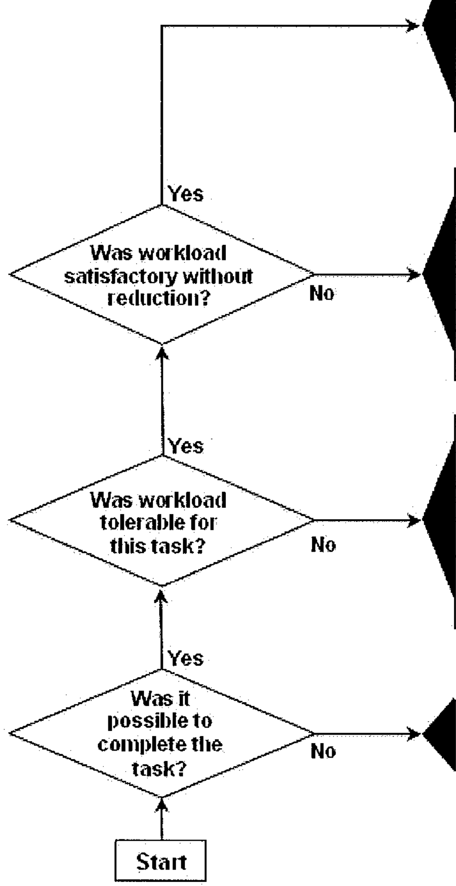
Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider only the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. **Using the chart below, how would you rate your *average* level of workload?**

(a) Working up from the bottom, answer each yes/no question.

(b) Select the numerical rating that best reflects your experience.



Difficulty Level	Operator Demand Level	Rating
Very Easy	Workload insignificant.	1
Easy	Workload low.	2
Fair	Enough spare capacity for all desirable additional tasks.	3
Minor, Annoying	Insufficient spare capacity for easy attention to additional tasks.	4
Moderately Objectionable	Reduced spare capacity. Additional tasks cannot be given the desired amount of attention.	5
Very Objectionable	Little spare capacity. Level of effort allows little attention to additional tasks.	6
Major Difficulty	Very little spare capacity, but the maintenance of the *primary* task is still possible.	7
Major Difficulty	Very high workload with almost no spare capacity. Difficulty in maintaining level of effort.	8
Major Difficulty	Extremely high workload, no spare capacity. Ability to maintain effort on primary task doubtful.	9
Impossible	Task abandoned. Unable to apply sufficient effort.	10

CPDLC

2. The time available to reply to FIM clearances over CPDLC is acceptable. (circle one)

1	2	3	4	5	6	7	NA
Strongly Disagree						Strongly Agree	

Comments:

3. The non-FIM clearance messages (e.g., crossing restrictions, speeds, altitudes) were acceptable. (circle one)

1	2	3	4	5	6	7	NA
Strongly Disagree						Strongly Agree	

Comments:

FIM Clearance Messages – Excluding Third Party Flight Identification

4. The FIM Clearance I received from ATC was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

5. I would be willing to receive the same FIM clearance in a *higher* workload environment. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

6. I would be willing to receive the same FIM clearance in a *lower* workload environment. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

7. I can imagine at least one environment where this FIM clearance would be acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

8. The *length* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

9. The *complexity* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

10. Rate the *complexity* of the FIM Clearance. (circle one)

1	2	3	4	5	6	7
Very Low Complexity						Very High Complexity

Comments:

11. The FIM Clearance communication exchanges were clear. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

12. I was able to retain the FIM Clearance information. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

13. Did any particular elements of the FIM Clearance cause difficulties? (circle one)

Yes **No**

If yes, describe:

14. Did you notice any errors during the communications? (circle one)

Yes **No**

If yes, explain:

15. Overall, the FIM Clearance communications were acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

b) If any were unacceptable, please describe.

16. Where there any follow-up communications necessary for the FIM clearance? (circle one)

Yes **No**

If yes, explain:

17. During CPDLC communications, did you ever want to revert to voice communications? (circle one)

Yes **No** **NA**

If yes, explain:

FIM Clearance Messages – Third Party Flight Identification

18. Did you have any issues during communications with ATC when third party flight identification was used? (circle one)

Yes **No**

If yes, describe:

B.4 Pilot Post Extra Scenario Questionnaire

IM CPDLC Post <u>Extra</u> Scenario <u>PILOT</u> Questionnaire

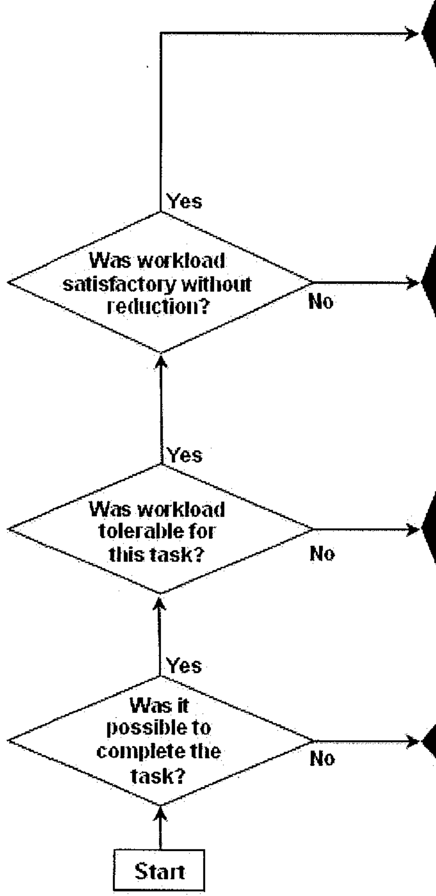
<u>Instructions</u>: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider other the current scenario when answering*. If you have any questions, please ask the experimenter.

Workload

1. **Using the chart below, how would you rate your *average* level of workload?**

(a) Working up from the bottom, answer each yes/no question.

(b) Select the numerical rating that best reflects your experience.



Difficulty Level	Operator Demand Level	Rating
Very Easy	Workload insignificant.	1
Easy	Workload low.	2
Fair	Enough spare capacity for all desirable additional tasks.	3
Minor, Annoying	Insufficient spare capacity for easy attention to additional tasks.	4
Moderately Objectionable	Reduced spare capacity. Additional tasks cannot be given the desired amount of attention.	5
Very Objectionable	Little spare capacity. Level of effort allows little attention to additional tasks.	6
Major Difficulty	Very little spare capacity, but the maintenance of the *primary* task is still possible.	7
Major Difficulty	Very high workload with almost no spare capacity. Difficulty in maintaining level of effort.	8
Major Difficulty	Extremely high workload, no spare capacity. Ability to maintain effort on primary task doubtful.	9
Impossible	Task abandoned. Unable to apply sufficient effort.	10

CPDLC

2. The time available to reply to communications over CPDLC is acceptable. (circle one)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

3. The non-FIM clearance messages (e.g., crossing restrictions, speeds, altitudes) were acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

Messages – Excluding Third Party Flight Identification

4. The message exchange was acceptable. (circle one)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

5. I would be willing to receive the same FIM clearance in a *higher* workload environment. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

6. I would be willing to receive the same FIM clearance in a *lower* workload environment. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

7. I can imagine at least one environment where this FIM clearance would be acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

8. The *length* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

9. The *complexity* of the FIM Clearance communications was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

10. The FIM communications were properly phrased. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

11. The communication exchanges were clear. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

12. I was able to retain the FIM Clearance information. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

13. Did any particular elements of the FIM communications cause difficulties? (circle one per row)

FIM Clearance	Yes	No
ATC FIM Termination	Yes	No
Pilot FIM Termination	Yes	No
FIM Report starting spacing	Yes	No
FIM Report Assigned Spacing	Yes	No

If yes, describe:

14. Did you notice any errors during the communications? (circle one per row)

FIM Clearance	Yes	No
ATC FIM Termination	Yes	No
Pilot FIM Termination	Yes	No
FIM Report starting spacing	Yes	No
FIM Report Assigned Spacing	Yes	No
Non-FIM instruction	Yes	No

If yes, explain:

15. Overall, the communications were acceptable. (circle one per row)

FIM Clearance	1	2	3	4	5	6	7
ATC FIM Termination	1	2	3	4	5	6	7
Pilot FIM Termination	1	2	3	4	5	6	7
FIM Report starting spacing	1	2	3	4	5	6	7
FIM Report Assigned Spacing	1	2	3	4	5	6	7
Non-FIM instruction	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

a) If any were unacceptable, please describe.

16. Where there any follow-up communications necessary for the FIM clearance? (circle one)

Yes **No**

If yes, explain:

17. During CPDLC communications, did you ever want to revert to voice communications? (circle one)

Yes **No**

If yes, explain:

FIM Clearance Messages – Third Party Flight Identification

18. Did you have any issues during communications with ATC when third party flight identification was used? (circle one)

Yes **No**

If yes, describe:

Appendix C Post Simulation Questionnaires

C.1 Controller Post Simulation Questionnaire

IM CPDLC POST SIMULATION ATC QUESTIONNAIRE

Instructions: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider all scenarios when answering.* If you have any questions, please ask the experimenter.

GIM

1. GIM is compatible with current ATC operations. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

2. I received an acceptable number of GIM speed advisories per aircraft. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

FIM

3. FIM is compatible with current ATC operations. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

4. It was acceptable to be responsible for separation during FIM. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

5. I was confident that the spacing being maintained by the FIM aircraft would remain outside my separation responsibility. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

6. I was confident that the FIM aircraft were driving towards the assigned spacing goal. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

7. My roles and responsibilities were clear.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

8. Was it difficult to control traffic in a mixed FIM capability environment (i.e., some aircraft conducting FIM and some conducting GIM)?

   Yes **No**

   If yes, explain:

9. Given appropriate training, FIM is operationally acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

CPDLC

10. I prefer the use of CPDLC over voice communications for FIM clearances. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

11. The time required to receive a response for the individual FIM clearances over CPDLC is acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

12. Was it difficult to control traffic in a mixed CPDLC capability environment (i.e., when only some aircraft were capable of CPDLC)?

Yes **No**

If yes, explain:

Displays / Interface

13. The direct loading of the FIM Clearance into the CPDLC interface was acceptable. (circle one)

1	2	3	4	5	6	7

Strongly Disagree ... Strongly Agree

Comments:

14. The presentation format of the FIM Clearance on the Clearance Template is acceptable.

1	2	3	4	5	6	7

Strongly Disagree ... Strongly Agree

Comments:

15. Did you have any difficulties with the interface for CPDLC?

Yes **No**

If yes, describe:

16. Did you have any difficulties with the interface for GIM FIM?

Yes **No**

If yes, describe:

17. I would be willing to perform FIM with the displays I used in this simulation (ignore simulation issues if any existed, e.g. readability of text on displays, etc.). (circle one)

1	2	3	4	5	6	7

Strongly Disagree ... Strongly Agree

Comments:

IM Clearance Messages – Excluding Third Party Flight Identification

18. Did the FIM clearances of different levels of complexity have different levels of acceptability? (circle one)

    Yes **No**

    If yes, explain:

    Which messages were more acceptable?
    Describe:

19. The FIM Clearances were phrased well. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

    Comments:

20. Did any particular elements of the FIM Clearance cause difficulties? (circle one)

    Yes **No**

    If yes, describe:

21. The *voice* communication *"Interval spacing clearance available. Advise when ready to copy"* prior to the FIM Clearance was necessary. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

    Comments:

22. Do you have suggestions on how to improve the FIM Clearance communications? (circle one)

    Yes **No**

    If yes, describe:

23. Was there a need for additional FIM CPDLC messages that weren't available? (circle one)

    Yes **No**

    If yes, explain:

24. During CPDLC communications, did you ever want to revert to voice communications? (circle one)

    Yes **No**

    If yes, explain:

FIM Clearance Messages – Third Party Flight Identification

25. Did you have any issues during communications with flight crews when third party flight identification was used? (circle one)

    Yes **No**

    If yes, describe:

26. The flight crew has only the 3 letter identifier of the aircraft on their traffic display. If the flight crew had difficulty decoding the airline name, would it be acceptable to issue the three letter identifier to the flight crew? [e.g., Brickyard / RPA] (circle one)

    Yes **No**

    Comments:

27. Use of the third party flight identification of the reference aircraft in the clearance would be operationally acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

Procedures

28. The procedures defined as the flight crew receiving an FIM Clearance, reading it back, entering it into the FIM equipment, and then ensuring they can fly the first FIM speed was acceptable. (circle one per row)

Voice	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

29. It would be preferable for the flight crew to accept the FIM Clearance only after ensuring they can fly the first FIM speed. (circle one)

Voice	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

Simulation Assessment

30. The overall simulation was effective as a context for evaluating IM and CPDLC. (circle one)

1	2	3	4	5	6	7	
Strongly Disagree						Strongly Agree	O Don't know

Comments:

31. Was there anything about the simulation that artificially affected using it as a context for evaluating IM and CPDLC? (circle one)

Yes **No** **Don't Know**

If yes, describe:

32. Did you receive an adequate amount of training? (circle one)

Yes **No**

If no, describe:

33. If you have any other comments about anything else in the simulation, please provide them:

C.2 Pilot Post Simulation Questionnaire

IM CPDLC POST SIMULATION <u>PILOT</u> QUESTIONNAIRE

<u>Instructions</u>: Please answer the questions by circling the option on each of the scales at the point which matched your experience. Unless otherwise indicated, *consider all scenarios when answering*. If you have any questions, please ask the experimenter.

FIM

1. FIM is compatible with current flight deck operations. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

2. I received an acceptable number of FIM speeds. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

3. I trusted that the algorithm was providing me the appropriate FIM speeds to achieve my interval. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

4. My roles and responsibilities were clear.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

5. Given appropriate training, FIM is operationally acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

CPDLC

6. I prefer the use of CPDLC over voice communications for FIM clearances. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

7. The time available to reply to FIM clearances over CPDLC is acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

Displays / Interface

8. The manual loading of the FIM Clearance into the FIM system was acceptable. (circle one per row)

Voice	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

9. The direct loading of the FIM Clearance into the FIM system from CPDLC was acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

10. The presentation format of the FIM Clearance message on the CPDLC display (i.e., CDU) is acceptable.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

11. The CDTI interface is acceptable for the entry of the FIM Clearance. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

12. The necessary information was available from the FIM clearance to detect and designate the reference aircraft. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

13. The traffic displays provided the necessary information to conduct FIM. (circle one per row)

CDTI	1	2	3	4	5	6	7
AGD	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Describe any instances where you would have liked more information, and the form in which additional information would have been most useful.

14. I would be willing to perform FIM with the CDTI and AGD displays I used today (ignore simulation issues if any existed, e.g. readability of text on displays, etc.). (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

FIM Clearance Messages – Excluding Third Party Flight Identification

15. Did the FIM clearances have different levels of acceptability? (circle one)

Yes **No**

If yes, explain:

Which messages were more acceptable?
Describe:

16. The FIM Clearance was phrased well. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

17. Did any particular elements of the FIM Clearance cause difficulties? (circle one)

Yes **No**

If yes, describe:

18. The FIM Clearance communications over *voice* are no more complex than other current day complex communications over *voice*.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

19. The voice communication *"Interval spacing clearance available. Advise when ready to copy"* prior to the FIM Clearance was necessary. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

20. Do you have suggestions on how to improve the FIM Clearance communications? (circle one)

Yes **No**

If yes, describe:

21. Was there a need for additional FIM CPDLC messages that weren't available? (circle one)

Yes **No**

If yes, explain:

22. During CPDLC communications, did you ever want to revert to voice communications? (circle one)

Yes **No**

If yes, explain:

FIM Clearance Messages – Third Party Flight Identification

23. I experienced confusion about whether my aircraft was being talked to (i.e., receiving an ATC communication) vs. talked **about** (i.e., being addressed as a third party aircraft). (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

24. Do you believe you would get used to being talked **about** (i.e., being addressed as a third party aircraft) and not just to (i.e., receiving an ATC communication)? (circle one)

Yes **No** **Don't Know**

a) Would that experience reduce any concerns? (circle one)

Yes **No** **Don't Know**

Explain:

25. Did you have any issues during communications with ATC when third party flight identification was used? (circle one)

Yes **No**

If yes, describe:

26. Did you have any issues during display interactions related to third party flight identification? (circle one)

Yes **No**

If yes, describe:

27. Use of the third party flight identification of the reference aircraft in the clearance would be operationally acceptable. (circle one)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Comments:

Procedures

28. The procedures defined as receiving a FIM Clearance, reading it back to ATC, entering it into the FIM equipment, and then receiving the first FIM speed was acceptable. (circle one per row)

Voice	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

29. It would be preferable to accept the FIM Clearance only after entering it into the FIM equipment and then receiving the first FIM speed. (circle one per row)

Voice	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

30. My level of situation awareness was acceptable. (circle one)

FIM	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

31. The coordination with the other flight crew member was acceptable. (circle one)

FIM	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

32. My level of head-down time was acceptable. (circle one)

FIM	1	2	3	4	5	6	7
CPDLC	1	2	3	4	5	6	7
	Strongly Disagree						Strongly Agree

Comments:

Simulation Assessment

33. The overall simulation was effective as a context for evaluating FIM and CPDLC. (circle one)

1	2	3	4	5	6	7	O Don't know
Strongly Disagree						Strongly Agree	

Comments:

34. Was there anything about the simulation that artificially affected using it as a context for evaluating FIM and CPDLC? (circle one)

Yes **No** **Don't Know**

If yes, describe:

35. Did you receive an adequate amount of training? (circle one)

Yes **No**

If no, describe:

36. If you have any other comments about anything else in the simulation, please provide them:

Appendix D Acronyms and Abbreviations

AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
A-P	Accept-the-Process
ADS-B	Automatic Dependent Surveillance-Broadcast
AGD	ADS-B Guidance Display
AIM	Aeronautical Information Manual
AMAN	Arrival Manager
ARTCC	Air Route Traffic Control Center
ASG	Assigned Spacing Goal
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATIS	Automated Terminal Information Service
ATS	Air Traffic Services
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
BWRS	Bedford Workload Rating Scale
C-D	CPDLC with Direct Load
C-M	CPDLC with Manual Load
CDTI	Cockpit Display of Traffic Information
CDU	Control and Display Unit
CPDLC	Controller Pilot Data Link Communications
DIK	Display Interface Keypad
DL	Direct Load
DM	Downlink Message
DSI	Display System Integration
DSR	Display System Replacement
EICAS	Engine-Indicating and Crew-Alerting System
ERAM	En Route Automation Modernization
ETA	Estimated Time of Arrival
EUROCAE	European Organisation for Civil Aviation Equipment

FA	FIM Active
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FC	FIM / IM Capable
FIM	Flight deck Interval Management
FMS	Flight Management System
FP	FIM Pending
GIM	Ground Interval Management
H	Higher
HMI	Human Machine Interaction
ICAO	International Civil Aviation Organization
IDEA	Integration Demonstration and Experimentation for Aeronautics
IFPI	Intended Flight Path Information
IM	Interval Management
KATL	Hartsfield-Jackson Atlanta International Airport
L	Lower
M	Moderate
MANOVA	Multivariate Analysis of Variance
MCDU	Multifunction Control and Display Unit
MCP	Mode Control Panel
ML	Manual Load
MOPS	Minimum Operational Performance Standards
MSP	Multiple Sector Planner
MTE	Meet Time Error
NATCA	National Air Traffic Controllers Association
ND	Navigation Display
NextGen	Next Generation Air Transportation System
P-A	Process-then-Accept
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring

PTT	Push-To-Talk
RCP	Required Communication Performance
RTA	Required Time of Arrival
RTCA	RTCA
SC	Special Committee
SE	Standard Error
STA	Scheduled Time of Arrival
TBFM	Time-Based Flow Management
TMA	Traffic Management Advisor
TPCS	Third Party Call Sign
TRACON	Terminal Radar Approach Control
UM	Uplink Message
UPS	UPS
US	United States
V	Voice
V-M	Voice with Manual Load
VDL	VHF Digital Link
VHF	Very High Frequency
WG	Working Group