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CONVEYING MESSAGE CRITICALITY VIA DATALINK

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ABSTRACT

This study investigated the potential to code message criticality into a pilot's datalink display while taxiing with an electronic moving map (EMM). Five coding conditions were tested: non-expedite text, expedite text, expedite color, expedite icon, and expedite reverse video. datalink text messages appeared as pilots taxied toward a designated runway. Eye tracking, magnitude of response, and mean taxi speed data was collected to measure pilot's reactions to the events. Subjective participant preference data was also collected via a post-experiment survey. The results from this study suggest a beneficial trend for using some form of salience coding (color, icon and reverse video) for conveying urgency in a datalink message, and confirm the need to further study how urgency levels should be coded into datalink messages.

Keywords

Criticality, Datalink, Coding, Urgency

INTRODUCTION

By now it's a forgone conclusion that datalink will enter the cockpit and become a secondary, if not primary, communication method between pilots and air traffic controllers. Darby and Shingledecker [1] report that the FAA expects to be "datalink compliant in the National Airspace System (NAS) by 2003." Thus datalink is a new domain involving electronic communication where verbal communication has prevailed. There are several inherent advantages to a datalink communication platform, including: 1) the reduction or elimenation of message blocking and congestion, 2) the persistence of message (ability to review later), and 3) greater flexibility in the management their workload as the communication does not require both parties attention at the same time.

Communication Modes

When talking face-to-face, information is communicated in the words that are spoken as well as through the intonation of those words [2]. Other non-verbal information is communicated through eye contact and gaze, personal space, gestures and body language, feedback channels (e.g., the other person shaking their head in agreement or giving a confirming "mmmm"), interruption, and turn taking [3].

When communicating on a telephone or over a radio frequency, visual cues are absent but cues are still provided through voice intonation, style (conversational vs. authoritative), cadence, and other speech affect characteristics. These cues help to determine the urgency or criticality of the information conveyed. Electronic text communication is limited to the content of the words and any additional information provided by punctuation, type, and page layout [1]. Thus, this latter mode of communication is devoid of many of the traditional cues used to convey message criticality.

Emoticons in E-Mail Communications

With such an increase in the use of electronic mail in recent years, efforts have been made to convey more of the non-verbal cues that are present in other forms of communication. Emoticon*s* and acronyms are used in e-mail communications to help convey information faster than typing text. Emoticons are formed from simple ASCII characters and represent simple "faces" presented sideways. These can improve the speed of communication and help avoid misunderstandings, provided that that the other person also knows their meaning. Examples of some of the most commonly used emoticons and acronyms and their meanings are presented in Table 1.

Table 1
Examples of common e-mail emoticons and acronyms.

Emoticon /Acronym	Meaning
:-)	Happy, a joke
;-)	Winking, sarcasm
:-(	Unhappy
:-O	Surprise
ROTFL	"Rolling on the floor laughing"
AFAIK	"As far as I know"
IMHO	"In my humble opinion"

Other methods have also been developed to convey other types of information such as urgency. In some e-mail reader applications, e.g., Microsoft's Outlook Express, the urgency of an entire message is conveyed through the use of a red exclamation mark at the beginning of the message line.

Datalink in Aviation: Different domain, same issue

It should be noted here that whilst data-link shares some of the characteristics of e-mail, it has some differences. These differences include: datalink messages will be context dependent, have a more structured format, may require a response in a timely fashion and will generally have a lower tolerance for misunderstanding. The lower tolerance for misunderstanding could become critical if for example a pilot crosses a runway that is in use. It is therefore critical that attention be paid to optimizing datalink message structure and format so that messages can be responded to in an accurate and timely manner.

An important first step in defining the problems that may occur in the proposed datalink system is to determine in what ways the current and proposed systems differ from each other. Historically, communication between the air traffic controller and the pilot has been by way of radio-telephone. The types of message conveyed between the two include air traffic clearances and flight advisory and warning information [4]. The information is broadcast over a VHF channel, providing the same information to a number of pilots simultaneously in a manner similar to a telephone party line. This shared information is useful, e.g., by allowing a pilot to know that another plane ahead is experiencing turbulence. It has also served to provide fault-finding information, e.g., when an air traffic controller gives two planes clearance for the same runway at the same time.

The existing speech-based communication method consists of a limited vocabulary of standard phraseology. For example, if under the current verbal system the air traffic controller (ATC) requires that a pilot drop 2000 feet they will say "drop 2000 feet." However, if it is urgent that the pilot drops 2000 feet in order to avoid imminent danger, the air traffic controller will say "expedite drop 200 feet now." The inclusion of "expedite," the voice intonation, and the speed of the speech of the air traffic controller conveys the urgency of the situation.

Previous Datalink Studies

A number of studies have been conducted to determine the impact that the new electronic text-based system will have on flight compared to the existing speech-based system. A complete review of the findings from simulation studies can be found in Kerns [4]. Kerns reports that studies have been conducted in the following areas: "*Communications efficiency, speed and timing of communications, workload, implications of party-line information, design-dependent effects – operational communications, flight crew and controller procedures, user-system interaction, automation, display surfaces and location, display modes and formats.*" Our interest lies in a understudied but critical area if research--how to alert the pilot of the level of criticality of a message.

Criticality Coding Studies

In aviation datalink displays, Groce and Boucek [5] indicated levels of criticality by using reverse video for urgent messages, green for normal messages, and flashing text to indicate the part of the display that required attention. For example, the text "ATC uplinks pending" would flash when an uplink was pending. In a similar fashion, Hinton and Lohr [6] used reverse video to indicate new messages. However, neither studied compared various display format techniques on their perceived degree of criticality, and so how to best code datalink messages for criticality remains unstudied.

Datalink Format Options

In terms of optimal display format, a number of studies have compared graphical, alphanumeric, and mixed displays on aircraft interfaces [7,8]. These studies suggest that icons can produce faster response times than alphanumeric[8], symbolic displays can produce faster and more accurate reaction times than text [7], and that graphical representation of spatial information can produce faster response times and provide more error detection in ATC messages than textual or verbal representation.

In developing a display from which the criticality of the message can be quickly ascertained, it is important to use techniques that direct the user's attention and facilitate fast comprehension. To achieve this, attention must first be drawn to the part of the display screen that holds the critical information and then the information must be coded to facilitate fast processing. Visual techniques considered for this study that both attract attention and facilitate information processing include: use of different language, text size, capitalization, bolding, color, icons, pictorial representations, reverse video, and parsing of information. Three of these techniques were selected for this study: color, reverse video, and icons. A plain text and a text display containing the word expedite were also designed to provide baselines for comparison.

A Pilot Concept Study

The main purpose of this concept study was to investigate whether different coding presentations of datalink messages can convey a sense of urgency, which in turn should invoke a faster response to the message.

Note that it was not the purpose of this experiment to test the coding presentation effect on search performance: measurements were taken from the pilot's first dwell on the message until they initiated the appropriate action. Pilots were informed in a practice trial that a chime would announce a new message and that messages would always come up in the same place.

METHOD

Participants

A total of 15 participants were tested, all of whom were general aviation (GA) pilots. There were two females and 13 males. Participants ranged in age from 25 to 56 with a mean age of 36. All 15 pilots had flown more than 330 hours (the range of hours flown was 330-4800 with a mean of 1510).

Design

The experimental design was a single-factor within-participants factorial design. The independent variable was Display Coding, which varied over five levels (Ptext, Etext, Ecolor, Eicon, and Ereverse video). Examples of each coding type can be seen in Figures 1 through 5. Each display contains the message in text. The Ptext message is just the message; the Etext message is the same as the Ptext message but contains the word expedite at the beginning of the message. The Ecolor display has the word expedite at the beginning with the message colored red. The Eicon message also contains the word expedite and has an icon of a triangle with an exclamation point inside it. The Ereverse video coding contained the word expedite at the front and is displayed in reverse video. Fifteen participants each completed 20 trials, five of which were no-event, leaving 15 experimental trials in which participants encountered three trials of each display coding condition.

Figure 1. Ptext message (baseline).

Figure 2. Etext message (expedite text).

Figure 3. Ecolor message.

Figure 4. Eicon message.

Figure 5. Ereverse message.

The display coding conditions were blocked and counterbalanced between participants. For a given event, each participant experienced that event over a different set of three code conditions. This resulted in a Balanced Incomplete Block Design (BIBD) for the distribution of event types per conditions. The five different event types were Contact Ground (tower), Cleared to Cross, Stop, Change Route, and Slow Down.

Apparatus

The simulated environment was of a Boeing 737 taxiing from terminal to runway at Chicago O'Hare airport. The forward out-the-window (OTW) scene was projected on a 6' high by 8' wide rear projection screen located 8' from the participants eye point. The side OTW scenes were displayed on two 19" monitors, one on each side of the participant. The Electronic Moving Map (EMM), shown in Figure 6, appeared as an 8" X 6" panel-mounted display at a common (for a B737) distance from the participants eye point. Eye tracking data was collected using an Applied Sciences Laboratories (ASL) Series 5000 Integrated Eye/Head tracking system. The bottom two lines of the EMM contained the datalink message.

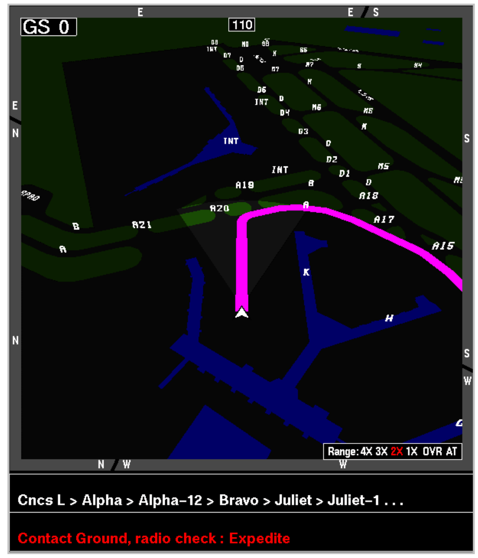

Figure 6. EMM Display with Datalink Area at Bottom

Procedure

Participants were then given a set of general instructions explaining their tasks. Next, participants were briefed on the part-task simulator, performing one practice trial at the end of the briefing. At the beginning of each trial, the participant received a datalink message containing their clearance, which the pilot confirmed by repeating the clearance and accepting the message. After responding, the pilot was cleared to taxi. Communications between ATC and the pilot during trials was limited to situations where the pilot was off route, did not comply with instructions, asked for directions or present location from ATC, or asked ATC questions regarding other aircraft. After completing all 20 trials the participants were given a survey, interviewed, debriefed, and thanked for their participation.

Dependent Variables

Eye-Tracker

For each event, the time from when the pilot first dwells on the message until they initiated the required action.

Simulation

Mean taxi time and magnitude of change data was collected from the simulation. Magnitude data collected included the maximum longitudinal acceleration recorded as a response to the Cleared to Cross and Speed Up events, the maximum longitudinal deceleration from the Stop and Slow Down events and the maximum steering angle for the Change Route events.

Survey
The survey was conducted to assess the pilots' datalink display design preferences for time critical messages. The survey compared the Etext, Ecolor, Eicon, and Ereverse video message coding types for presenting time critical messages.

RESULTS

The main data of interest were the response time to each message and the magnitude of response (relevant for only a subset of measures). The data were analyzed several ways, including ANOVA and Rank analyses. We present the latter here.

Response Time

In order to determine what effect the event types have on the response time, Table 2 ranks the coding method response time for each message type, with 1 being the fastest response and 5 being the slowest.
The rankings do show some support for the hypothesis that Color Coding will yield the fastest response, in that it has the lowest sum of the overall rankings and has the second overall mean. The Eicon display had the lowest overall mean and the second lowest sum of overall rankings. The sum of the rankings for Ecolor, Eicon, and Ereverse video are all lower than the sum of the Ptext and the Etext conditions. It should be noted, however, that there is much variability in the effect of the coding methods between the different event message types.

Table 2
Mean Response Time Broken down by Message Coding Condition and Then Ranked

	Coding Condition				
Event	**Ptext**	**Etext**	**Ecolor**	**Eicon**	**Ereverse**
Contact Ground	2	5	1	4	3
Cleared to Cross	2	5	3	4	1
Stop	2	5	1	3	4
Change Route	5	4	3	1	2
Change Speed	5	2	3	1	4
Overall RT Mean (Ranked)	5	4	2	1	3

Magnitude of the Response

It is of interest to know if there is any correlation between the coding conditions that were responded to the fastest and the coding conditions that were responded to with the greatest magnitude of response. To investigate if the different message coding types affected the magnitude of the response we looked at the mean absolute acceleration change for the Cleared to Cross, Stop, Change Route and Change Speed event types.
Table 3 shows the magnitude of response ranked by message type. A ranking of 1 indicates the largest response and 5 indicates the smallest. Both the mean and the sum of the rankings suggest the Eicon display had the largest magnitude of response followed by Ereverse video, then Ecolor, Etext and Ptext.

Table 3
Mean Response Time Broken down by Message Coding Condition and Then Ranked

	Coding Condition				
Event	**Ptext**	**Etext**	**Ecolor**	**Eicon**	**Ereverse**
Cleared to Cross	4	5	3	1	2
Stop	3	4	5	1	2
Change Route	5	2	4	3	1
Change Speed	5	4	2	1	3
Mean Ranking	4.25	3.75	3.5	1.5	2

Pearson correlation coefficients were calculated comparing reaction time to magnitude of response data for the coding types mean scores and the sum of the rankings. Though the correlation's were not significant (mean scores $r(3)=^{+}.44$ and sum of rankings $r(3)=^{+}.72$) they do indicate a general trend for a fast response being coupled with a strong magnitude of response.

Subjective Survey Data

Figure 7 shows the subjective data for the participants' display coding preferences for carrying out the detection, reaction, and interpretation tasks. Eleven participants (73%) thought that the Ecolor display was easiest to detect. Thirteen participants (87%) thought that the Ecolor method of display would be the fastest to react to. Ten participants (67%) thought that the Ecolor display was "easiest" to interpret the need for urgency.

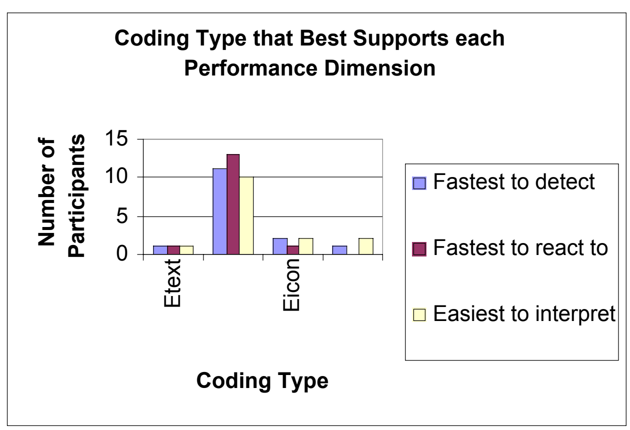

Figure 7. Coding type participants felt best supports each performance dimension.

DISCUSSION

The main purpose of this study was to investigate if urgency could be coded into a datalink message that would facilitate a faster correct response. While the relative ranking the response times did show an overall benefit for the color coding condition relative to other coding types (Ptext, Etext, Eicon and Ereverse video) this was only for two event types (Contact Ground and Stop), with minimal difference in response times for the Ecolor and the Eicon displays. The rankings do suggest that the three coding conditions that contain urgency coding (Ecolor, Eicon and Ereverse video) yielded consistently faster ranked responses than the Ptext and the Etext coding types.

While the data from this concept study are limited, it is important to note that the pilots in this study indicated coding the urgency level into the display as a critical issue. For example, one pilot commented that "the loss of controller tonal quality in voice is a big loss [of] useful information".

A number of factors in this study made it difficult to accurately determine if our coding types had an effect. The first of these factors is the slight confound that the pilots were not highly or multi-tasked during the experiment. This meant that when a message was received the pilots reacted to it quickly, as apart from taxiing they were not required to perform any other tasks. The second factor is that the messages were short (less than one line) and not part of a larger, multi-message display where a pop-out salience effect would be advantageous.

In reviewing the ranking data it is also of interest to note that some coding methods produced variable response times; this may suggest that different events may be best suited by different coding methods. The results from this study tend to indicate that messages such as Contact Ground and Stop may be best presented either by color or plain text, whereas Change Route and Change Speed may be best presented by an icon.

Survey Data

When asked which coding method was easiest to detect, fastest to react to, and easiest to interpret, participants preferred the Ecolor coding display. When asked more specifically if any of the presentations should not be used one participant did raise questions about the use of color, stating too much visual clutter as the problem. However when asked to define or design a better display, five participants indicated that color should be used, with four of the five mentioning use of red. Seven participants thought that the Etext display should not be used as it did not stand out enough, and three participants felt that the Eicon coding display should not be used as they had difficulty interpreting it.

Participants made the following design change recommendations for urgent messages: that the screen should flash, clearer text (use of a serif type was mentioned), use of capital letters and bolding and the use of color as mentioned above. Legibility of the display was also an issued raised by pilots with some finding our display hard to read.

Implications of this Study

Need

The change from any voice communication system to a text based system raises questions about how to best display the information. The change in aviation from the radio-telephone communication system to datalink messaging presents the challenge of how to best display the urgency level of a message that would previously have been transmitted via speed of speech and tonal intonation. The pilots in this study clearly confirmed the importance of developing a method of communication urgency in datalink messaging systems.

Data

This study presented the first test of coding message urgency into datalink messages. While not statistically significant the data does show a general trend for the benefit of using some form of salience coding "color, icon or reverse video" for conveying urgency, as opposed to a simple text message or the message preceded by the word "expedite."

Preference

While participants preferred the color coding presentation, this preference did not translate to a faster response time. This result could be explained in two ways. First, it could be that there is a performance difference in reaction time to the different coding methods but that the measurement techniques in our study were not sensitive enough to capture the performance change. Second, it may be that there is performance preference disassociation similar to that mentioned in Andre & Wickens, 1995, in that the pilots' preference for the color display leads them to consider it as better. It is the position of this thesis that the former explanation is a more accurate reflection of our study. This position is taken for two reasons. First, as mentioned previously there were a number of factors that would minimize any effect (e.g., short, simple messages in a low-task environment) making it hard to accurately measure any real differences. Second, the trend for salience coding to show some performance advantage suggests that our study did find some small but consistent performance differences.

Future Research

Further research needs to be conducted to determine if improvements in response times and behaviors can be shortened in environments where pilots are carrying out greater task loads with messages of greater complexity. It may be that coding urgency does not work with simple messages under low workload. There is also a need to determine optimal alternative displays. For example, if an icon display is to be used it may be that a better icon could be found or it may be that a combination of the techniques used in this study or other techniques are better. From the survey part of this study the following appear to be plausible design methods for communication of urgency:

- Flashing – perhaps the screen could flash three times to indicate a new message

- Color
- The use of capital letters and bolding
- A multiple line display whereby one line (the last line) is dedicated to urgent messages
- An icon that is universally representative of urgency

CONCLUSION

This study provided a preliminary investigation of the potential to code message criticality into a pilot's datalink display. The data from this pilot study, whilst not conclusive, does suggest that it may be possible to invoke a faster response to messages by using one of the following coding methods: coloring the message red, using an icon, or by displaying the message in reverse video. More importantly, this study highlights the immediate need for further research aimed at identifying effective ways to distinguish between critical and non-critical messages in datalink communications between pilots and air traffic control.

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