Air Force Institute of Technology

AFIT Scholar

Faculty Publications

3-6-2012

Allocation of Communications to Reduce Mental Workload

Travis J. Pond

Brandon M. Webster

John P. Machuca

John M. Colombi
Air Force Institute of Technology

Michael E. Miller
Air Force Institute of Technology

See next page for additional authors

Follow this and additional works at: https://scholar.afit.edu/facpub

Part of the Performance Management Commons, and the Systems Engineering Commons

Recommended Citation
Pond, T., et al. (2012). Allocation of Communications to Reduce Mental Workload. Procedia Computer Science, 8(0), 242–248. https://doi.org/10.1016/j.procs.2012.01.052

This Article is brought to you for free and open access by AFIT Scholar. It has been accepted for inclusion in Faculty Publications by an authorized administrator of AFIT Scholar. For more information, please contact richard.mansfield@afit.edu.

Authors

Travis J. Pond, Brandon M. Webster, John P. Machuca, John M. Colombi, Michael E. Miller, and Randall Gibb

This article is available at AFIT Scholar: https://scholar.afit.edu/facpub/83

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Computer Science 8 (2012) 242 – 248

Procedia Computer Science

New Challenges in Systems Engineering and Architecting
Conference on Systems Engineering Research (CSER)
2012 – St. Louis, MO
Cihan H. Dagli, Editor in Chief
Organized by Missouri University of Science and Technology

Allocation of Communications to Reduce Mental Workload

Travis Pond*, Brandon Webster, John Machuca,
John Colombi, Michael Miller, Randall Gibb

Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, 45433, USA

Abstract

As the United States Department of Defense continues to increase the number of Remotely Piloted Aircraft (RPA) operations overseas, improved Human Systems Integration becomes increasingly important. Manpower limitations have motivated the investigation of Multiple Aircraft Control (MAC) configurations where a single pilot controls multiple RPAs simultaneously. Previous research has indicated that frequent, unpredictable, and oftentimes overwhelming, volumes of communication events can produce unmanageable levels of system induced workload for MAC pilots. Existing human computer interface design includes both visual information with typed responses, which conflict with numerous other visual tasks the pilot performs, and auditory information that is provided through multiple audio devices with speech response. This paper extends previous discrete event workload models of pilot activities flying multiple aircraft. Specifically, we examine statically reallocating communication modality with the goal to reduce and minimize the overall pilot cognitive workload. The analysis investigates the impact of various communication reallocations on predicted pilot workload, measured by the percent of time workload is over a saturation threshold.

© 2012 Published by Elsevier Ltd. Selection Open access under CC BY-NC-ND license.
Keywords: Workload; Multiple Resource Theory; multiple autonomous systems; Human computer interface

* Travis Pond Tel.: 937-255-3636 x7123; Fax: 937-255-4981.
E-mail address: travis.pond@afit.edu.

1877-0509 © 2012 Published by Elsevier B.V. Open access under CC BY-NC-ND license.
doi:10.1016/j.procs.2012.01.052

1. Introduction

Over the past several decades, the US Air Force has harnessed and exploited the immense tactical power that middle and high-altitude Remotely Piloted Aircraft (RPAs) bring to the battlefield. As a consequence, the demand for RPA operational support continues to increase. It is important to realize that RPAs are part of a complex system. The system has many components including one or more air vehicles, ground control stations (GCS) for both primary mission control and takeoff/landing, a suite of communications (including intercom, chat, radios, phones, a satellite link, etc), support equipment, and operations and maintenance crews [1]. Assets and requisite resources to support those operations are limited and personnel resources, particularly RPA pilots, often prove a nontrivial constraint. This inevitably leads innovators to seek out RPA force-multiplying efficiencies to assist in bridging the resource/demand gap. One such efficiency being pursued is simultaneous control of multiple aircraft by a single pilot, or Multi Aircraft Control (MAC). This concept of operations has been documented in the US Air Force UAV flight Plan [2].which calls for future systems in which a single pilot will simultaneously control multiple RPAs to enable increased aerial surveillance without increasing pilot manpower requirements. Previous research on the cognitive workload experienced by pilots during MAC indicated that frequent, unpredictable, and oftentimes overwhelming volumes of communication events can produce unmanageable levels of system induced workload for MAC pilots [3]. To further investigate this identified problem, our study makes use of IMPRINT Pro, a Multiple Resource Theory (MRT) based dynamic, stochastic simulation to analyze impacts to cognitive workload by a disciplined communication modality reallocation construct.

2. Background

In the RPA domain, communication is a continuous and demanding process. Crews must track, at a minimum, information regarding weather, threats, mission tasking, mission coordination, target coordination, airspace coordination, fleet management, and status and location of any friendly units. The RPA pilot is not only responsible for aircraft control but is also a critical member in a multi-path communications infrastructure [4]. In the ground station, communication with the pilot takes place in one of two modalities: textual chat window(s) or the speech-based radio systems. At any given moment, a pilot may need to monitor multiple chat windows and listen to numerous parties operate over the radio. The multitude of communication sources and different media coupled with the quick inter-arrival rate of these events during a dynamic scenario drives an incredible cognitive workload for the pilot.

Cognitive or mental workload expresses the task demands placed on an operator [5]. Calculation of task demand, or task load, often considers the goals of the operator, the time available to perform the tasks necessary to accomplish the goals, and the performance level of the operator [6]. Therefore, workload increases when the number or difficulty of tasks necessary to perform a goal increase, or when the times allotted to complete these tasks decrease. Assuming that the operator has a limited amount of mental resources (e.g., attention, memory, etc.) that he or she can utilize to complete the necessary tasks, mental workload corresponds to the proportion of the operator's mental resources demanded by a task or set of tasks. Several methods have been employed to measure and quantify mental workload over the past four decades and have been summarized in numerous publications [5,7,8]. For example, [7] summarizes secondary task measures of workload where a subject is asked to perform a secondary task which intrudes upon the primary task. The secondary task performance is measured, giving an indication of how much mental resources the subject had available to them. If the secondary task performance is high, it is taken as an indication that the primary task induces relatively low workload on the subject. This measure is not ideal, however, because it is subject to a variety of mitigation strategies, which could skew performance results. The measure also does not work for situations with many tasks where overall workload measures are desired. Stand alone performance measures are also discussed [7]. Stand alone measures tend to be effective for single tasks but cannot be extended to multiple tasks. Measuring methods also tend to be intrusive and may interfere with results. The current analysis incorporates Multiple Resource Theory (MRT) into the workload calculations to account for channel conflict driven workload. MRT

As a theory, MRT purports the existence of four mental dimensions (or channels) available to process information and perform tasks. The dimensions include processing stages, processing codes, perceptual modalities and visual channels. These channels are allocated to concurrent tasks with the difficulty of the tasks and the demand conflict between channels driving the overall mental workload value [9]. MRT accurately describes the concurrent nature of tasks imposed on an RPA pilot (performing primary tasks while communicating and monitoring communication) and is therefore an appropriate theory to apply to the present analysis.

3. Method

Therefore, the specific channels employed by the modeled communication events are highly relevant to the MRT workload calculations. As communication events begin to conflict with existing work activities on the various channels, the calculated overall cognitive workload will account for such conflicts. This construct enables the analysis to address the question of whether or not adjusting the intentional allocation of communication events to particular modalities will be able to meaningfully affect overall cognitive workload.

3.1. Model

A previous model of pilot mental workload [3] was utilized to understand the impact of communications modality. This model employed functional analysis and task allocation to construct an executable architecture of the multiple RPA system. This architecture was then replicated within the Improved Performance Research Integration Tool (IMPRINT) to estimate the pilot's workload under various mission segments, such as handover, transit, emergency, benign and dynamic surveillance, etc. IMPRINT is a human performance tool used by the Army Research Lab to simulate cognitive tasks and mental workload, as well as manpower and maintenance missions. This model relied on subject matter expert input to develop distributions for the length, frequency, and difficulty of the events that induce workload on the pilot. The original research on this model indicated that workload was particularly high during what were termed dynamic mission segments. These mission segments often involve high levels of communication between the pilot and external actors to facilitate the tracking or observation of moving targets. High levels of communication resulted in particularly "high" pilot workload while operating a single aircraft and, "excessive" workload while controlling multiple dynamic-mission aircraft. The original research indicated that a reduction in pilot workload imposed by communication would be necessary to facilitate MAC.

To understand the potential impact of communication modality on operator workload, the communications portion of the earlier workload model was modified to permit communications events to be reallocated to alternate communications modalities. The revised model permits communication events that were originally allocated to the auditory channels where the operator listens and speaks to the visual and fine motor channels where the operator reads and types, or vice versa.

Figure 1 depicts the high level structure of the revised communications model. The gray boxes indicate model elements that were added to facilitate this particular evaluation. Communication events are generated with a mission segment dependent frequency and their interarrival times are exponentially distributed. In the original model, as a communication event is generated, it is assigned as either an auditory event or a text-based event with 25% of the events being allocated as auditory events and the remaining allocated as text events. Half of the auditory events then required the pilot to talk or listen while 90% of the text events required the pilot to read while only 10% of the events required the pilot to type a response.

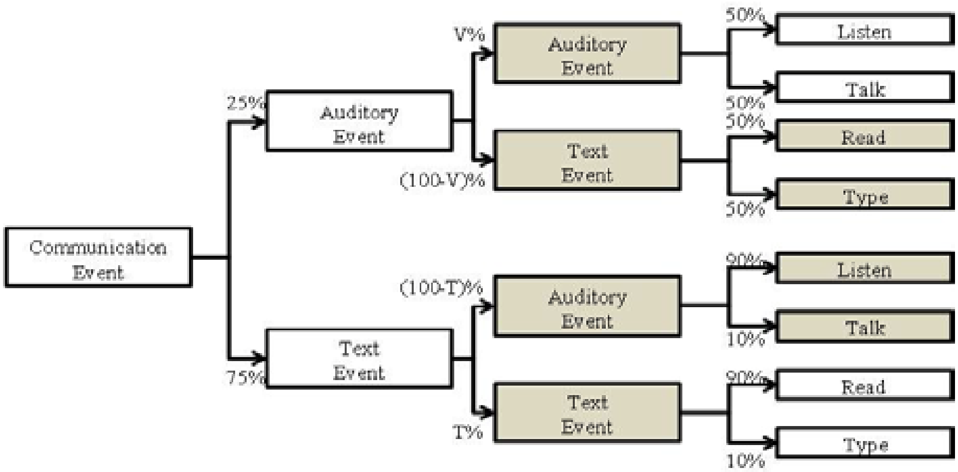

Fig. 1. Modified communication model of pilot workload

To conduct the current evaluation, the model was modified as shown above. The auditory and text events shown in *gray* have the potential (through a notional device or software) to either pass an auditory or text event as a respective auditory or text event or to convert an auditory event to a text event or convert a text event to an auditory event. With this modification, it is assumed that the characteristics of the communication are due to communication needs, such that if a text event in the original model had a 90% chance of providing an input to the pilot and only a 10% chance of an output to the pilot, a text event converted to an auditory event has a 90% probability to require the pilot to listen and only a 10% probability to require the pilot to talk. The parameters V (for Voice reallocation) and T (for Text reallocation) provide the ability to convert auditory or text events to its compliment. If V and T are both

100%, the revised model is the same as the original model. Reducing either of these parameters permits a portion of one type of communication event to be reallocated to the complimentary communication event. Although not shown, it is then assumed that some percentage of the final events generate a repeat communication event, indicative of a continued conversation. This aspect of the model was not changed.

3.2. Experimental Design

For this paper, a total of six "levels" of voice/text allocation were selected such that the percent of voice communication were varied between 0 and 100 percent. For levels of voice communications less than 25%, *V* was varied while *T* was maintained at 100%. However, for levels of voice communications greater than 25%, *V* was maintained at 100% while *T* was varied to achieve the desired communications levels. All analysis was performed for a 10 hour dynamic mission segment with a single pilot operating the aircraft. Although IMPRINT does not currently have built-in Monte Carlo functionality for the metrics of our concern, an external batch application was developed to automate replications. A total of 10 replications for each of six levels using 10 different random number seeds were performed to gather the output data.

The output of the IMPRINT model was analyzed to determine the proportion of time that the operator would experience workload values over a specified task saturation threshold. A workload value of 60 was calibrated to be about the 90% of operator "red-line", which indicates the workload value a pilot can experience without degraded performance [10]. The mean and variance across the 10 replications for each communication ratio was calculated. Analysis of Variance (ANOVA) and the Tukey post-hoc tests were employed determine the statistical differences between the average of percent time over threshold.

4. Results

Figure 2 shows the percent time over threshold as a function of the percentage of voice communication. A one way ANOVA indicated a significant effect of the percent of voice communication upon the percentage of time over threshold ($p < 0.001$). As shown in Figure 1, the percent of time over threshold is reduced as the percent of voice communication is increased from 0% to 40%. At 40% voice communication the percent time over threshold is reduced to 24.5% compared to 33.1% with 0% voice communication. This change is statistically significant. The change in percent time over threshold is statistically insignificant as the percent of voice communication is increased from 40% to 60%. This trend indicates that pilot workload is reduced by the use of both auditory and text-based communications in this system.

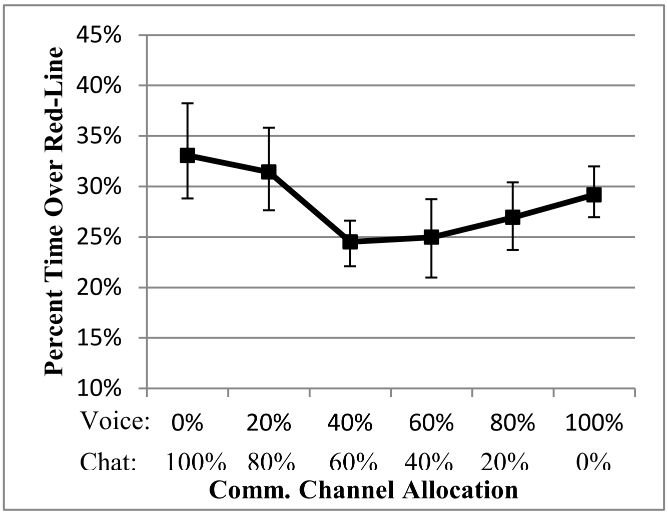

Fig. 2. Percent Time Over Threshold as the percentage of reallocated voice events

Results further show that the percent time over threshold is greater at 0% voice than at 100% voice communications. This might have been expected as reading and typing likely conflicted directly with other tasks being performed by the pilot, including visually monitoring the status and manipulating the controls of the RPAs. As such workload is highest when all of the communication is allocated entirely to the visual channel.

5. Conclusions

The model indicates that by deliberately allocating communication between auditory and text-based modalities the pilot's workload and particularly the percentage of time the pilot operates beyond their task saturation red-line can be statistically reduced. The model shows that the percent of time over red-line is greatest when all of the communication is allocated to the text-based communications such that zero percent of the communication is allocated to voice. This type of communication is most likely to conflict with other tasks involving the visual system to monitor the RPA and the small motor system, which is used by the pilot to control the RPA. As communication events are moved from text to auditory, the workload decreases. However, as more communication is moved to the auditory channel, the percent of mission time over the red-line to increases. The increase likely occurs as the auditory tasks begin to overlap and conflict with one another to increase workload. There appears to be an optimal allocation of communications between voice and text modalities to achieve the lowest workload given a constant traffic load. Future research will examine dynamic reallocation of modalities.

References

[1] USAF MQ-1B Predator Fact Sheet. Air Combat Command, Public Affairs Office, 130 Andrews St., Suite 202; Langley AFB, VA 23665-1987. Sep 2010

[2] USAF, Headquarters. USAF Unmanned Aircraft Systems Flight Plan 2009-2047; Washington, DC; 2009.

[3] Schneider M, McGorgan J, Colombi J, Miller M, and D Long. Modeling Pilot Workload for Multi-Aircraft Control of an Unmanned Aircraft System. *Proceedings fo the INCOSE International Workship*; Denver, CO; 2011.

[4] MITRE. (2009). *Air force unmanned aircraft systems unconstrained architectures,* USAF.

[5] Beevis D,Bost R, Dring B, Nordo E, Oberman F, Papin JP, Schuffel H, and D Streets. Analysis techniques for human-machine systems design. CSERIAC SOAR 99-01; 1999.

[6] Hardman N, Colombi J, Jacques D, and J Miller. Human systems integration within the DOD architecture framework. Paper presented at IIE Annual Conference and Expo; May 17-21, Vancouver, BC; 2008.

[7] Gawron, VJ. Human performance, workload, and situational awareness measures handbook. 2nd ed. Boca Raton, FL: CRC Press; 2008.

[8] Neville S, Salmon P, Walker G, Baber C, and D Jenkins. Human factors methods: A practical guide for engineering and design. Burlington, VT, USA: Ashgate; 2005.

[9] Wickens, CD. Multiple resources and mental workload. Human Factors, 50(3); 2008. pp 449-455.

[10] Grier, R., C.D., Wickens, David K, et al. The red-line of workload: Theory, research, and design. Paper presented at Human Factors and Ergonomics Society Annual Meeting Proceedings, New York, NY; 2008.