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INVESTIGATION OF ERROR RATES WHEN CONTROLLING MULTIPLE UNINHABITED COMBAT AERIAL VEHICLES

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ABSTRACT

As systems become more and more complex the use of automation tools becomes more important. Although automation is introduced to reduce human workload, improve situational awareness, and system reliability, increases in automation features also increase the overall complexity of the system. Despite the fact that research has been and is being conducted investigating the effects of automation on human performance, the results are often contradictory. This suggests the need for a universal way of presenting results so that trade-offs can be carried out between different studies. The purpose of this research was to investigate how a decision structure approach might be used as an aid for designers and researchers to conduct design trade-offs when designing user interfaces for Uninhabited Combat Aerial Vehicles (UCAVs).

1 INTRODUCTION

Advancement in technology has brought a new revolution in the military domain. Remotely operated vehicles (ROVs) are vehicles that are commanded and controlled from a remote location. The success of the two unmanned reconnaissance prototypes ‘Predator’ and ‘Hunter’ have paved the way to the development of more challenging remotely operated vehicles like Uninhabited Combat Aerial Vehicles (UCAVs). UCAVs are used for locating, identifying and destroying the enemy targets. Currently one UCAV is controlled by multiple operators. In the future multiple UCAVs will be controlled by one operator. The success of the mission depends on how well the human operator interacts with the intelligent UCAVs.

Human operators of these complex systems have many responsibilities (e.g., multiple UCAV coordination, handling multiple targets and/or target areas, detecting targets, identifying targets, planning routes, destroying targets, and timely returning UCAVs to base). The dynamic and complex nature of UCAV systems and the overwhelming amount of data that must be handled by these systems are making automation a critical part in planning, decision-making and execution. Automation is defined as a method in which operations are done automatically at some level. Bruemmer, Marble, and Dudenhoeffer (2002) observed a dramatic reduction in many types of human errors due to automation. However, automation itself has failed in many ways (Thurman, Brann, and Michell 1999; Cook and Corbridge 2000). First, an automation aid can fail to produce a response or a signal message. Second, an automation aid may have a low accuracy due to technology limitations including over simplification of the underlying decision making models. Third, automation aids may work perfectly but fail to respond at the right time. Thus, human-centered automation design is needed, an approach in which the human is seen as a critical element in the system.

The taxonomy of 10 levels of automation that were developed by Sheridan (1980, 1987) clearly states that any automated system will allow the operator some form of control over the automation. Wiener and Curry (1980) reported that the advent of automation brings new problems associated with human computer interaction (HCI). Some problems associated with automation are vigilance decrements (Heilman 1995), out-of-the-loop performance problems (Barnes and Matz 1998; Endsley and Garland 2000), complacency (Mosier, Skitka, and Korte 1994; Mosier and Skitka 1996), and skill degradation (Hopkin 1995; Mooij and Corker 2002). Understanding these factors that affect the use of automation is important for design considerations. Other factors that affect the overall efficiency, and performance of the system as well as human error are workload (Riley, Lyall, and Wiener 1993), reliability (Parasuraman, Molloy, and Singh 1993), and situational awareness (Coury and Semmel 1996).

Although researchers have investigated the effects of many variables on performance, results are often contradictory. Literature indicates that in complex systems 90% of the accidents that occur can be attributed to human error (Jones and Endsley 1996; Mosier, Skitka, Heers, and Burdick 1998;

Sarter and Alexander 2000). Researchers and system designers try to determine possible errors in order to eliminate them or build error tolerant systems. However, this is a difficult undertaking due to the complexity of the system and variety of tasks. There is also no standard way of representing research results related to human errors and automation making it difficult to compare studies and make design decisions. As illustrated in Figure 1. independent variables (such as level of automation, reliability, workload, SA) are discussed as having general outcomes. However, the actual effects that the independent variables have on the decision process are often not reported.

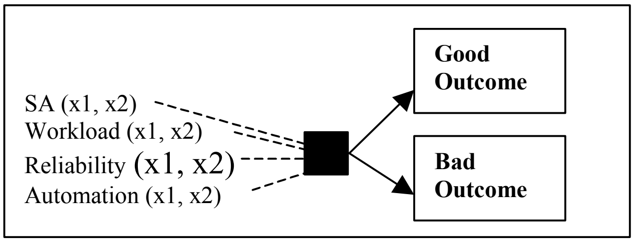

Figure 1: Description of Results for Decision-Making Tasks in a Complex System

Therefore researchers need to develop a standard approach for reporting how different variables specifically affect human performance so that system designers and researchers can interpret and integrate results into designs. Lucas, Gallimore, and Prabhala (2001) suggested using a decision structure approach. Each time a decision is made by an operator a general decision structure constrains the possible decision choices. The decision choices (made by human and /or machine) can be mapped onto that structure. Given enough mappings information about the decision process for a particular situation can be determined. For example, a UCAV operator must be aware of fuel level and determine if it is adequate to accomplish a mission. If the fuel level is inadequate the operator must decide on possible corrective actions such as reducing airspeed or returning to base. The structure looks at possible decision points and probability of outcomes are reported in a decision tree or influence diagram (See Figure 2.). In this research we used this approach to investigate human performance when controlling multiple UCAVs. In figure 2. a diamond shaped block characterizes decisions, and a rectangular shaped block characterizes outcomes. An 'A' in the diamond represents a decision/action made by the automation. A 'U' in the diamond represents a decision/action made by the user. An 's' in the left most corner of the diamond represents a starting point for the decision structure. Outcomes can be passive, such as "Ignored" or active such as "Good Outcome" and "Bad Outcome".

This particular approach is also different from another error rate prediction tool known as THERP (technique for human error rate prediction). THERP is used to predict human error probabilities in order to evaluate the degradation of human-computer systems by (a) identifying system functions that can be influenced by human error, (b) listing detailed task analysis to analyze human error, and (c) estimating error probabilities using expert judgment. Drawbacks of THERP include lack of error monitoring and specifying possible errors and error probabilities for each action based on expert judgment. The approach we are suggesting is to evaluate system design by analyzing the decisions and their outcomes and collecting data showing how often outcomes occur.

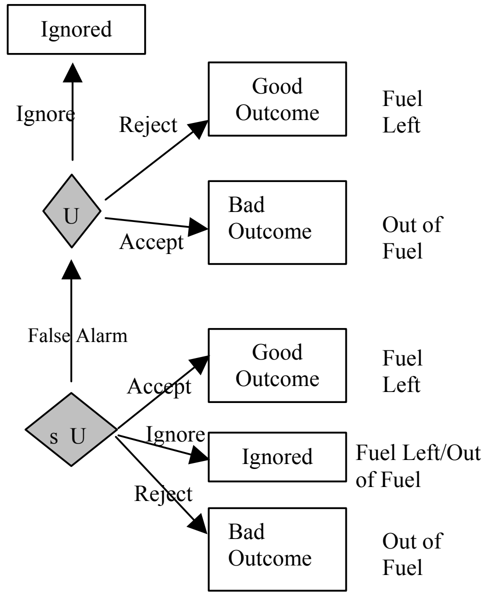

Figure 2: Decision Structure for Fuel Indication Task in Manual Level of Automation

The purpose of this experiment was to investigate the effects of level of automation and system reliability on performance when controlling multiple UCAVS. The outcome is presented using the decision structure.

2 METHODOLOGY

A simulation was developed using JAVA in which multiple UCAVs fly along a preset route over a terrain filled with targets. Targets are identified using a sensor onboard each UCAV. When the target is within range of the UCAVs, the sensor senses the target which appears on the controller's screen (Figure 3.). The simulation was run with three levels of automation. In the **AUTOMATION ON** mode, the targets are automatically identified by an automation tool and are highlighted for the operator to take the appropriate action. In the **MANUAL** mode, the user must identify the type of target and select the appropriate munition. In the automation **SELECTIVE** mode, the operator can turn on/off the automation tool at any point depending upon the perceived workload. In automation **SELECTIVE** mode, if the automation tool is turned on, the targets are automatically queued by the sensor and the images appear directly on the screen. Also, the targets are identified as friend or foe and are highlighted for the operator to take the appropriate action. When off, the system reverts to manual mode.

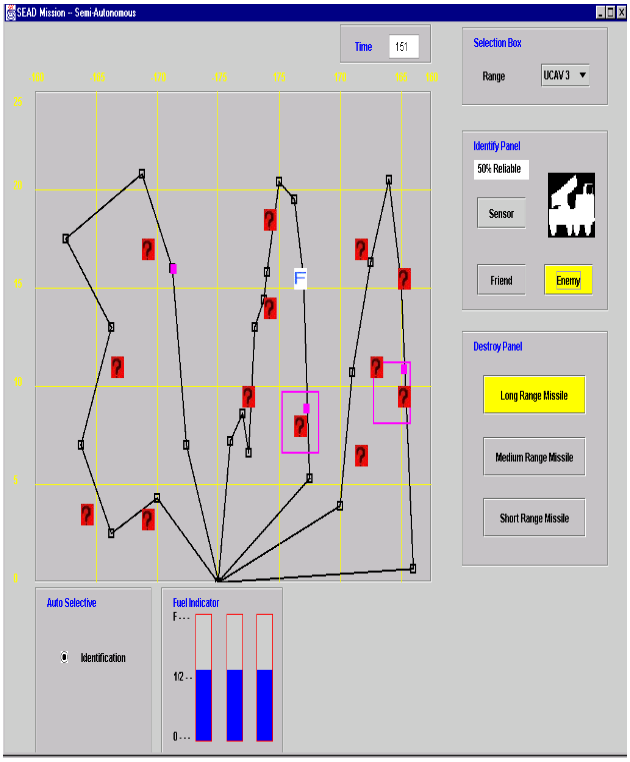

Figure 3: Screenshot Showing the Human Controller Interface

The experimental design was a 3x2 within-subjects design. The independent variables were level of automation (ON, MANUAL, SELECTIVE) and system reliability. System reliability was set to 50% or 75% of targets correctly identified by the automation. The dependent variables were percentage of targets correctly identified, percentage of targets incorrectly identified, and percentage of targets miss-identified. It was hypothesized when automation is SELECTIVE more targets will be correctly identified than under full automation or manual conditions. It was also hypothesized that subjects would perform better when reliability is 75% compared to 50%.

Six men and six women from Wright State University volunteered to serve as subjects. The apparatus included a 333 MHz Dell personal computer running NT with a 17'' color CRT. The input devices were a standard 101 keyboard and mouse. The experiment took place in an office type environment with dim lighting. The subjects sat in an adjustable office chair, and the keyboard and mouse were placed at comfortable positions determined by each subject.

An interactive simulation was created in JAVA. Three UCAVs flew along a preset route over a terrain in which targets appeared randomly. For each simulated UCAV, there were six targets. When system reliability was set to 50%, three out of the six targets were friendly targets and three targets were enemy targets. When the reliability level was 75%, there were two friendly targets and four enemy targets for each UCAV. The friendly targets and the enemy targets can be distinguished from each other using the sensor images.

Subjects were trained to use the UCAV interface including, how to identify targets, manipulate UCAV waypoints, and monitor time and mission progress. Training lasted one hour. Subjects participated in three practice trials then participated in the six experimental conditions. Each simulated mission lasted 350 seconds.

3 RESULTS AND DISCUSSIONS

The three dependent variables were each analyzed using ANOVA to determine statistical significance. The results were mapped to the decision tree (Figures 4-6.). The analysis of variance (ANOVA) results for the three dependent variables indicated a significant main effect of the level of automation. A significantly greater percentage of targets were correctly identified in automation SELECTIVE condition, than under MANUAL condition and AUTOMATION ON condition. Similarly the percentage of targets not-identified and incorrectly identified was less in automation SELECTIVE condition than in the other two levels of automation. The ANOVA results also indicated significant main effects of system reliability in the case of percentage of targets correctly identified. There was no significant difference in the levels of system reliability in the case of targets miss-identified and targets incorrectly identified. As hypothesized, more targets were correctly identified when automation is SELECTIVE than in automation ON or MANUAL conditions. It appears that when automation is always on the operators may put too much trust in the systems choices. When they controlled automation as workload changed, they performed better. These results are in keeping with other research (Ruff 2000).

Figure 4. illustrates the decisions and errors made under the MANUAL condition when reliability is set to 50% presented using a decision structure. The targets were identified correctly 89.74% of the time, not identified 5.26% of the time, and incorrectly identified 5.0% of the time. Figure 5. illustrates the decisions and errors made under the AUTOMATION ON condition when reliability was set to 50%. When targets are correctly identified by automation, the outcome that they were correctly identified by the subjects is 86.11%, not identified is 2.78%, and identified incorrectly is 11.11%. When the targets are identified incorrectly by automation, the outcome that they were correctly identified by the subjects is 85.18%, not identified is 2.79%, and identified incorrectly is 12.03%. Figure 6. illustrates the decisions and errors made under automation SELECTIVE condition when reliability was set to 50%. Under this condition automation was turned on/off at any time during the mission depending upon workload of the

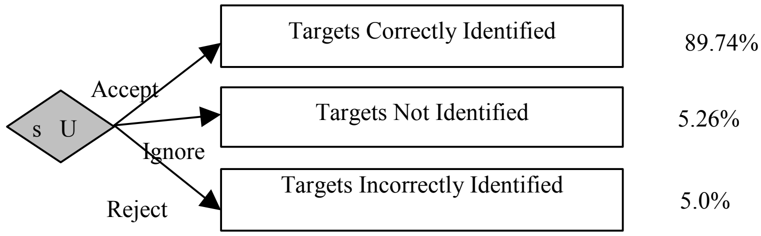

Figure 4: Decision Structure When Automation is OFF and Reliability is 50%

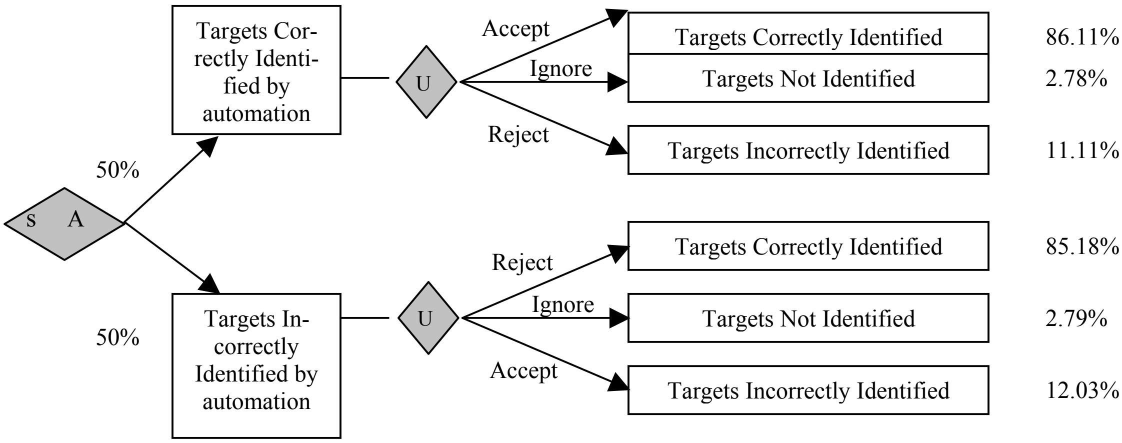

Figure 5: Decision Structure When Automation is ON and Reliability is 50%

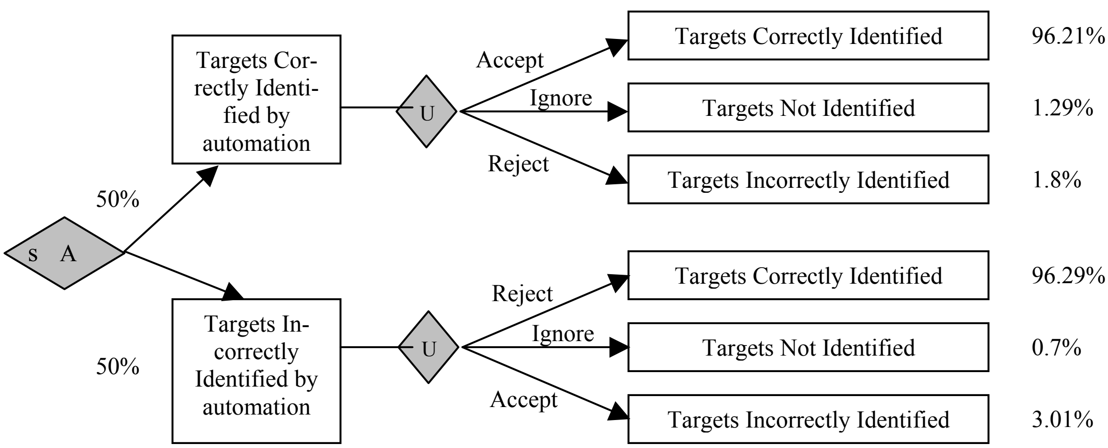

Figure 6: Decision Structure When Automation is SELECTIVE and Reliability is 50%

operator. In figure 6. for the condition when automation is SELECTIVE and automation was on subjects correctly selected the automation level to perform the task 96.21% of the time, not identified 1.29% of the time and incorrectly identified 1.8 % of the time. When automation was off, subjects were still able to correctly identify targets 96.29% of the time, not identified 0.7% of the time, and incorrectly identified 3.01% of the time.

4 CONCLUSIONS

Looking at the results using decision tree structure can be very complicated for complex missions; however, it provides researchers and designers with a way of analyzing why a certain outcome occurred. However, statistical analysis is still crucial. In order to compare different studies so that design tradeoffs can be evaluated, it is essential to know the operators decision process. ANOVA results, of the independent variables, do not give a detailed explanation of the decision structure of the human operator. For example, consider the case of automation ON and reliability 50% (see Figure 5.) the ANOVA results indicates the average value of the targets correctly identified as (86.11+85.18)/2=85.64 whereas the decision structure approach splits the values according to the decisions made by the operator. Also, decision structure approach can be used as a post analysis tool as it indicates the error rate and the places where they occur or in other words provides feedback to the designers about the system design. In addition, it can also be used as a learning tool in designing better systems by keeping a track of the error rates. Future research which includes a more complex mission scenario should be conducted and results plotted in this way to determine if this approach helps designers, and better identifies decision making performance.

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