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THESIS

COMMAND AND CONTROL WITH HUMAN–MACHINE TEAMS

by

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The amount of information to analyze in the decision-making process for command and control is increasing past human cognitive limits. The effects of augmenting human information processing with machine-processing capability are not fully understood. This research examined the interdependence between machine and human teammates and its impact on the current command and control structure. The experiment (2X4 repeated measures analysis) was conducted online utilizing Qualtrics and Amazon’s Mechanical Turk. Each of the 119 participants was asked a set of questions about 34 faces. Participants were asked to identify the category of the face and what reaction they would have, friendly or defensive. This question order was reversed and each of the questions was asked individually. This process was repeated while adding the assistance of a machine teammate. The machine teammate displayed a suggested answer to the first question that the human had to acknowledge before continuing to answer.

This research is preliminary. However, conceptually, the additional communication between a human and machine teammate adds time into the command and control process. This interaction may also affect the decision maker by priming the human to an action or through automation bias. Furthermore, reducing information to the human in a human-machine team has significant potential to reduce team situational awareness. Follow-on research is needed before any conclusions can be reached.

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COMMAND AND CONTROL WITH HUMAN–MACHINE TEAMS

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
ACT-R	Adaptive Control of Thought-Rational
CNA	Center for Naval Analysis
COVID-19	Corona Virus Disease 2019
DOD	Department of Defense
EPIC	Executive-Process Interactive Control
EUT	Expected Utility Theory
EVT	Expected Value Theory
HMT	Human Machine Team
IBM	International Business Machines
JP	Joint Publication
NDP	Naval Doctrine Publication
OODA	Observe-Orient-Decide-Act
RGB	Red, Green and Blue
RMA	Revolution in Military Affairs
SA	Situational Awareness
SHOR	Stimulus-Hypothesis-Option-Response
SOAR	State, Operator And Result

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I. INTRODUCTION

The amount of data that are generated and collected is growing at increasing rates. In 2013, it was estimated that over 90% of the world's data had been created in the last two years (Dragland, 2013). There is no shortage of publications promoting the use of computer system analytics (Elgendy & Elragal, 2014) and the value they add to decision-making by these computer-based decision support systems. The application of computer system analytics enables pattern recognition in large datasets that improves decision making (Henry & Venkatraman, 2015). A recent example of this is with the novel coronavirus (which causes the disease COVID-19). AI platform Bluedot was able to alert on the COVID-19 threat one week before national surveillance centers and the World Health Organization (Fitzpatrick et al., 2020). Advances in computer systems and analytical tools can empower military leaders to make faster decisions and to use various information fusion techniques for decision superiority in the big data era (Bean, 2016; Sayler, 2019). To make effective decisions in complex environments, a decision maker must have access to the most complete real-time information. We have the capability to collect this data from various platforms; for example, data for almost every mission and training exercise can be sent in near real time back to the command and control center (Sayler, 2019).

The utility of analyzing large amounts of data with little or no delay is realized when otherwise, unrecognized patterns are incorporated into the decision-making process that eventually leads to making better decisions (Sayler, 2019). Most of the analysis is done by a human manually filtering and analyzing large volumes of data. As a result, processing large volumes of data can be time-consuming and inefficient. The ability to process large volumes of data expeditiously exceeds human information processing capabilities (Anastasia, 2015). Ergo, analysts are unable to keep pace with increasing volumes of data, and most importantly, potentially overlook the subtle but critical insights; as a result, mission-critical context-sensitive information can be missed. This research is important because it examines decision-making performance of human-machine teams at the confluence of the information processing, situational awareness, mutual trust, and risk; in doing so, the goal is to deliver a systemic perspective to the human machine team decision making process. Since the future of command and control will depend on human-machine teams (HMT), it is imperative that the U.S. military understands the benefits, risks, and complexities associated with this revolution in the command and control paradigm.

A. PROBLEM STATEMENT

To maintain a relative advantage against our adversaries, we must leverage technological advances, such as AI, to support military operations in all war-fighting domains. Central to this endeavor is command and control, as Marine Corps Doctrinal Publication MCDP- 6 states, "No single activity in war is more important than command and control" (U.S. Marine Corps [USMC],1996, p. 35). The problem is that the amount of information required to analyze in the decision-making process is increasing past human cognitive limits. A machine teammate can mitigate this; however, this introduces new command and control issues related to situational awareness, mutual trust, prudent risk, and ultimately decision effectiveness, that we do not fully comprehend yet.

B. PURPOSE STATEMENT

The purpose of this research is to examine the interdependence between machine and human teammates. This becomes critical to identify and mitigate new command and control issues that can emerge in situations in which orient of the Observe-Orient-Decide-Act (OODA) loop or situational awareness (SA) constrains the team performance. For example, a service member has a machine teammate that starts to dominate his/her decision space. Although the information processing capability of the service member increases, the contextual SA can be suppressed. Hence, the decision comfort level of the service member may change, and the command and control related repercussion of this situation can affect shared awareness, mutual trust, and prudent risk, which are critical to effective command and control.

C. RESEARCH QUESTIONS

1. What are the new command and control issues that can arise in HMTs while the dominating decision makers vary?

2. Does interaction with a machine affect the situation awareness?

3. H1: HMT will have greater decision effectiveness

D. ORGANIZATION OF THESIS

This thesis is organized into four additional chapters. Chapter II is a literature review that investigates what makes up command and control, and briefly touches on models and theories. Chapter III describes the research methodology. It goes into details about the experimental design and how the experiment was conducted. Chapter IV presents the results of the experiment and goes into the analysis that was conducted. Finally, chapter V provides the conclusion of this research and provides recommendations for further research.

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II. LITERATURE REVIEW

A. HISTORICAL CONTEXT

The term command and control was not formally defined until the 20th century; however, it has been thought about and practiced for centuries (Alberts et al. 2010). Early command and control was a relatively simple task: the commander would be able to see all his forces and the entire battlefield. He would be able to direct and be involved in the action; thus, he would see the results (the consequences of his directions). This can be seen in the work of one of the most well-known military theorists, Carl von Clausewitz. In his famous book *Vom Kriege* (*On War*), Clausewitz stated "each commander can only fully know his own position; that of his opponent can only be known to him by reports. Which are uncertain" (Clausewitz, 1989, p. 9). Thus, control was limited to what the commander could see; essentially it was about the distance for visual and audio signals. This makes sense because in that era battlefields were generally small and well defined. Fighting was done with short-range weapons in large masses. Modern command and control draws its origins from Napoleon who is credited with the development of the first headquarters and staff (Alberts et al., 2010). Martin Van Creveld recognizes that commanding and controlling an armed force with effective communication is as old as war itself (Creveld, 1987). As technology has increased so has the quest for information and certainty which leads to the problem of effective command and control. Sun Tzu wrote in *The Art of War*:

> If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle. (Tzu, 2004, p. 15)

Martin Van Creveld also recognizes this same point as a quest for certainty (Creveld, 1987):

> [A quest for] certainty about the state and intentions of the enemy's forces; certainty about the manifold factors that together constitute the environment in which the war is fought, from the weather and the terrain to radioactivity and the presence of chemical warfare agents; and, last but definitely not least, certainty about the state, intentions, and activities of one's own forces. (Creveld, 1987, p. 264)

Modern warfare does not have the same luxuries as the past commanders had. Specifically, in the sense they could see and direct action.

In 1995, Secretary of Defense William J. Perry stated, “historically, an [revolution in military affairs] RMA occurs when the incorporation of new technologies into military systems combines with the innovative operational concepts and organizational adaptations to fundamentally alter the character and conduct of military operations.” (Perry, 1995). “Even the most casual glance at business history makes it clear each time a new information infrastructure becomes available (e.g., railroad, telegraph, telephone) the entities which are ultimately most successful are also the first to reshape their structures in order to gain maximum advantage of the new information conduits” (New Worlds Vistas, 1996). Joint Publication 3-0, Joint Operations states “Advances in information technology increase the tempo, lethality, and depth of warfare.” Thus, a commander who is operating at a slower tempo is at a great disadvantage.

The United States has sought to leverage technology two pervious times in an effort to offset the large buildup of forces its enemies have accumulated (Manea, n.d.). The first was in the 1950s with President Eisenhower’s “New Look” (Manea, n.d.). The second came in the 1980s with Secretary Harold Brown promoting an “Offset strategy” (Manea, n.d.). As adversaries of the U.S. endeavored to close the gap formed by the “second Offset Strategy,” a need for a new strategy ensued. This was the beginning of the third offset strategy (Bertuca, 2014; Manea, n.d.). This strategy focuses on technologies such as: robotics, autonomously operated guidance and control systems, visualization, biotechnology, miniaturization, advanced computing and big data, advanced energetics, additive manufacturing, and 3D printing to gain an advantage (Host, 2015). In a 2015 speech the Deputy Secretary of Defense, Bob Work, said that “we will use machines to help our decision-makers make better decisions” (Work, 2015). In order to effectively deploy machines as a means to improve decision processes in the military, the effects of machines on command and control must be understood.

B. DOCTRINE AND DEFINITIONS

1. Maneuver Warfare Doctrine

The Marine Corps has adopted maneuver warfare. In this context winning is contingent on maintaining quick, flexible plans; in doing so, adaptive behavior can be sustained in the complex battlefield especially important is time. To win, one must be able to generate a faster tempo than the enemy (USMC, 1996). Furthermore, to be successful in maneuver warfare one must have speed and surprise in order to concentrate combat power at the right time at the decisive point. Speed is how rapid an action takes place (USMC, 1997). “Speed over time is tempo” (USMC, 1997, p. 2-19). Absolute speed does not matter, it is your speed relative to the enemy. If you can act faster than the enemy then the enemy will be forced to react to your actions, thus gaining the initiative. Since speed is what matters, it follows that we should do everything we can to increase our speed of action without degrading the quality. One way to do this is through improved command and control operations with the use of machine teammates.

War is a fluid battle of wills, during this battle many opportunities will present themselves but will be fleeting (MCDP 1, 1997). To be able to exploit these fleeting opportunities we must apply focus (MCDP 1, 1997). Focus applies to time and space, meaning we must be able to effect action at the right location at the right time (MCDP 1, 1997). To be able to apply this focus we must be able to effectively command and control the force.

2. Command and Control Definitions

Command and control bestows the legal authority on the commander to give direction to all assigned forces (MAGTF Expeditionary Operations 8906, 2019). Command and control is the warfighting function that allows the other warfighting functions to be effective (MAGTF Expeditionary Operations 8906, 2019). According to MCDP 6 [Command and Control] “No single activity in war is more important than command and control.” Furthermore, MCDP 1–2 [Campaigning] states “it [command and control] provides the intellectual framework and physical structures through which commanders transmit their intent and decisions to the force and receive feedback on the results.” Command and control by itself will not destroy a single enemy target or drive home a single attack (MCDP 6, 1996). “Yet none of these warfighting activities, would be possible without effective command and control” (MCDP 6, 1996). A comparison between how the Department of Defense and the other services define command and control can provide some insight to this concept. The Department of Defense (DOD) definition for command and control from the 2020 DOD dictionary of Military and associated terms:

> The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Also called C2. (JP 1). (DOD Dictionary of Military and Associated Terms, 2020, p. 40)

This serves as the foundation for the services, most have adopted this definition with a few exceptions. The Army defines command and control as:

> The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. (JP 1). (Headquarters, Depart of the Army [DOA], 2019, Glossary-2)

The Navy definition is:

> Command and control enables the naval commander to understand the situation in his battlespace, select a course of action, issue intent and orders, monitor the execution of operations, and evaluate the results. It is the primary tool he uses to cope with the disorder and uncertainty of warfare. (Department of the Navy, 1955, p. 6)

The Air Force adopts the original definition and adds to it:

> Command and control is "the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission" (JP 1). C2 enables mission accomplishment by collaborative planning and synchronizing, integrating forces and operations in time and purpose. Fluid horizontal and vertical information flow enables effective C2 throughout the chain of command (U.S. Air Force [USAF], 2020, p. 69).

Finally, the Marine Corps' definition is:

> The means by which a commander recognizes what needs to be done and sees to it that appropriate actions are taken. (MCDP 6, 1996, p.37)

These definitions contain the necessary elements for successful command and control. In order to fully understand the command and control process it is important to understand the two components. The first is command, command bestows on the commander the legal authority to give directions to all assigned forces (MAGTF Expeditionary Operations 8906, 2019). Control is fundamentally part of command. Control allows a commander's staff to monitor the status of command and ensure corrections are made where needed to align subordinates to the will of the commander (MAGTF

Expeditionary Operations 8906, 2019). These two concepts will be explored in detail in the next section.

3. Command

Vital to the understanding of command and control is the component of command. The 2020 DOD dictionary of Military and associated terms defines command as:

> 1. The authority that a commander in the armed forces lawfully exercises over subordinates by virtue of rank or assignment. 2. An order given by a commander; that is, the will of the commander expressed for the purpose of bringing about a particular action. 3. A unit or units, an organization, or an area under the command of one individual. (DOD Dictionary of Military and Associated Terms, 2020, p.40)

From this definition it is clear the commander has been given authority to issues orders to bring about a particular action by individuals, a unit, or units. With authority also comes responsibility. Command has two parts: decision-making and leadership (MAGTF Expeditionary Operations 8906, 2019). Decision-making in this regard has two important components: choosing if a decision needs to be made and then when and what needs to be decided (MAGTF Expeditionary Operations 8906, 2019). Leadership, however, is about taking responsibility, being inspirational, and demonstrating physical and moral courage (MAGTF Expeditionary Operations 8906, 2019). Command can then be thought of as more of an art, assigning missions, prioritizing resources, providing guidance, and directing subordinates toward a single goal (Bornman, 1993). In the context of this thesis, the focus will be on the decision-making aspect of command.

4. Control

The 2020 DOD dictionary of Military and associated terms defines control as:

> 1. Authority that may be less than full command exercised by a commander over part of the activities of subordinate or other organizations. (JP 1) 3. Physical or psychological pressures exerted with the intent to assure that an agent or group will respond as directed. (JP 3-0) (DOD Dictionary of Military and Associated Terms, 2020, p.40)

The second and fourth definitions were omitted because they deal with mapping and charting, and intelligence usage, which are not relevant to the context of this study. In the

DOD definition, the function of control is not elucidated. The U.S. Army Training and Doctrine Command's *Command and Control Measures of Effectiveness Handbook's* definition of control is that "Control is the science of defining limits, computing requirements, allocating resources, prescribing requirements for reports, monitoring performance, identifying and correcting deviations from guidance, and directing subordinate actions to accomplish the commander's intent" (p. 15). Control by this definition exists because of command. It is there to regulate the forces in command. This is mainly done by a staff, but the commander is still vital to supervising control activities.

C. THE COMMAND AND CONTROL PROCESS

The process of command and control is a collection of related activities (MCDP 6, 1996). This process may contain procedures (a specific sequence of steps) but should not be thought of as one (MCDP 6, 1996). The basic elements of the command and control process are "people, information, and the command and control support structure" (MCDP 6, 1996). It is people who act in the process, whereas the other parts exist to serve them. The process does not exist in isolation and external factors such as an enemy or other outside entity will affect the process and its effectiveness. Consequently, the quality of the process of command control becomes contingent on the people who are utilizing it. It is challenging to have these three components working in harmony where people understand the structure and how to optimize information flow while dealing with external factors. Furthermore, there are two salient concepts that constrain the process of the command and control, these are uncertainty and time.

MCDP 6 (1996) states one purpose of command and control is to be able to reduce uncertainty in order to make the best decision available; Reducing uncertainty can be accomplished through increasing information. While MCDP 6 (1996) states the goal is to reduce uncertainty to zero, there will always be some information we lack. According to MCDP 6 (1996), uncertainty is defined as what is not known about a given situation. Certainty is therefore "a function of knowledge and understanding and not merely data" (MCDP 6, 1996). Where data is required for knowledge, more data does not equate to more knowledge (MDCP 6, 1996). These concepts will be discussed further in the information topic. This is because knowledge is a cognitive process of adding meaning to information (MCDP 6, 1996). Additionally, some data may lead to more uncertainty (MCDP 6, 1996). The subtle point here is that uncertainty cannot be reduced simply by more data (MCDP 6, 1996). More importantly, it is the quality and timing of the information and the willingness to accept a certain level of uncertainty while still making a decision (MCDP 6, 1996). This leads to the second major element that affects command and control, time.

Time is the most important factor that affects successful command and control (MCDP 6, 1996). If uncertainty is a lack of information, then we can reduce uncertainty by gaining information (MCDP 6, 1996), which takes time to gain and process it (MCDP 6, 1996). Having enough time, one would be able to reduce the amount of uncertainty to almost zero. This invokes three problems in a competitive environment. First, knowledge is perishable, as it takes time to gain and process information, the information that was previously gained becomes obsolete (MCDP 6, 1996). Second, no situation is static, a competitor is utilizing the same process and is therefore acting on a situation, changing it in the process (MCDP 6, 1996). Finally, the tempo of operations limits the amount of data that can be gathered and used before a decision must be made (MCDP 6, 1996). As a result, effective command and control then becomes an information race in which the winner will be who can gather, process, and act faster (MCDP 6, 1996). Hence, to win, a command a control system must be fast, faster than the enemy's (MCDP 6, 1996). Furthermore, the time differential does not need to be vast (MCDP 6, 1996). The command and control system should be easily repeatable to take advantage of even a small-time advantage (MCDP 6, 1996). Thus, even a small advantage builds quickly over time so long as the process is easily repeatable (MCDP 6, 1996). The enduring point here is that is does not matter what advanced technology exists in some future time, but how well you deal with the fundamental problems of uncertainty and time (MCDP 6, 1996). Similarly, to achieve effective command and control the measure will be having the right information at the time to allow military forces to act faster than the enemy (MCDP 6, 1996).

1. People

People are the essence of any command and control system (MCDP 6, 1996). People gather information, process that information, communicate, make decisions, and take actions (MCDP 6, 1996). The rest of the system is designed to help the humans improve their ability to command and control (MCDP 6, 1996). Humans have emotions such as fear, hope, fatigue, and others. Additionally, they have the capacity for judgment, intuition, and imagination (MCDP 6, 1996). Command and control must account for these unique human aspects because these aspects make command more an art than science (MCDP 6, 1996). However, with computers becoming more powerful and having better predictive algorithms, they can perform better than the human in specific situations. Examples include IBM’s Deep Blue computer which defeated chess champion Garry Kasparov in 1997 (Tegmark, 2017). Next, IBM’s Watson computer defeated Brad Rutter and Ken Jennings in Jeopardy in 2011 (Tegmark, 2017). In 2015, Google’s computer DeepMind was able to master dozens of Atari computer games by playing them and learning the controls by only given the objective of maximizing the score (Tegmark, 2017). Finally, in 2016 Google built AlphaGo, and defeated the 18-time world champion Lee Sedol (Tegmark, 2017). It is easy to see how powerful computers have become and why they have become an indispensable part of the command and control process.

Another important aspect worth briefly exploring is human cognition as it relates to learning. Cognition is a complicated topic with many attempting to develop a unified theory of cognition (Chong, Wray, 2005). In the context of this study, cognitive behaviors research will be examined rather than exploring theories such as State, Operator And Result (SOAR), Adaptive Control of Thought-Rational (ACT-R), and Executive-Process Interactive Control (EPIC) (Chong, Wray, 2005). Learning is vital to cognition and therefore is an important element to consider when looking at the cognitive load capacity of a human (Collins, 2019) Learning is an active process that requires the new material to become integrated with existing knowledge you already have (Clark, 2008; Walcutt, Schatz, 2019). This can be done in different ways and there are generally three different views (IntroBooks, 2019; O’Donnell, Lawless, Sharp, O’Donnell, 2015). The three different views of learning are: the behavioral view, the cognitive view, and the construction view (IntroBooks, 2019; O'Donnell, Lawless, Sharp, O'Donnell, 2015). Since learning requires information to be stored it makes sense that memory is the only way to justify that learning has occurred (Sprenger, 1999).

Cognitive load is generally considered "the load that performing a particular task imposes on the cognitive system" (Sweller at al., 1998). This theory is basically stating that a human's learning ability is severely hindered while solving difficult problems (Sweller at al., 1988). Cognitive load has two facets: mental load and mental effort (Sweller et al., 1998). Mental load is "the load that is imposed by task demands" (Sweller et al., 1998). Mental effort is "the amount of cognitive capacity or resources that is actually allocated to accommodate the task demands" (Sweller et al., 1998). This concept has particular important implications when a large amount of information is being presented and then the human is asked to make decisions. Sweller et al. (2011) pointed to a study by Ayres (2001) that when decision making was at its highest intensity, error rates were at their highest, thus poor performance under a high cognitive load. One way to reduce the cognitive load of a human is to share the load with a machine. When sharing information with another human you are trusting what they are telling you is true. This is no different than with a machine.

While trust is not a part of this experiment, it is still a vital piece of dealing with people. Trust is vital in a military context, and must exist between commanders, subordinates, and staffs (MCDP 6, 1996). Mutual trust is a function of familiarity and respects and effects cooperation and moral (MCDP 6, 1996). This is trust between people, but how does this change between man and machine? This is a very important question and should be thoroughly researched in future command and control systems dealing with machine teammates but falls outside the scope for this thesis.

2. Information

According to MCDP 6 (1996), information refers to representations of reality which we use to make decisions and take actions. Information in this sense takes the form of numbers, letters, symbols, images, that we use to represent things or ideas (MCDP 6, 1996). As a result, the process of command and control relies on information (MCDP 6, 1996).

To be able to control a situation, information must be collected, processed, interpreted, acted on, and shared with others. The value of information in the military context is accentuated in the context of time (MCDP 6, 1996). In order to make decisions faster than the enemy, speed matters. Therefore, if information describing a fleeting opportunity is not gained, processed, interpreted, acted on, and communicated with speed, the information becomes irrelevant at best and misleading at worst (MCDP 6, 1996).

In this context there are two functions for information (MCDP 6, 1996). The first is to create situational awareness, the second is to direct and control actions (MCDP 6, 1996). These two functions are not mutually exclusive as the same information can serve both purposes (MCDP 6, 1996). Information allows the commander to gain situational awareness, this in turn allows the commander to make decisions and communicate them (MCDP 6, 1996). Without this situational awareness, the commander will be unable to make a decision no matter how much previous experience they have (MCDP 6, 1996). This might imply that having more information will lead to a better decision (MCDP 6, 1996). This, however, is inaccurate. Most information will be irrelevant, and some will be inaccurate and even misleading when considering time as a critical factor (MCDP 6, 1996). Considering the rate at which technology continues to progress and the amount of data that is generated daily, there is a distinct danger of overwhelming a commander with too much information (MCDP 6, 1996). In this sense, too much information is just as detrimental to decision making as too little information (MCDP 6, 1996). The key is having the right information when needed in useful form not the amount (MCDP 6, 1996). The same technology that is generating and gathering this overwhelming amount of information can also help us process and sort it. Machines can process vastly more information than a human can. If we utilize these machines as teammates, we will be able to process and sort more information, looking for the right information in the right form delivered when it is needed than we could before. But what is the consequence of utilizing a machine teammate to assist in this process? Does it affect the decision-making process in humans?

3. Information Hierarchy

According to MCDP 6 (1996), information has four levels ranging from data to understanding (see Figure 1) (MCDP 6, 1996). The lowest level is comprised of signals that have not yet “been processed, correlated, integrated, evaluated, or interpreted in any way” (MCDP 6, 1996). This is called raw data (MCDP 6, 1996). This level of data is not of much use until it goes through some transformation process (MCDP 6, 1996). The next level of the information hierarchy is processed data (MCDP 6, 1996). It is data that have undergone a process and is converted into a form that is understandable by people (MCDP 6, 1996). Examples of this are film, a computer file or image displayed on a screen (MCDP 6, 1996). This process may have limited value to people but falls short of being evaluated or analyzed (MCDP 6, 1996). The next level is knowledge (MCDP 6, 1996). This is data that has been processed and analyzed to provide meaning (MCDP 6, 1996). Knowledge has been screened based on its reliability, relevance, and importance (MCDP 6, 1996). Knowledge is then the synthesis of different pieces of information that have been screened to start building a picture of the situation (MCDP 6, 1996). The last and highest level is understanding (MCDP 6, 1996). Understanding results when we go through a similar process as in the knowledge level, we screen pieces of knowledge and synthesis the relevant pieces together (MCDP 6, 1996).

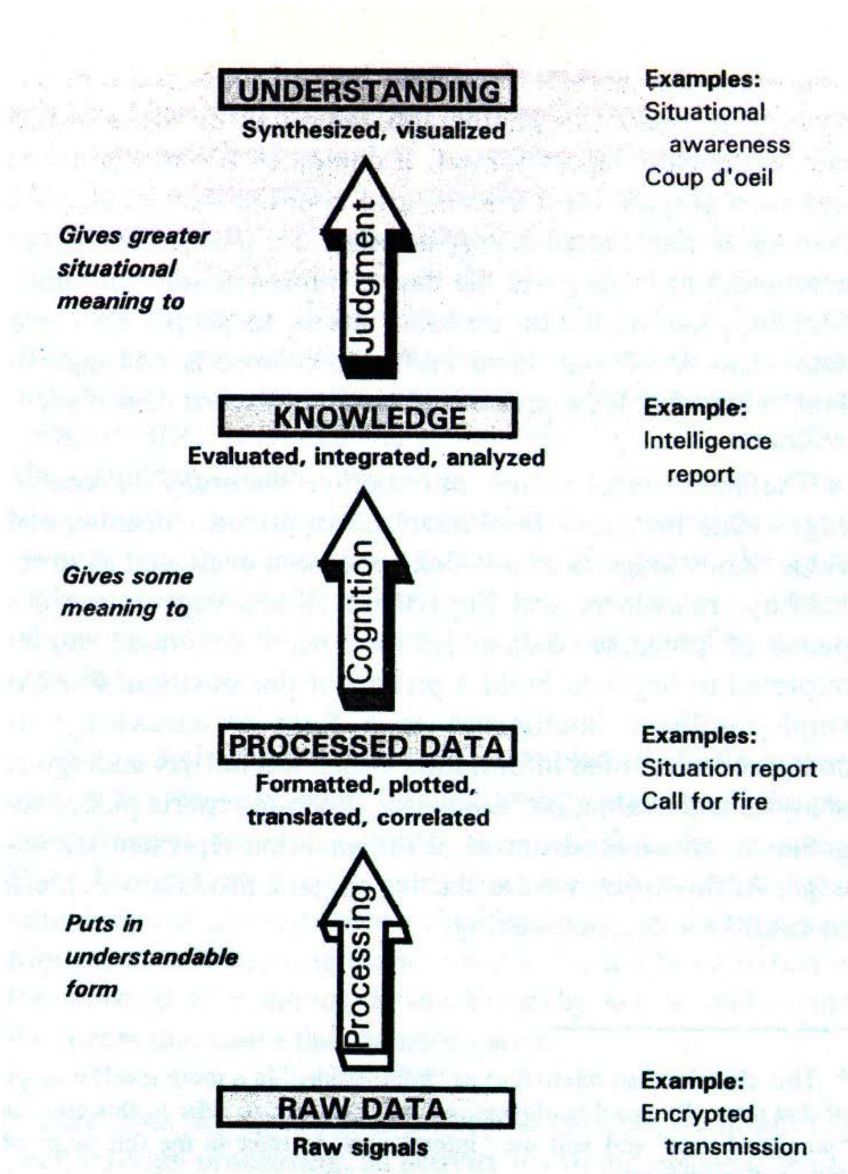

Figure 1. Information Hierarchy.
Source: MCDP 6 (1996).

There may be gaps in this synthesized picture, and we use our intuition and judgement to fill those gaps to get a complete mental image of the situation (MCDP 6, 1996). Therefore, understanding equates to situational awareness (MCDP 6, 1996).

The process of turning processed data into understanding is done through learning, or stated another way, through a cognitive process (Levis & Athans, 1987; MCDP 6, 1996). While a certain degree of this process will follow rules or logical processes, it is primarily a human mental activity (MCDP 6, 1996). Through learning, humans can use their past experiences in the form of intuition and judgement to fill in knowledge gaps to gain situational awareness (MCDP 6, 1996). Endsley (1995) defined situational awareness as:

> the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. (p. 36)

This hierarchy can be thought of as a wide filter at the bottom (raw data) and narrow at the top (understanding) (MCDP 6, 1996). It is through this filtering the amount of raw data, processed data, and knowledge we get to understanding (MCDP 6, 1996). If this filter is too wide the commander at the top trying to make a decision will be inundated with information (MCDP 6, 1996). If the filter is too narrow the commander may be starved for information (MCDP 6, 1996). To adjust the filter, one has to adjust the knobs of time and effort (MCDP 6, 1996). Some of this cost in time and effort could be offloaded to a machine teammate to arguably keep the filter wide at the bottom and not be overloaded at the top.

4. Communication of Information

Communication is an important requirement for executing command and control effectively. There are three different types of communication channels (MCDP 6, 1996). Information can flow vertically, horizontally, or diagonally (MCDP 6, 1996). For example, in the vertical information flow, information vertically moves up and down in the chain of command (MCDP 6, 1996). In the case of horizontal information flow, information flows between units (MCDP 6, 1996). When information flows diagonally it is a combination of the two aforementioned channels. For example, a company talking to an adjacent battalion (MCDP 6, 1996). Information can flow in two different ways through these channels (MCDP 6, 1996). It can be informal or formal (MCDP 6, 1996). Informal information is information that is passed based on personal relationships vice formal information which is conveyed through official and professional relationships (MCDP 6, 1996). Moreover, people can communicate implicitly or explicitly (MCDP 6, 1996). Implicit communication is the ability to gain a mutual understanding while only transferring a small amount of information (MCDP 6, 1996). This is possible through familiarity and because of shared past experiences and a common outlook (MCDP 6, 1996). Explicit communication is fully and clearly expressing something, transferring more information to ensure mutual understanding is achieved.

5. Command and Control Support Structure

In MCDP 6 (1996) the command and control support structure "aids people who create, disseminate, and use information" (p. 51). It continues that the command and control support structure "includes the organizations, procedures, equipment, facilities, training, education, and doctrine that support command and control" (p. 51). While we often think about effective command and control is a product of advanced technology such as communication and situational awareness software such as: satellite communications and the command post of the future software. MCDP 6 further states this does not guarantee effective command and control. Effective command and control first and foremost begin with good people (MCDP 6, 1996). It is with good people comes great guiding principles and philosophies (MCDP 6, 1996).

6. Situational Awareness

Mica Endsley (1995) states that it becomes more and more difficult to maintain situational awareness in a dynamic environment. She goes on to say that in dynamic environments complexity and the amount of interactions with the environment are high. She says "in dynamic environments, many decisions are required across a fairly narrow space of time, and tasks are dependent on an ongoing, up-to-date analysis of the environment. Because the state of the environment is constantly changing, often in complex ways, a major portion of the operator's job becomes that of obtaining and maintaining good SA" (p. 33). This SA is more than simply perceiving the environment but must add meaning to what is being perceived thereby gaining understanding (Endsley, 1995). Another important element of SA is time. Endsley (1995) talks about how SA is not gained instantaneously, that it is acquired over time. SA is a "state of knowledge" (Endsley, 1995, p. 36).

Endsley (1995) explains that in her model she displays SA distinct from decision making (Figure 2). She continues that even the best decision maker will make a bad decision given inaccurate or incomplete SA. She points out the converse is also true, that a decision maker with perfect SA can still make a bad decision. She also points out that attention, working memory, workload, and stress are separated as well because while they can interact with SA they are independent and can interact with SA. Endsley explains her SA model in three levels. Her level 1 deals with being able to “perceive the status, attributes, and dynamics of relevant elements in the environment” (p. 36). To achieve the next level, she states one must be able to combine level 1 elements that appear to be unrelated, that level 2 “goes beyond simply being aware of the elements” (p. 37). She says that it is with experience a decision maker is able to synthesize the various level 1 elements together to create a holistic picture. Finally, level 2 SA Endsley explains deals with the ability to project near future actions. This is done by combining both level 1 and level 2 elements (Endsley, 1995). She uses an example of a fighter pilot to highlight what elements of each level are:

> a. Level I: location, altitude, and heading of ownship and other aircraft; current target; detections; system status; location of ground threats and obstacles
>
> b. Level 2: mission timing and status; impact of system degrades; time and distance available on fuel; tactical status of threat aircraft (offensive/ defensive/neutral)
>
> c. Level 3: projected aircraft tactics and maneuvers, firing position and timing. (Endsley, 1996, p. 38)

Understanding SA is an important aspect of decision making, but how does having a machine teammate affect SA. Endsley (1995) provides some insight on how teams affect SA. She concluded that “the quality of team members' SA of shared elements (as a state of knowledge) may serve as an index of team coordination or human machine interface effectiveness” (p. 39). She also points out that as a member of the team you must maintain SA of your responsibilities or risk becoming the weak link. She uses an example of a pilot and copilot, if the copilot has perfect SA on something but the pilot does not then their shared SA will suffer. There must be a communication channel to transmit the information to have shared SA. Her model for team SA is depicted in Figure 3. This is important to decision making and command and control because Endsley (1995) points out that the context of a problem greatly affects the decision maker’s ability to adopt a problem-solving strategy because they lack contextual information. Endsley (1995) states "In the absence of an appropriate model, people will often fail to solve a new problem, even though they would have to apply the same logic as that used for a familiar problem" (p. 39).

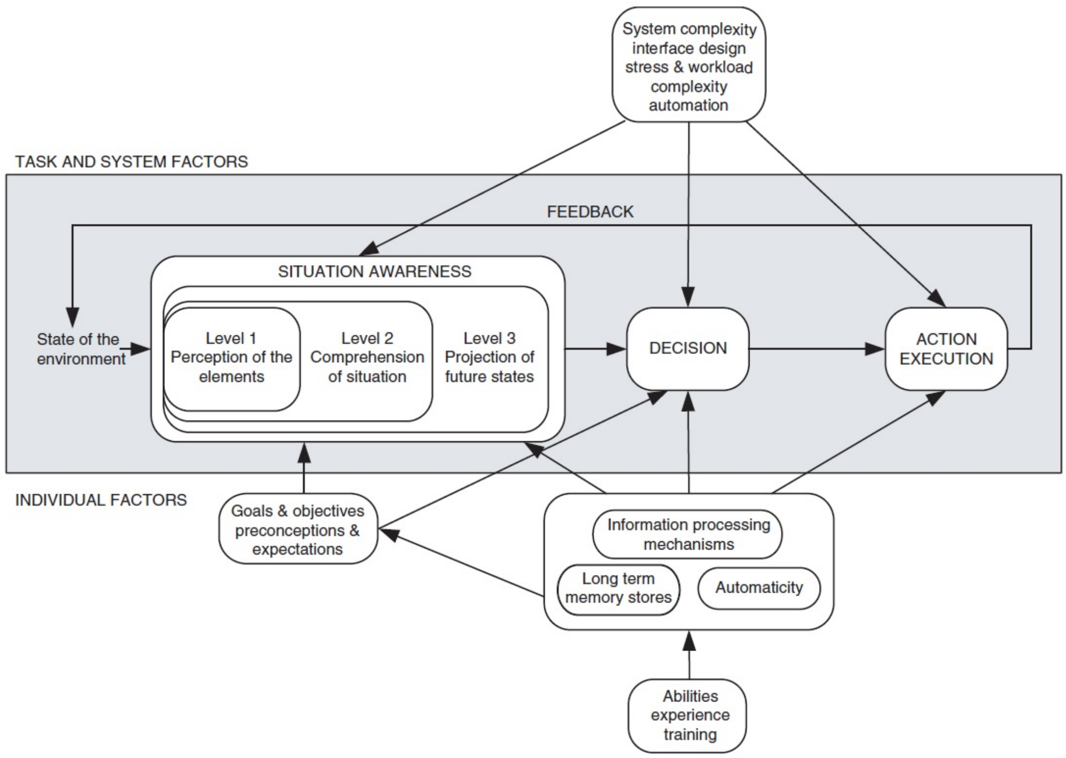

Figure 2. The Three-Level Model of Situational Awareness.
Adapted from Endsley (1996).

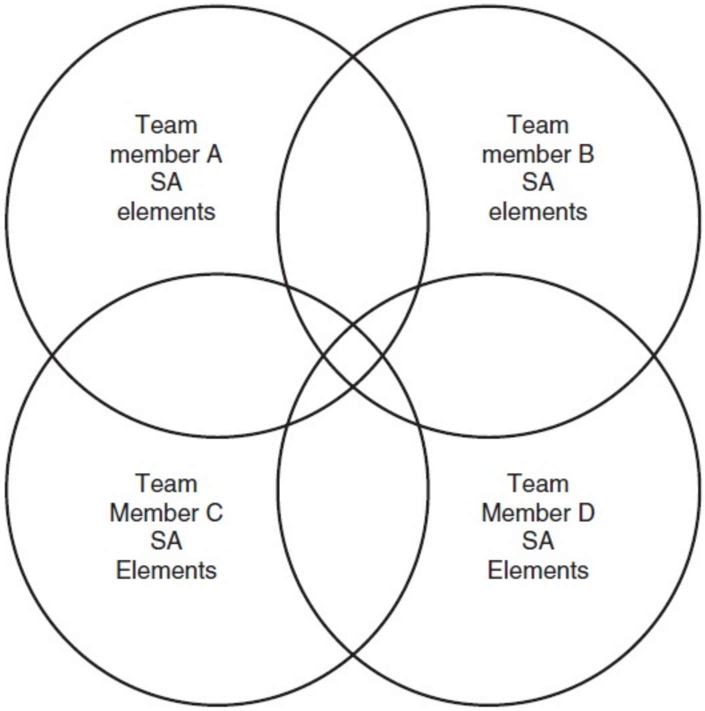

Figure 3. Team Situational Awareness. Source: Endsley (1995).

An alternate view of SA comes from Smith and Hancock (1995), they describe SA as "externally, directed consciousness" that is an "invariant component in an adaptive cycle of knowledge, action and information" (p. 303). Their view was adapted from Niesser's (1976) perceptual cycle model. This model viewed SA as how one interacted with the world and used these interactions to compare to internally held schemata (Endsley, 1995). The perceptual cycle happens because the interactions with the environment modifies the internally held schemata which in turn leads back to the environment for further exploration (Endsley, 1995). Smith and Hancock built upon this previous model, arguing that SA is built around mental models which contain expectations of certain situations (Endsley, 1995). The expectations held within the mental models direct the individual to search for matching cues in the environment to inform their decision making (Endsley, 1995). If something unexpected is found, the individual seeks more information from the environment to update their mental model (Endsley, 1995). Smith and Hancock's model is depicted in Figure 4.

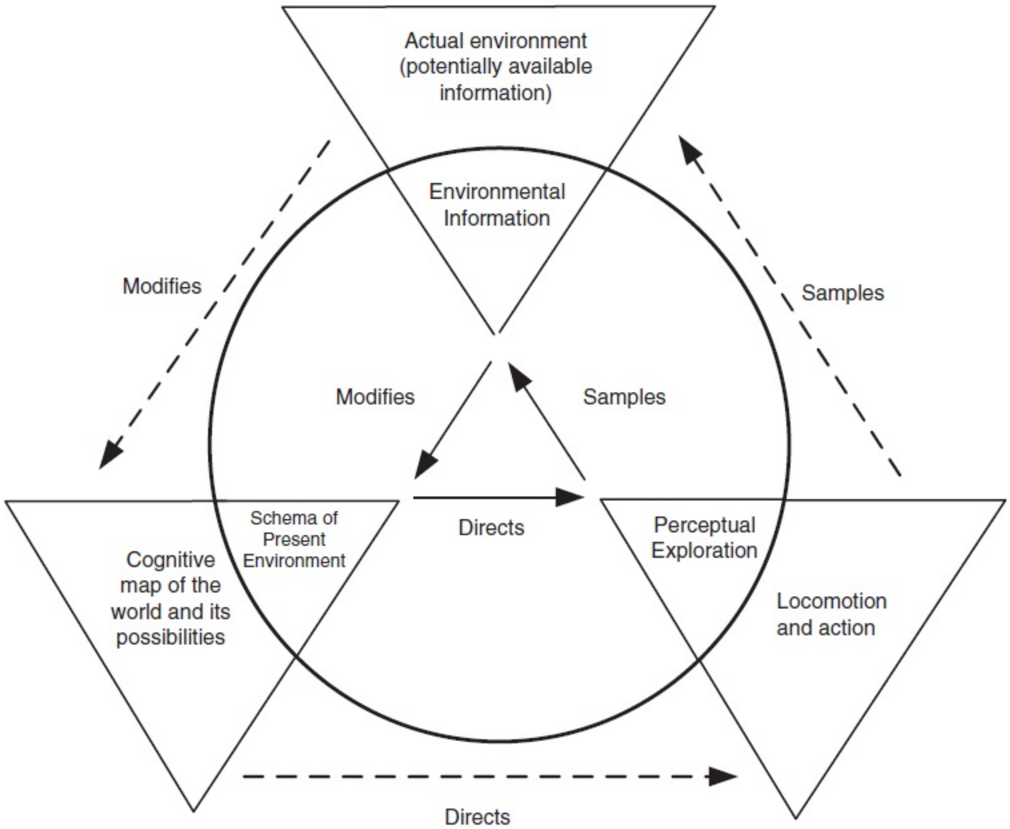

Figure 4. The Perceptual Cycle Model of Situational Awareness.
Source: Smith and Hancock (1995).

D. THEORY AND MODELS

People make decisions in many different ways and use different mental tools when making decisions. Although it has been widely studied, and continues to be investigated, it may remain a mystery how exactly humans make decisions. Nevertheless, decision theory has come a long way in the last 100 years and has "uncovered substantial and systematic regularities in how people make decisions and has led to the formulation of general psychological principles that characterize decision-making behavior" (LeBoeuf & Shafir, 2005). For a theory or model to be useful it must be able to explain widely observed properties and behaviors in their basic form, such as, fundamental components or concepts (Builder et al., 1999). While there are many ideas and different theories about decision making, only expected utility and expected value theories along with Boyd's observe orient, decide, and then act (OODA) model, the Lawson model, and the (Stimulus-Hypothesis-Option-Response) SHOR model will be used in this research. Although there are a considerable number of recognized theories and models for decision making, they are not distinct from the ones chosen for this research. Other theories that were reviewed but will not be covered are: the economic human and rational man, naturalistic decision making, decision making under risk, routine decision making, and explanation based decision making (Simon, 1956; Lichtenstein & Slovic, 1971; Tversky & Kahneman, 1986; Persky, 1995; Hollnagel, 2007; Edwards, 2009). Similarly, other models that were reviewed but will not be covered are the recognition primed decision making model, the Critique-Explore-Compare-Adapt Loop, Plan-Do-Check-Act model that originated from Shewhart in 1939 and espoused by Demming in 1951, Rasmussen's 1983 model of human thinking in supervisory control, and Klein's 1998 model of recognition-primed decision-making (Simon, 1956; Lichtenstein & Slovic, 1971; Tversky & Kahneman, 1986; Persky, 1995; Hollnagel, 2007; Edwards, 2009).

1. Expected Value Theory

Expected Value Theory (EVT) was originally designed for economics. EVT states "the expected value is the sum of possible outcomes weighted by their probabilities of occurrence" (LeBoeuf & Shafir, 2005). A decision maker that uses EVT is constrained by objective values put on each object by the decision maker (Katsikopoulos & Gigerenzer, 2008). This prevents the use of other outside information. For example, the cost of a new software package is higher than the cost of another, but the one that cost more provides interoperability with multiple other systems while the cheaper software does not. This limitation was acknowledged, and a new theory was formulated by Daniel Bernoulli in 1738 called Expected Utility Theory (EUT) (Katsikopoulos & Gigerenzer, 2008; LeBoeuf & Shafir, 2005).

2. Expected Utility Theory

EUT states that an option has different attributes and each attribute has a different amount of utility in which it helps to achieve the goals of the decision maker (Markman & Medin, 2002; Russell, 2019). Each one of these attributes has an importance and each attribute is then weighted by the product of the utility value and the importance value (Markman & Medin, 2002; Russell, 2019). Hence, “the overall utility of an option is then the sum of the weighted utilities of the attributes” (Markman & Medin, 2002; Russell, 2019). Stated another way, the decision maker cannot consider more than just the monetary value of an object. This means one could decide to realize a short-term loss for the benefit of the expected long-term gain (Edwards, 2009; Russell, 2019). Thus, the long-term gain can be said to have greater utility to the decision maker and are then willing to take a short-term loss to realize the gain. However, utility is not well defined, and it is upon the decision maker to determine the importance of the components of the decision (Markman & Medin, 2002).

3. Models

Decision making models are typically categorized into three different categories: normative models, descriptive models, and normative-descriptive models (Wohl et al., 1983). Normative models by definition specify how decision should be made when the objectives are explicit (Wohl et al., 1983). Descriptive models aim to mimic human behavior in a non-human way and are used when decisions are repeatable (Wohl et al., 1983). Finally, Normative-descriptive models strive to find an optimal solution but are constrained by cognition and neuromotor limitations (Wohl et al., 1983). The normative-descriptive models will be explored in greater detail.

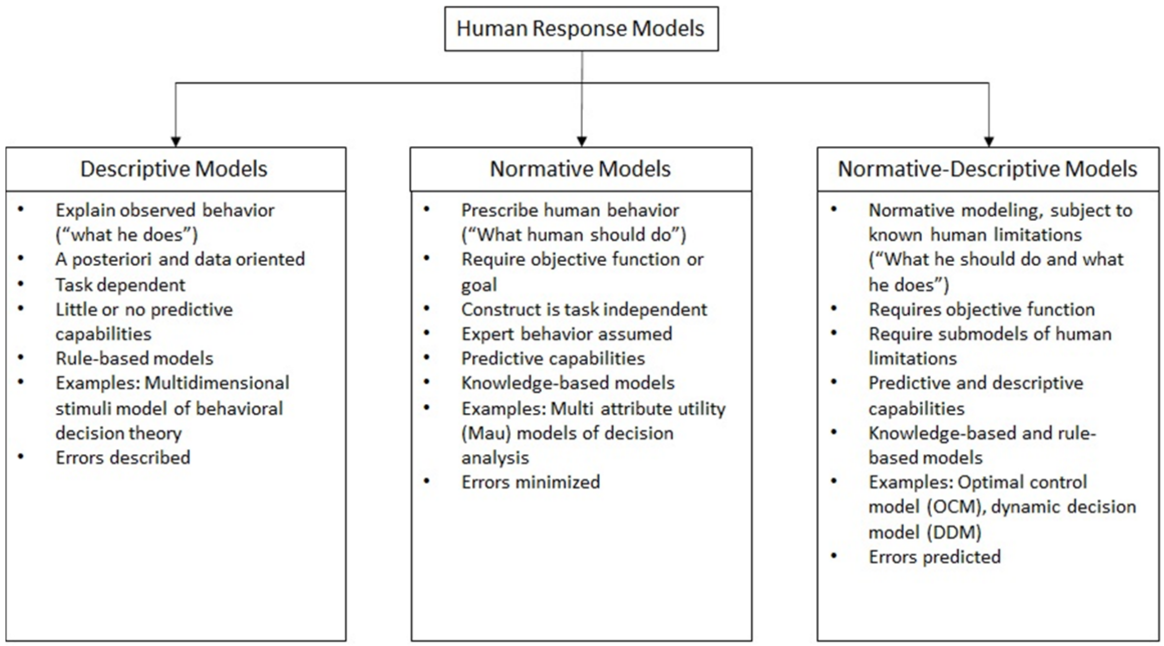

Figure 5. Types of Models.
Source: Wohl et al. (1983).

4. OODA Loop

One of the most widely recognized and popular models for the command and control process is the OODA loop developed by Colonel John Boyd. This OODA cycle happens continuously; thus, it is called the OODA loop. The basic concept of this model is to make a decision, the decision maker must first observe what is happening, orient on what is being observed to what is known, past experiences, and the context the observations are in, make a decision based on that orientation, and finally act to implement a decision. Once complete the loop begins again. One of the most profound implications of this model is that whoever can complete the loop faster has an advantage over their opponent. This is because if you can complete the loop faster than your adversary, you will be able to react to changing situations more quickly and gain the initiative.

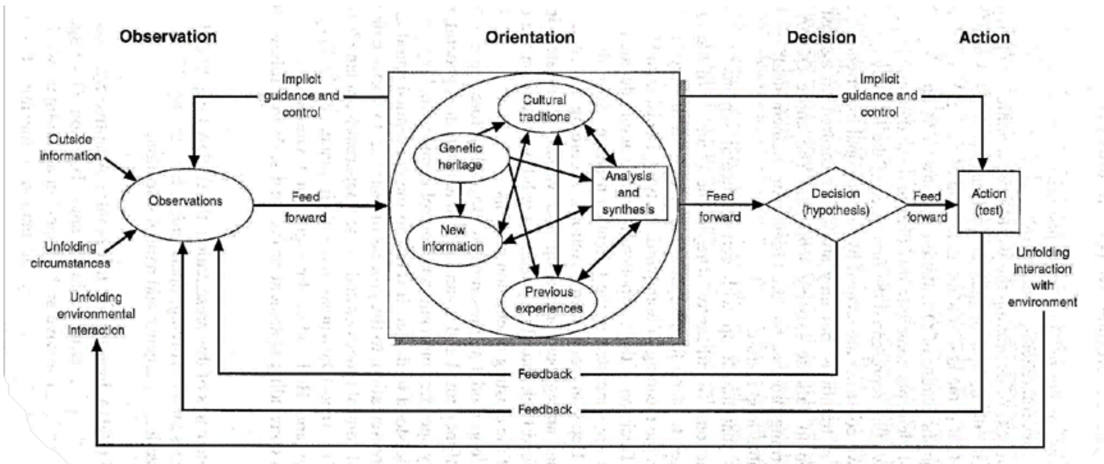

Figure 6. Boyd's OODA Loop.
Source: Boyd (1999).

The OODA loop is happening at all levels of command, each having their own loop, each going through them simultaneously. Each going through the cycle at different rates, each constrained by the loop below it that is feeding data higher. The same is true from higher in the form of action decisions being transmitted in the form of data lower. Data flows up and down the levels of command. It is important to highlight the only thing that gets transmitted is data, each level must digest that data and does not gain understanding until it is interpreted during the orientation stage.

5. A Deeper Look into the OODA Loop

To obtain a better understanding of the OODA loop process, Roman (1997) believes it can be explored as two processes instead of one. He states the first process is the information gathering cycle. He goes on to say the second process is the decision-making cycle. He continues by asserting the first process is trying to answer the question "What is actually happening?", while the second process tries to answer, "what can I or should I do about it?". The information gathering process of this simplified model includes observation and orientation functions, while the decision-making cycle includes the decision and action functions (Roman, 1997). Consider a commander who has very good information gathering capability but is either unwilling or unable to make a decision (Roman, 1997). This means that his ability to observe and orient are high, but his ability to make a decision and act are not (Roman, 1997). This suggests an imbalance in the two cycles, the information cycle is working faster than the decision-making cycle (Roman, 1997). In this example, the commander's uncertainty may be low but because of the commander's inability to make a decision and act and utilize his control process to distribute such action the subordinates will suffer (Roman, 1997).

Now, consider the opposite situation, a commander who decides and acts but has poor information gathering capability (Roman, 1997). In this situation, it would mean that the decision-making cycle is operating faster than the information gathering cycle (Roman, 1997). This commander uses what little information is available to still make a decision and act on it (Roman, 1997). Even if the commander makes decisions and act in this type of uncertainty eventually, they will make poor decision based on little information (Roman, 1997). In this situation the people who follow the commander will suffer (Roman, 1997).

These examples indicate that there must be balance between information gathering and decision making which define the commanders operating tempo (Roman, 1997). As Boyd has pointed out the goal is to conduct the OODA loop faster than the adversary. To do this effectively the commander must have a balance between gathering information and making a decision (Roman, 1997). Technology can speed up the amount of and type of information that is being gathered (Roman, 1997). However, as we have seen more information does not necessarily lead to better decisions (Roman, 1997). Realistically, the system will never be in perfect harmony (Roman, 1997). The commander will have to make a decision on less than perfect information and sometimes the commander will have to make a decision while being inundated with too much or conflicting information (Roman, 1997). It is important to point out that technology can help gather information and it can help to sort that information and suggest possible courses of action. The technology does little good if the systems are not balanced. Stated another way, we must be very careful of technology that focus on one area over the other.

A good example of this is in the ratio of radios to men from World War II to the Vietnam war. During World War II there was one radio for every 38.6 men (Van Creveld, 1987). This number rose to one radio for every 4.5 men in Vietnam (Van Creveld, 1987). This was an 857 percent increase (Van Creveld, 1987). Furthermore, Campen, in *The First*

Information War, points out that “During Operation Desert Storm, the U.S. military had a 98 percent communications reliability rate in handling 700,000 telephone calls, 700,000 messages per day, and over 30,000 radio frequencies.” As technology has shortened the time for commanders to gather information it has also decreased the time to make a decision as well as our reliance on technology to support the increase in speed see Table 1 (Roman, 1997).

Table 1. Tempo and Command.
Source: Roman (1997).

	Revolutionary War	Civil War	World War II	Gulf War	War of Tomorrow
Observe	Telescope	Telegraph	Radio/ Wire	Near Real Time	Real Time
Orient	Weeks	Days	Hours	Minutes	Continuous
Decide	Months	Weeks	Days	Hours	Immediate
Act	A Season	A Month	A Week	A Day	< An Hour

The time between information gathering a decision-making is being compressed so much they are near simultaneous. With near real-time information gathering the commander must make decisions quickly or risk being outpaced by his adversary. So, decision makers must rely on technological tools to assist them in gathering and processing information. But, by using these tools do they alter the decision-making process in an unintended way? A March 2019 study from the Center for Naval Analysis (CNA) found that machines can sense more from the environment, and sense better than humans and they can also take that information and act faster than humans (Center for Naval Analysis [CNA], 2019). Thus, applying Col. John Boyd’s OODA Loop as a framework, the machines performing better at the observe and act stages (CNA, 2019). However, humans dominate orientation, humans are better at understanding the context of a situation (CNA, 2019). The decision step can be left to either the human or the machine (CNA, 2019).

6. Lawson's Model

The Lawson model (Figure 7) was developed by Joel S. Lawson Jr. in the 1970s (Levis & Athans, 1987). Two important differences between this model and the OODA model were the introduction of the desired state and interaction with the environment (Brehmer, n.d.; Coakley, 1993; Levis & Athans, 1987). The OODA model is representative of what people do. The Lawson model is representative of the environment, people inclusive (Brehmer, n.d.). Coakley (1993) states that the Lawson model has "five functions: sense, process, compare, decide, and act" (p. 32). He explains the sense function gathers data on the environment, this includes friendly, enemy, terrain, weather, etc. He continues to explain the process function combines and correlates the data to produce information for the commander about the environment. He describes how the compare function relates the existing environment with to desired state regarding relative strengths, weaknesses, positions etc. He further describes the decide function as it "chooses between the available courses of actions for reconciling the existing state of the environment with the desired state" (p. 33). Finally, he adds the act function converts "the decision into action" (p. 33). Hughes added to the Lawson cycle by correcting what he called "one of the flagrant deficiencies of Lawson's 1977 model was that it originally treated control as a one-sided process" (Hughes, 2000). He addressed this by adding the interaction between friendly and enemy command and control cycles within a shared environment (see Figure 8).

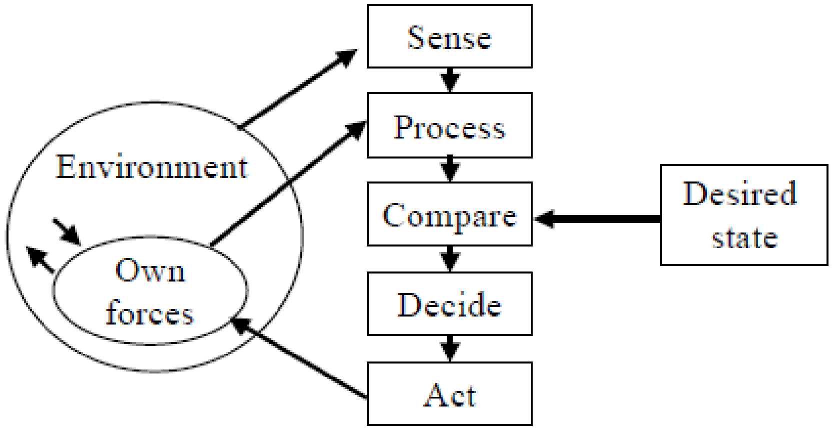

Figure 7. Lawson's Model.
Source: Brehmer (n.d.).

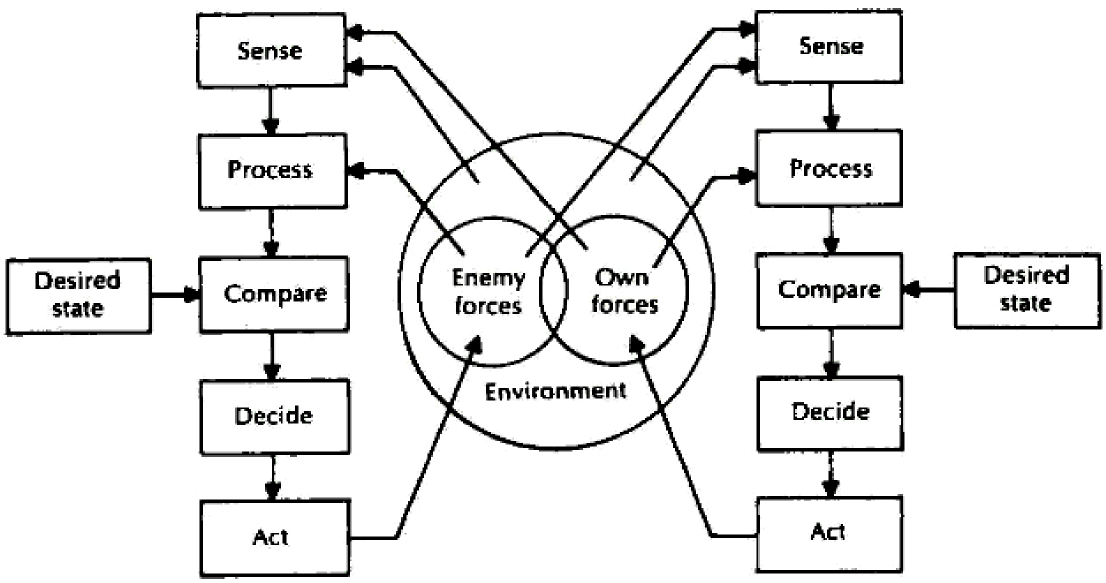

Figure 8. The Hughes/Lawson Model.
Source: Hughes (2000).

7. Wohl's SHOR Model

Another example of a decision-making model is Joseph Wohl's stimulus-hypothesis-option-response (SHOR) model (Figure 9). This model differs from Lawson's model in that it attempts to account for psychological entities (Brehmer, n.d.). The stimulus process gathers, filters, aggregates, and stores data (Grant & Kooter, 2005). The hypothesis process creates, evaluates, and selects a hypothesis based on the situation (Grant & Kooter, 2005). The option process creates, evaluates, and selects a response (Grant & Kooter, 2005). Finally, the response process plans, organizes, and executes the response (Grant & Kooter, 2005). The key result of this model and Wohl's 1981 paper were the divergence between models and that of decision making in reality (Grant & Kooter, 2005).

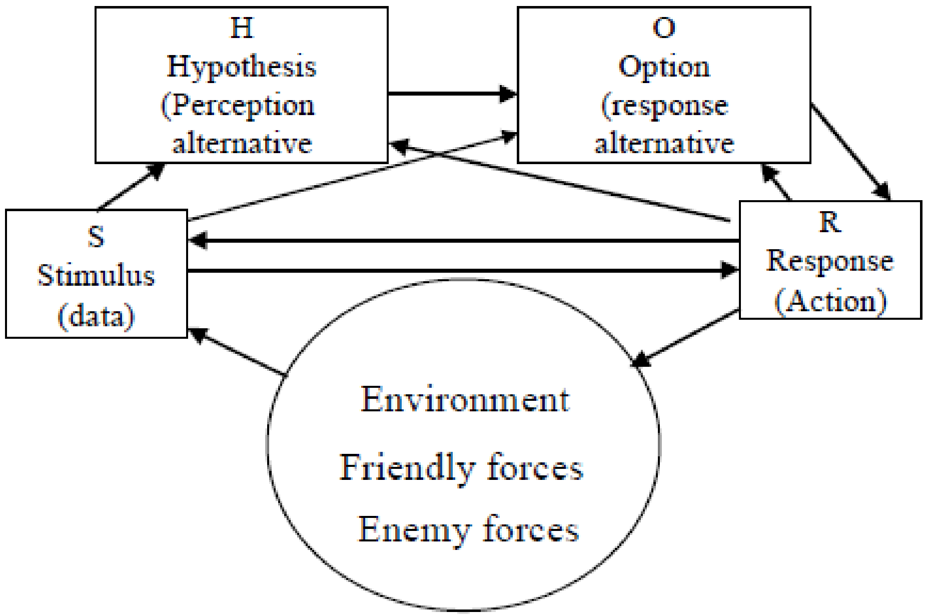

Figure 9. Wohl's SHOR Model.
Source: Brehmer (n.d.).

The effectiveness of the model is based on perspective. These different models highlight important issues in the study of command and control. Boyd's OODA model is a relatively simple model that focuses on making decisions faster than an adversary. Lawson's model is slightly more complex and focuses on the environment and the interactions with it. Wohl's model introduces psychological aspects of the decision-making process. All the processes are subject to the impact of information technology and uncertainty in the environment.

E. RISKS

While it may seem that faster and improved technology may be the answer to increased speed, it requires careful consideration to adapt new technologies. Technology can be part of the problem. As it has been stated earlier, there is a limit to how much information a human can absorb in a given amount of time and situation. If technology is saturating a human decision maker with more information that they are able to process it can lead to information overload (MCDP 6, 1996). Furthermore, this can lead to the illusion that certainty and precision is attainable and decision paralysis can set in (MCDP 6, 1996).

Another risk lies in the complexity of the system (MCDP 6, 1996). As the system increases in complexity it increases its attack surfaces, having more areas an adversary can infiltrate, disrupt, or monitor (MCDP 6, 1996). Furthermore, as complexity increases so does the opportunity for humans to not understand how the system works (MCDP 6, 1996). This is sometimes called a black-box system, where it receives an input and mysteriously does some calculations, and then provides an output. These types of systems can lead to a lack of trust in the human teammate because they do not fully understand the reasoning, programming, behind the system. Another risk is becoming overly reliant on technology (MCDP 6, 1996). The more humans rely on systems to do work for us the danger comes in skill atrophy (MCDP 6, 1996). If humans stop using certain skills for a long enough time, while relying on a machine teammate to do the work, when the machine no longer works, either by attack or through failure, humans may not be able to quickly reproduce what the systems was doing (MCDP 6, 1996). This leads into another risk, which is systems failure (MCDP 6, 1996).

No matter how well a system is designed, it can still have internal failures, or bugs in the system. These may not be discovered until it is too late. A great example of this was occurred on 4 June 1996 with the launch of the unmanned Ariane 5 rocket launched by the European Space Agency (Tegmark, 2017). The ARIANE 5 Flight 501 injury board concluded that the rocket exploded after about 37 after launch because of a software bug. The report specified, "The internal SRI [Inertial Reference System] software exception was caused during execution of a data conversion from 64-bit floating point to 16-bit signed integer value. The floating point number which was converted had a value greater than what could be represented by a 16-bit signed integer." Finally, any mechanical system has the possibility of mechanical breakdown (MCDP 6, 1996). Where this can easily be mitigated though redundant systems, it is none the less is still a risk.

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III. RESEARCH METHODOLOGY

A. EXPERIMENTAL DESIGN

Data will be collected through the conduct of the experiment. The experimental design for this study is a 2X4 repeated-measures analysis (Table 2). The experiment includes one procedure, and each participant participated in all of the trials. The 2X4 design allowed us to study the variation of the probabilistic decision making between tasks with the condition of having a machine assistant and not having a machine assistant.

Table 2. Experimental Design

Team Condition	Task 1	Task 2	Task 3	Task 4
Human only	D-only	C-only	C-D	D-C
Human and Machine	M-D	M-C	M-C-D	M-D-C

Table (2) Experimental design matrix. D=Decision, C=Categorization, M=Machine

This research approach studied command and control issues in the HMT with human subject experimentation. Conducting this experiment allowed us to develop a theoretical understanding of the new command and control issues in HMTs. Specifically, this design can be used to study the inadvertent decision dominance within the same echelon decision makers who have different command and control responsibilities. By doing so, theoretical requirements can be comprehensively captured and used to improve context sensitive SA which includes the orient step of the OODA loop. The human subject experimentation included a time pressure in decision-making paradigm. The manipulation the participants performed was decisions making tasks with a machine teammate and without a machine teammate to simulate the following decision procedure: perceive → interact → decision vs. perceive → decision (Wang & Busemeyer, 2016). In doing so, we tested whether an interaction between a machine and the human might distort the SA. The significance of this distortion is that it is not the final decision. Thus, any impact at this stage of the human SA can give rise to command and control problems. The participants answered questions regarding the tasks that they completed. The experimental work was completed on-line via Amazon Mechanical Turk (MTurk).

B. CONDUCT OF EXPERIMENT

This experiment follows on previous work done by James Townsend, Kam Silva, Jesse Spence-Smith, and Michael Wenger in their paper *Exploring the relations between categorization and decision making with regard to realistic face stimuli* published in Pragmatics and Cognition in 2000, Jerome Busemeyer, Zheng Wan, Ariane Lambert-Mogiliansky in their paper "Empirical Comparison of Markov and Quantum Models of Decision Making" published in the *Journal of Mathematical Psychology* in 2009, and by Zheng Wang and Jermoe Busemeyer in their paper "Interference Effects of Categorization on Decision Making," published in *Cognition* in 2016. The same head shots from these previous works were used in this study. These heads shots were taken from the book *Heads* by Alex Kayser. This book has pictures of 184 different faces. These pictures were all taken from the same distance with the same lighting conditions (Kayser, 1997). Additionally, all the selected faces used in this experiment were bald with no facial hair or facial jewelry. The faces were separated into two categories the "Jekos" and "Kekos." The names were modified from a previous experiment and hold no specific meaning.

1. ImageJ

After choosing the faces for the experiment, the first step was to measure facial features; in doing so, the faces were put into two distinct categories using quantitative values. This measurement process is unique to this research. The goal of the research is to understand subtle effects of human machine communication. Since machines typically provide decision support with a certain accuracy, in addition to putting faces into two categories, the measurements were used in the rational design of the machine teammates. The program used for these measurements was ImageJ. ImageJ is an open source program created for use in life sciences (Schindelin et al., 2015). Scientists, hobbyists, and students use the program on a daily basis for data visualization, advanced image processing, and statistical analysis (Schindelin et. al., 2015). While it got its start in biomedical imaging processing and analysis it works perfectly for the type of image analysis we needed for this experiment (Schindelin et. al., 2015; Schneider et al., 2012). We used this software combined with the book *Facial Geometry* by Robert M. George. Specifically, from this book, two ratios for facial dimensions were adapted in the measuring process of this study. The first one is the facial length index (see Figure 10); the second, is the labial index (see Figure 11).

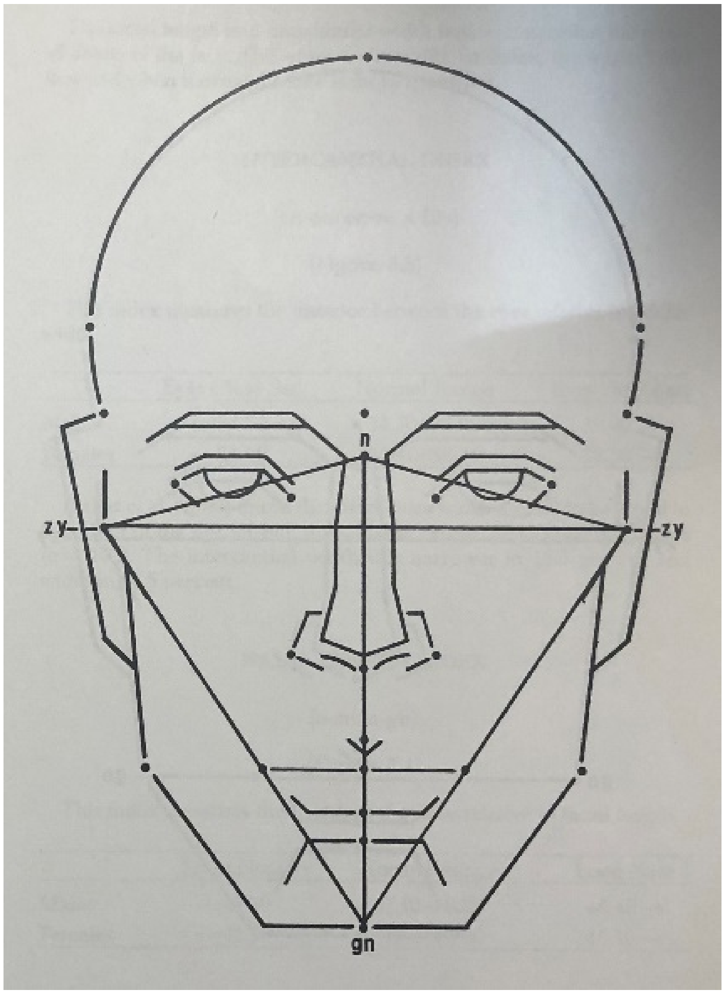


Figure 10. Facial Length Diagram. Source: Kayser (1997).

Table 3. Facial Length Index. Source: George (2007).

Facial Length Index				
(n-gn/zy-zy x 100)				
This index measures the length of the face relative to its width				
	Wide Face	Normal Range	Narrow Face	
Males	← 83.30	83.40-93.60	93.70 →	
Females	← 81.40	81.50-90.86	90.97 →	

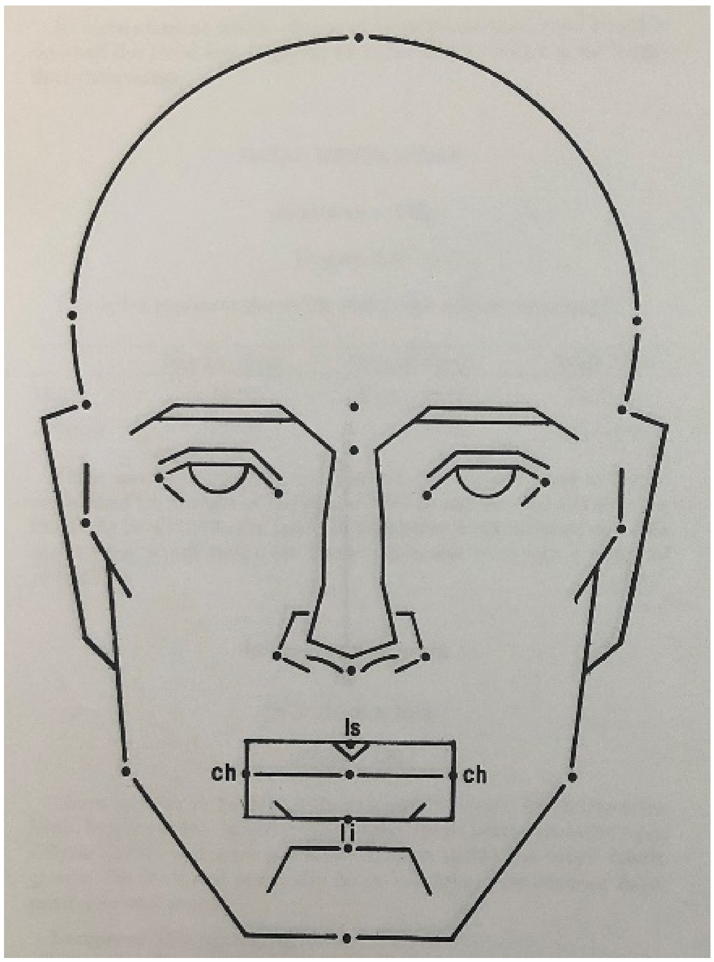


Figure 11. Labial Diagram Source: Kayser (1997).

Table 4. Labial Index Source: George (2007).

Labial Index				
(ls-li/ch-ch x 100)				
This index measures the labial height relative to width				
	Thin-lipped	Medium Thickness	Thick-lipped	
Males / Females	← 34.90	35.00-44.90	45.00 →	

These two ratios provided a quantitatively generalizable way of distinguishing the heads into two distinct categories

As the first step, the facial length and labial indexes of all the available heads in Alex Kayser's book were measured. While some of the faces naturally fell within each category there were some that did not fall within the facial and labial index criteria of the experimental categories. As a result, some features of the faces were manipulated (Table 5). Most of the Jeko faces fell naturally into their category without a lot of manipulation. The Keko faces were a different story. After measuring and analyzing all the facial ratios the faces with the fewest number of stand deviations from the desired criteria were selected. The faces were then manipulated using Adobe Photoshop. Once the manipulations were completed the faces were then remeasured to ensure they fell within the desired facial and labial range. Additionally, the manipulations were done to ensure the face was within one standard deviation of the desired criteria. While some faces naturally were greater than one standard deviation none were manipulated to an extreme. After conducting manipulations and measurements, two distinct categories were identified to conduct this study. These two categories are faces with wide facial length with thin lips, and faces with was narrow facial length with thick lips (Table 6).

Table 5. Pre-manipulation Measurements

Head #	ZY-ZY	N-GN	Face Ratio	LS-LI	CH-CH	Labial Ratio	Face	Lips	Lip	Face	Category
7	1796	1448	80.62360802	624	104	16.66666667	Wide	Thin			Jeko
23	1728	1408	81.48148148	596	168	28.18791946	Wide	Thin			Jeko
24	1676	1452	86.63484487	524	68	12.97709924	Normal	Thin		1 Std	Jeko
26	1652	1352	81.8401937	500	172	34.4	Wide	Thin			Jeko
43	1804	1432	79.37915743	604	160	26.49006623	Wide	Thin			Jeko
45	2012	1548	76.93836978	636	116	18.23899371	Wide	Thin			Jeko
46	1820	1468	80.65934066	612	136	22.22222222	Wide	Thin			Jeko
50	1776	1468	82.65765766	564	148	26.24113475	Wide	Thin			Jeko
52	1688	1344	79.62085308	560	180	32.14285714	Wide	Thin			Jeko
57	1832	1512	82.53275109	656	116	17.68292683	Wide	Thin			Jeko
63	1820	1400	76.92307692	556	168	30.21582734	Wide	Thin			Jeko
64	1712	1296	75.70093458	592	80	13.51351351	Wide	Thin			Jeko
67	1752	1364	77.85388128	588	140	23.80952381	Wide	Thin			Jeko
68	1640	1400	85.36585366	560	92	16.42857143	Normal	Thin		1 Std	Jeko
82	1764	1428	80.95238095	588	156	26.53061224	Wide	Thin			Jeko
86	1654	1340	81.01571947	576	104	18.05555556	Wide	Thin			Jeko
90	1656	1448	87.43961353	540	68	12.59259259	Normal	Thin		1 Std	Jeko

Head #	ZY-ZY	N-GN	Face Ratio	LS-LI	CH-CH	Labial Ratio	Face	Lips	Lip	Face	Category
1	1720	1596	92.79069767	584	264	45.20547945	Normal	Thick		1 Std	Keko
2	1652	1420	85.95641646	540	236	43.7037037	Normal	Medium	1 Std	2 Std	Keko
5	1660	1392	83.85542169	604	220	36.42384106	Normal	Medium	4 Std	2 Std	Keko
11	1652	1472	89.10411622	560	228	40.71428571	Normal	Medium	2 Std	1 Std	Keko
12	1684	1532	90.97387173	560	228	40.71428571	Normal	Medium	2 Std	1 Std	Keko
14	1584	1352	85.35353535	516	188	36.43410853	Normal	Medium	4 Std	2 Std	Keko
15	1672	1484	88.75598086	569	256	44.99121265	Normal	Thick		1 Std	Keko
17	1708	1448	84.77751756	552	208	37.68115942	Normal	Medium	3 Std	2 Std	Keko
18	1608	1496	93.03482587	528	204	38.63636364	Normal	Medium	3 Std	1 Std	Keko
19	1680	1468	87.38095238	480	208	43.33333333	Normal	Medium	1 Std	2 Std	Keko
25	1624	1436	88.42364532	576	236	40.97222222	Normal	Medium	2 Std	2 Std	Keko
31	1652	1476	89.34624697	596	216	36.24161074	Normal	Medium	4 Std	1 Std	Keko
38	1692	1432	84.63356974	548	216	39.41605839	Normal	Medium	3 Std	2 Std	Keko
39	1724	1388	80.51044084	588	220	37.41496599	Wide	Medium	3 Std	3 Std	Keko
55	1740	1500	86.20689655	504	200	39.68253968	Normal	Medium	3 Std	2 Std	Keko
80	1612	1524	94.54094293	508	216	42.51968504	Narrow	Medium	1 Std		Keko
85	1556	1452	93.31619537	624	284	45.51282051	Normal	Thick		1 Std	Keko

Table 6. Post-manipulation Measurements

Heads #	ZY-ZY	N-GN	Face Ratio	LS-LI	CH-CH	Labial Inde	Face	Lips	Lip	Face	Category
7	1796	1448	80.62361	624	104	16.66667	Wide	Thin			Jeko
23	1728	1408	81.48148	596	168	28.18792	Wide	Thin			Jeko
24 Edit	1812	1496	82.56071	524	68	12.9771	Wide	Thin			Jeko
26	1652	1352	81.84019	500	172	34.4	Wide	Thin			Jeko
43	1804	1432	79.37916	604	160	26.49007	Wide	Thin			Jeko
45	2012	1548	76.93837	636	116	18.23899	Wide	Thin			Jeko
46	1820	1468	80.65934	612	136	22.22222	Wide	Thin			Jeko
50	1776	1468	82.65766	564	148	26.24113	Wide	Thin			Jeko
52	1688	1344	79.62085	560	180	32.14286	Wide	Thin			Jeko
57	1832	1512	82.53275	656	116	17.68293	Wide	Thin			Jeko
63	1820	1400	76.92308	556	168	30.21583	Wide	Thin			Jeko
64	1712	1296	75.70093	592	80	13.51351	Wide	Thin			Jeko
67	1752	1364	77.85388	588	140	23.80952	Wide	Thin			Jeko
68 Edit	1760	1412	80.22727	560	92	16.42857	Wide	Thin			Jeko
82	1764	1428	80.95238	588	156	26.53061	Wide	Thin			Jeko
86 Edit	1784	1416	79.3722	576	104	18.05556	Wide	Thin			Jeko
90 Edit	1832	1452	79.25764	540	68	12.59259	Wide	Thin			Jeko

Heads #	ZY-ZY	N-GN	Face Ratio	LS-LI	CH-CH	Labial Inde	Face	Lips	Lip	Face	Category
1 Edir	1648	1608	97.57282	564	268	47.51773	Narrow	Thick			Keko
2 Edir	1500	1440	96	504	236	46.8254	Narrow	Thick			Keko
5 Edit	1476	1420	96.20596	548	248	45.25547	Narrow	Thick			Keko
11 Edit	1508	1468	97.34748	540	244	45.18519	Narrow	Thick			Keko
12 Edit	1584	1516	95.70707	576	264	45.83333	Narrow	Thick			Keko
14 Edit	1424	1360	95.50562	456	212	46.49123	Narrow	Thick			Keko
15 Edit	1564	1496	95.65217	569	256	44.99121	Narrow	Thick			Keko
17 Edit	1552	1480	95.36082	504	236	46.8254	Narrow	Thick			Keko
18 Edit	1472	1460	99.18478	492	224	45.52846	Narrow	Thick			Keko
19 Edit	1480	1452	98.10811	476	216	45.37815	Narrow	Thick			Keko
25 Edit	1512	1424	94.17989	548	256	46.71533	Narrow	Thick			Keko
31 Edit	1536	1464	95.3125	600	272	45.33333	Narrow	Thick			Keko
38 Edit	1556	1492	95.88689	580	264	45.51724	Narrow	Thick			Keko
39 Edit	1520	1428	93.94737	532	248	46.61654	Narrow	Thick			Keko
55 Edit	1596	1504	94.23559	504	236	46.8254	Narrow	Thick			Keko
80 Edit	1612	1524	94.54094	508	232	45.66929	Narrow	Thick			Keko
85 Edit	1512	1488	98.4127	624	284	45.51282	Narrow	Thick			Keko

2. Photoshop

To manipulate the images, first the file types were adjusted such that the file type supports the use of Face-Aware Liquify function of Adobe Photoshop. This was a simple procedure which was completed by selecting the image and choosing RGB color from the available modes; following this, filter and liquify was selected. This would bring the image up in a separate editing screen with the Face-Aware Liquify function. This tool allows manipulation of head measurements and specific facial features. The face and labial features that were manipulated were the upper lip, lower lip, chin height, jaw line, and face width. The upper lip, lower lip, and face width were the predominant features adjusted; only a small number of faces required chin height and jaw line manipulations. Once the manipulations were complete, all the new head pictures were remeasured by using ImageJ; in doing so, the manipulations and adjustments were checked with the index ratios to ensure enough adjustments were made to fall into the desired categories. Once the face had the desired index measurements and was saved the photos appeared whitewashed. To correct this issue the levels of the image were adjusted such that they are not appeared as washed out. This was done by selecting the adjustments tab and clicking the levels icon. Each photo was adjusted to a tone input level of .44. Each head that was manipulated was done so not to exceed one standard deviation above the categorical threshold for both the Facial Length Index and Labial Index.

3. Experiment Setup

The experiment setup was based on the previous work done in 2000 by Townsend et. al., the work done in 2009 by Busemeyer et. al., and the work done in 2016 by Wang and Busemeyer. The same idea of two distinct categories of people from a different planet was used. Additionally, a fictitious scenario was used which enlisted the help of our participants to categorize the two different people. For the experiment we broke away from the previous experiments and used a different naming convention for our fictitious people. We used “Jeko” and “Keko” instead of “Adok” and “Lork.” We did this to simplify the participants’ response process since we would be conducting our experiment via a web platform vice conducting it in person as it has been previously done. We kept the decision action the same as was previously done as being either friendly or defensive. We kept the same face features to distinguish between the two different people. The Jekos tend to have round faces and thin lips, and the Kekos tend to have narrow faces with thick lips.

4. Qualtrics

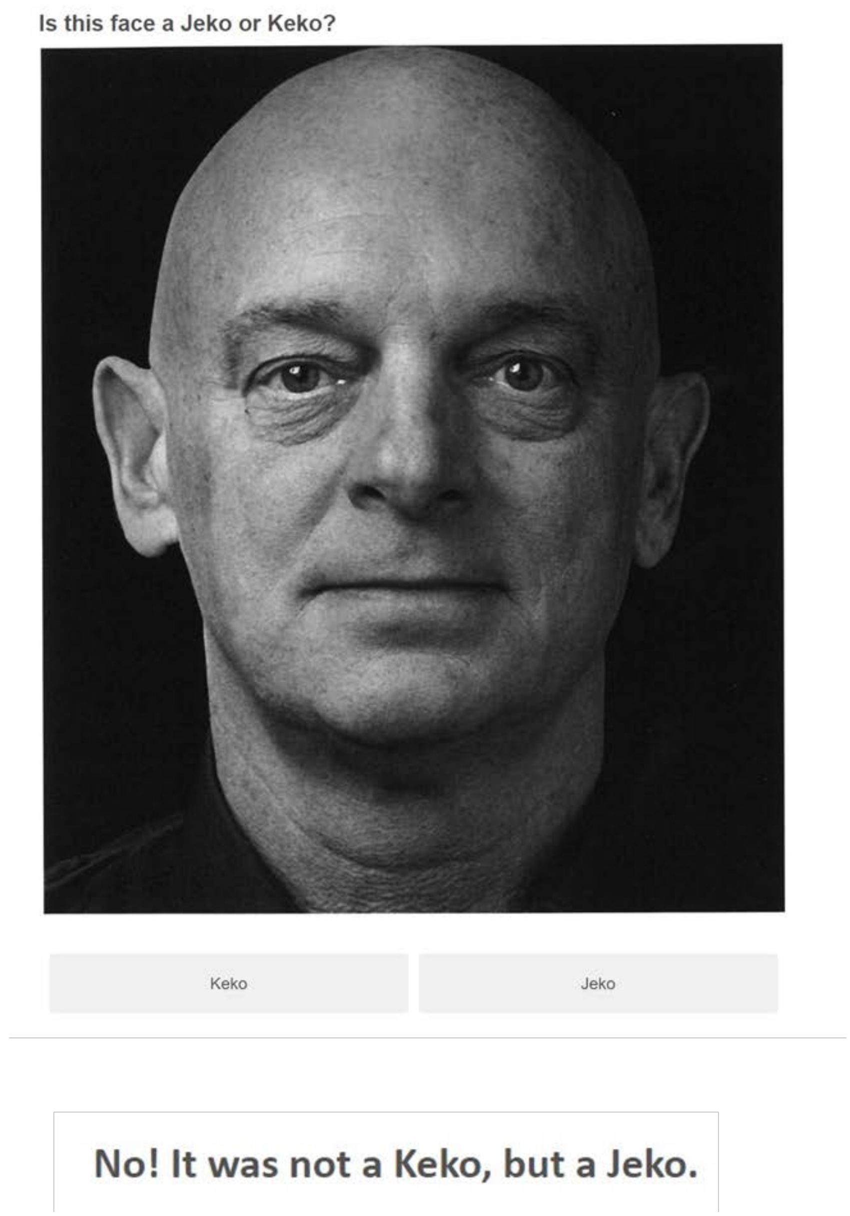
To facilitate a wide range of participants and to quickly gather data it was decided to conduct the experiment online through MTurk. The program that was used to create the experiment is called Qualtrics. While creating the experiment in Qualtrics java script was added to each question to hide the next button so the only two buttons displayed were the response buttons. Additionally, java script was added to submit the response when the button was click vice having to select the response then have to click an additional button to submit the response. We made this decision due to the limited amount of time given for each question and wanted to avoid a response being selected but not being recorded because of the additional time to make additional mouse movements and clicks. Timing was added to each question to limit the amount of time each participant had to respond to 10 seconds. When the time limit was reached the form would auto submit with no response recorded. Timing was also added to auto advance after three seconds once feedback was displayed. Display logic was used to ensure accurate feedback was given based on the response. Page breaks were used to separate question and timing blocks. To ensure a wider range of screen resolutions could see the question and responses without having to scroll down we changed the minimum width to 800 pixels. This increased the chance that someone on a laptop computer with a different screen resolution would have the same view as someone on a desktop computer. Additionally, we did not change the optimization for viewing on a mobile device.

After the participants consented to the experiment, they were given the following set of instructions:

> You have been selected by the IBI (Interstellar Bureau of Investigation) to travel to the planet Camdere to find out more about two colonies, the Jekos and the Kekos. As you interact with the two colonies, you will be first asked to categorize each face as either a 'Jeko' or a 'Keko.'

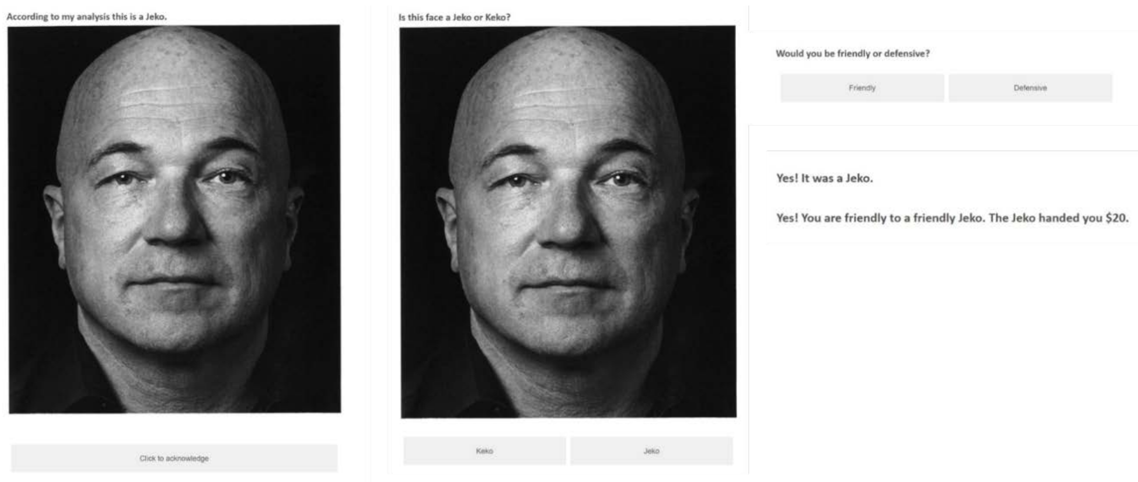
> The Jekos tend to have round faces and thin lips, and the Kekos tend to have narrow faces with thick lips. But this is not absolute! As in any culture, there is cross-over. A face with the features of a Jeko may actually be a Keko, and a face with the features of a Keko may actually be a Jeko.
>
> You have up to 10 seconds to view each face (you may answer before the 10 seconds are up). You should click the ‘Jeko’ button for Jeko or click the ‘Keko’ for Keko. Then, you have a choice to make, you can be friendly or defensive to the face. Jekos have the tendency to be friendly while Kekos tend to be hostile. This is not absolute! Since you do not know how the individual will act towards you, make your decision carefully. You should click the ‘friendly’ button to be friendly or click the ‘defensive’ button to be defensive. Again, you have up to 10 seconds to make the decision.
>
> Additionally, you may be partnered with a machine teammate to assist you. The machine teammate is highly accurate in its analysis. The machine teammate will display a categorization, or an action based on its analysis. You will be asked to acknowledge the categorization by clicking the acknowledge button. Then, the procedure follows the same as before.
>
> You will be given feedback for three seconds on your categorization and action decision after each face. After three seconds you will be presented with the next face.

The participants were then led through four training rounds of four faces each. The training was meant to familiarize the participants with the format and flow of the experiment. The training began by asking only one question and providing feedback on a separate screen without a time limit (Figure 12). The next part of training added both a categorization question and decision question with a time limit. The third training block introduced the machine teammate and only asked one question without a time limit. Finally, the participant was given a machine teammate and asked both a categorization question and decision question with a time limit (Figure 13). The experiment then progressed through each of the tasks as stated before.



The feedback is displayed on a different screen but for simplicity they have been combined.

Figure 12. Example Display with Feedback



The acknowledgement is displayed on a different page from the Jeko or Keko Question. Additionally, the friendly or defensive appears separately after answering the first question. Finally, the feedback is displayed on another page after answering the previous question.

Figure 13. Example Display with Feedback Randomization

The randomization was done using Excel. The probabilities were replicated from the earlier work of Townsend, Silva, Spencer-Smith, and Wenger (2000). The probability for the face category type and action type were fixed for this experiment. For example, of the 34 faces half were Keko and the other were Jeko. Of the 17 Keko faces, a randomly selected 60% were assigned to be hostile (bad guy category), and of those selected faces a randomly selected 70% were assigned to be hostile (hostile action). The remaining faces were assigned to be friendly (friendly action) see figure 14. Of the remaining 40% that was assigned friendly (good guy category), 70% were randomly assigned to be friendly (friendly action), the remaining were hostile (hostile action). The same logic is applied to the 17 Jeko faces except the percentages are reversed for hostile (bad guy category) and friendly (good guy category), 40% and 60%, respectively. Once each group of faces had been randomly assigned to a category and action they were combined and the order to which the faces were displayed were randomized between tasks.

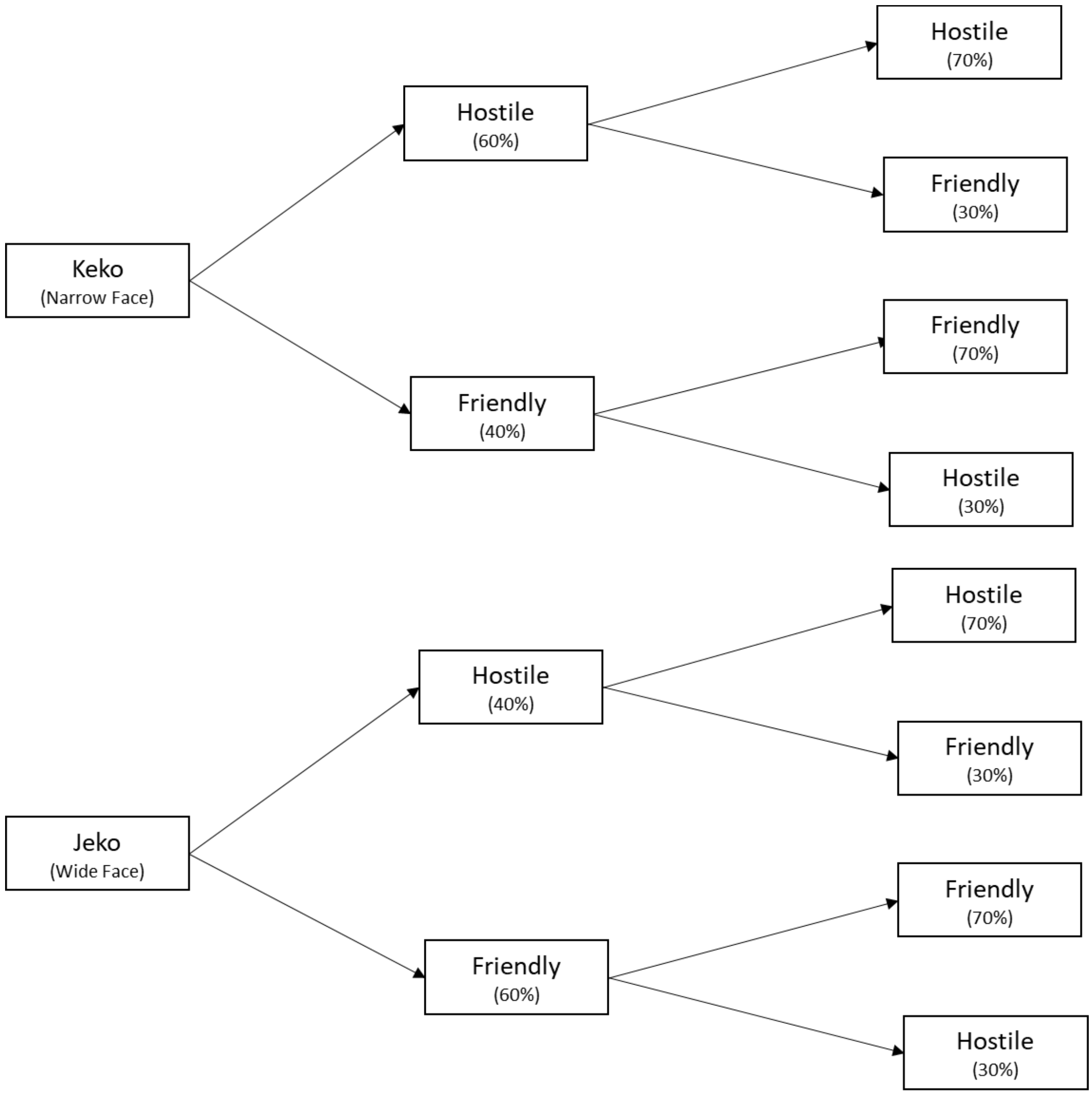


Figure 14. Randomization Diagram.
Source: Townsend, Silva, Spencer-Smith, and Wenger (2000).

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IV. RESULTS AND ANALYSIS

The 34 faces that were used to conduct the experiment were tested to see if they do in fact fall into two distinct categories. The faces were correctly identified 92% of the time. While 100% was the goal the faces are distinct enough to be correctly identified above 90% of the time is sufficient for the conduct of the experiment. One potential explanation for not getting 100% was due to the small variation that some of the faces had done to them that put then within one standard deviation inside their group. This small difference may have given confusion on occasion. However, this was done by design to have minimal manipulations to replicate a real scenario where a computer would be able to calculate more data points than a human to recognize subtle differences that a human might not. This gives merit to the design of utilizing a machine teammate to assist in decision making.

After the experiment was conducted 119 responses were collected. This was fewer than was expected but the experiment was cut short due to lag issues from the hosting server. Several respondents expressed there was a significant amount of time between clicking a response button and the response from the website. Due to this issue the survey was taken down before all the desired number of responses were collected. However, there were still 119 people that were able to complete the survey. Of the 119 participants 58 were male and 60 were female and one preferred not to answer. The average age was 42 with a minimum of 21 and a maximum of 77.

A statistical analysis was not conducted due to time constraints. The data required a significant amount of cleaning due to lag issues. This lag resulted in several questions being left blank. During the coding process a blank response was considered an incorrect response and coded the same. This was done to account for those unable to answer within the time limit. The amount of unanswered questions was significant in some participants which brought the overall correct percentage down in the HMT. The data would need to be further inspected and cleaned to possible gain a different result. Additionally, the experiment may be run again with mitigations put into place to reduce to possibility of unanswered questions because of technical problems vice inability to make a decision within the allotted time.

A. NEW COMMAND AND CONTROL ISSUES

An interaction with a machine teammate may not be considered as communication; however, interacting with a machine can have the same impact on the decision as in the case of communicating to a human. Secondly, having a machine teammate introduces a new communication channel into the command and control process. For information to flow through this new channel may take time. Although the amount of time may be relatively small it may vary depending on the interface and the type of information being communicated. This additional time may be detrimental to the decision-making process even if the information is of higher value because the information my no longer be relevant or due to lost initiative by acting too slowly.

If the dominating decision maker is the machine, issues of maintaining a comprehensive common operational picture for the other members in the combat operations center may become difficult. Again, this will depend on the ability to display information to the other humans. This additional communication channel adds to the amount of time it takes to gain understanding of the decision, this in turn will affect the common operational picture. Furthermore, the machine must be able to explain its rational for making the decision it did, as a human would to anyone who did not fully understand why the decision was made. This touches on understanding of intent and aligning the focus of the staff to meet the desired objective. If a machine cannot understand intent or explain its decision it will be very difficult for humans to effectively partners and to adequately contribute to obtaining the objective.

Although this is not a new issue, the ramifications might have gone unnoticed. As the general perception is that by processing more information machine teammates begin to help humans to make better decisions. However, there is a subtle risk for humans; over time, forgetting how to do the original task. This has become more relevant because of an over reliance of computers. For example, the autopilot feature now standard on most commercial airplanes. In 2007, an experiment was conducted by Matthew Ebbatson with a group of airline pilots (Carr, 2014). He concluded “Flying skills decay quite rapidly towards the fringes of ‘tolerable’ performance without relatively frequent practice” (Carr, 2014, p. 3). He calls this effect “skill fade,” but we know it in the military as skill atrophy.

We have traditionally applied this affect to field skills that require constant maintenance to be proficient such as land navigation and marksmanship. This affect is now potentially creeping into the command and control domain with processes. If we are not diligent in what and how we let machines assist us in decision making, if the machine is unable to process information in its normal manner for whatever reason then we may be in for a rude awakening.

This can be further expanded in the sense that by adding machines into the command and control system they will be assisting humans by automating the tasks that the human used to do. This changes the humans' tasks to managing the system and analyzing the output instead of conducting the task themselves. This introduces a new set of skills; as a result, the humans have to be trained to be able to effectively perform their task. If we expect humans to maintain proficiency in their primary task and in alternate tasks, such as, taking over for the machine. This may lead to an inability to maintain acceptable proficiency in certain secondary task. This is sometimes referred to as the law of stretched systems (Bradshaw et al., 2013). David Woods and Eric Hollnagel describe it as "every system is stretched to operate at its capacity; as soon as there is some improvement, for example in the form of new technology, it will be exploited to achieve a new intensity and tempo of activity" (Bradshaw et al., 2013, p. 59). By adding a machine to the system to offload some work the human used to do we will undoubtedly find new work for the human to maximize the capacity of the system. This can become dangers because humans have an amazing ability to contextualize information that computers currently do not possess. By "speeding up" the processing of information with a machine teammate we may be inadvertently removing valuable contextual information for the human to make an effective decision. This issue will need to be carefully considered to mitigate compromising SA.

This also points to another issue of automation bias. This basically means that humans place too much trust in machines (Laudrain, 2019). Where machines offer great potential to sort through larger amount of data and realize patterns hidden to humans, they are still following algorithms. These algorithms may have bugs or are not the optimal way of conducting the analysis. This presents a problem when the human places too much trust in the system. While trust was not a part of this study, the participants were asked what their perceived accuracy of their machine teammate was. The average was 83.89 with a low of 6 and a high of 100. A better description would be a histogram (Figure 15). As you can see the majority of respondents thought the machine was above 90% accurate. In this case they were right, since trust was not of interest in this experiment the machine was right 100% of the time. To complete the picture, we will compare the averages of all responses for the given task. In the decision alone task the participants were correct 49% of the time, with the machine teammate 69% of the time. For the Condition only task the participants were right 47% of the time. With the machine teammate, again 69%. Compare this to the condition decision task. The participants were correct 47% of the time compared to 47% with a machine teammate. This suggests participants trusted what the computer recommended. One explanation for this is an automation bias.

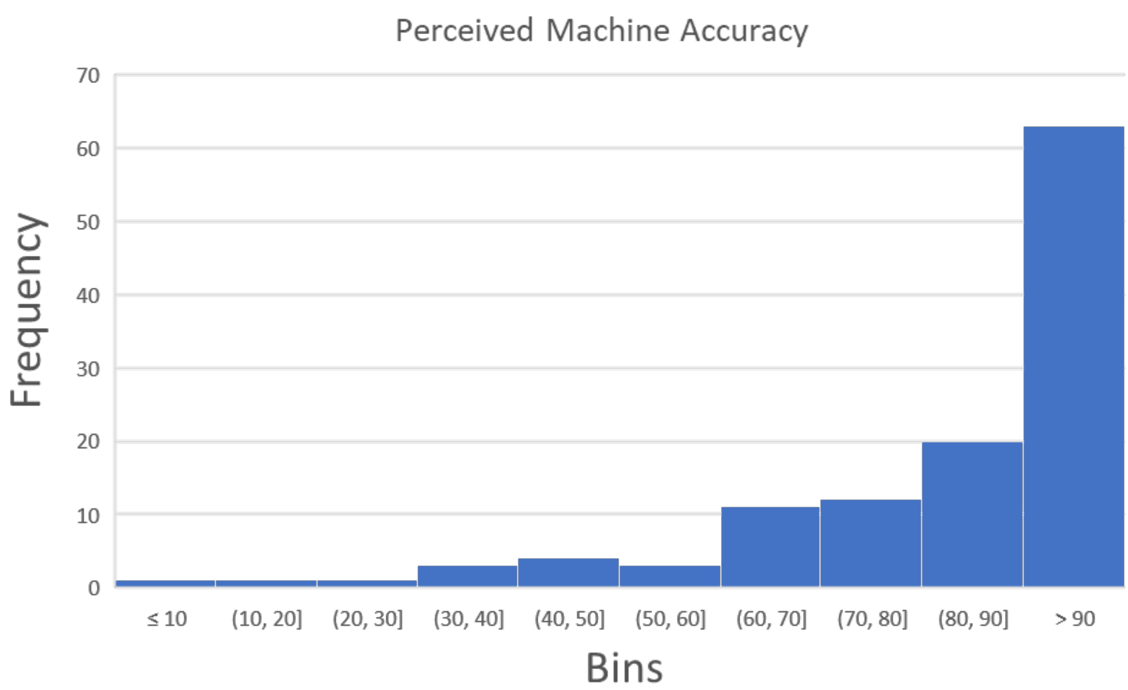

Figure 15. Perceived Machine Accuracy

B. MACHINE INTERACTION AND SITUATIONAL AWARENESS

As we have seen information gets filtered and analyzed as it moves from raw data to understanding. If a human and machine are both presented with the same information and each allowed to analyze the information, then interaction with a machine does not dramatically affect situational awareness (Figure 13). However, when we allow machines to process more information than given to a human, which we have seen a human cannot process all available information. The human begins to lose situational awareness (Figure 14). This is because the human is not able to know what information the machine used in its analysis; more importantly all of the available AI/Machine systems are categorized as Narrow AI and they are not sensitive to context. This is similar to the same point previously stated that as information diminishes to the human they will lose contextual information and additionally situational awareness because some of that missing information may be critical for the human to understand what the machine is using to make its decision with. The problem gets further compounded when machines become so advanced that humans are unable to understand how the machine makes a decision. This was previously mentioned as a black box system. Then the human must rely on the machine to explain its decision which can lead to diminished situational awareness.

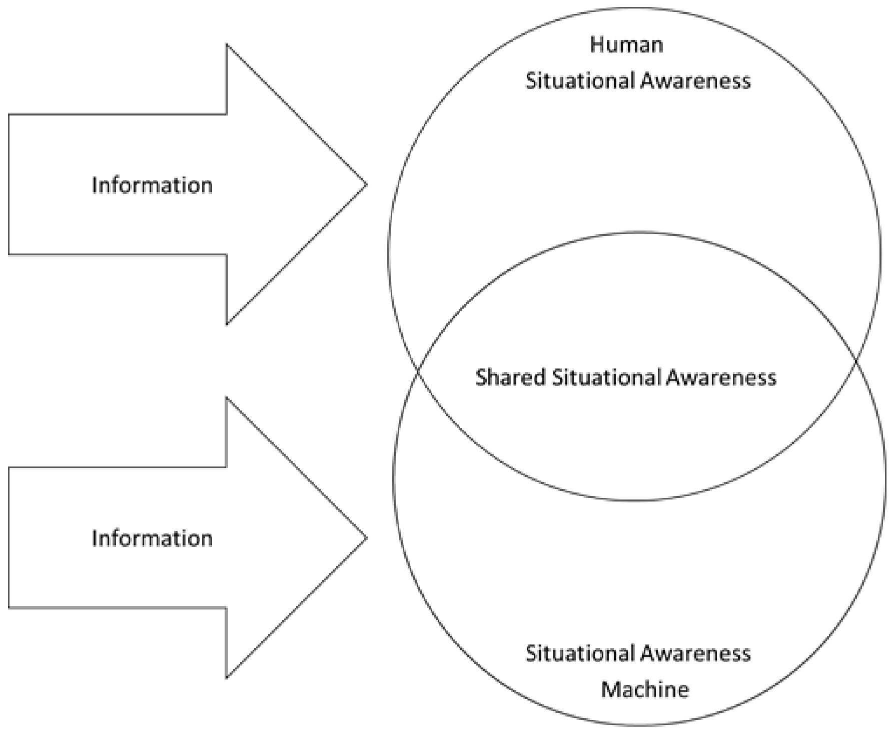

Figure 16. Situational Awareness Equal Information

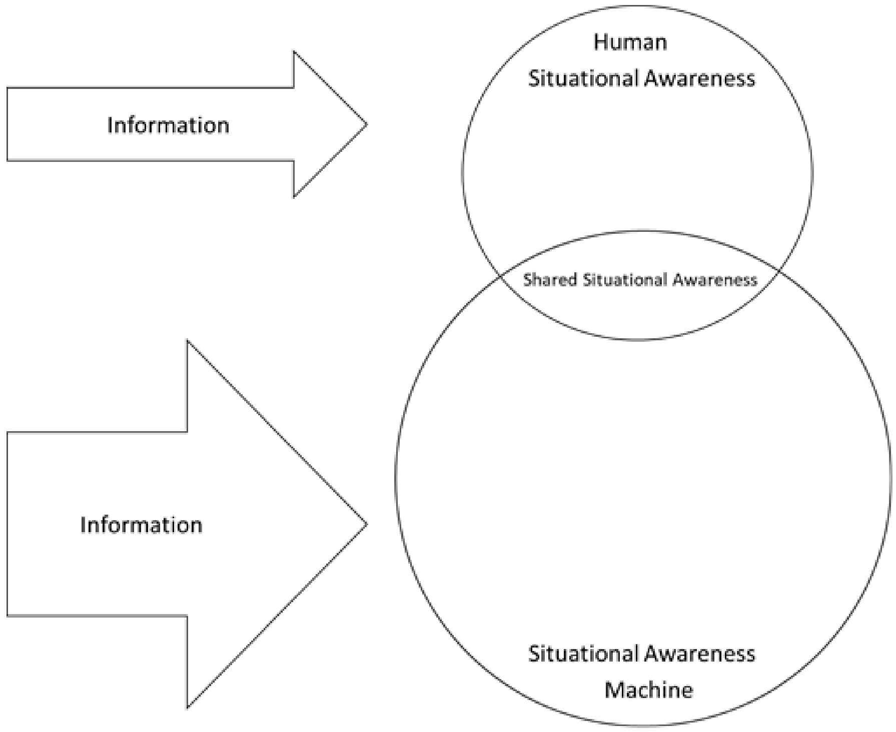

Figure 17. Situational Awareness Unequal Information

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

There is no question that the amount of data that is generated and collected will continue to increase in the future. Humans have a cognitive load capacity to only be able to process so much information at once. The point has already been reached where humans cannot process the amount of data that is being collected. This suggests that other means must be used in order to process the data that is being collected. If this data is not processed properly, there is high risk of not realizing vital information and ultimately making a poor decision. It should be noted that to aid in this processing of information machine teammates will be utilized. It has already been demonstrated that through analyzing large amounts of data patterns unrecognizable to humans have been found. While this seems like a reasonable response to the flood of data being collected it should be approached with caution. Two critical factors to any command and control system are uncertainty and time. While processing this data will help to reduce uncertainty, we must remain cognizant that we will never lift the fog of war and that it takes time to reduce uncertainty. It may now be possibly to keep uncertainty to the lowest levels we have ever seen; however, it will never be eliminated. This is because of the time trade off. While machines have superhuman capabilities of processing information it still takes time. Additionally, these machines are not humans and cannot put things into context. Remember humans still excel at the orientation step in the OODA Loop (CNA, 2019). It has been stated that information overload can be just as detrimental as too little information and just because we have the capability to feed all available information to a decision maker does not necessarily mean we should. Furthermore, relinquishing more data processing to machines could potentially reduce SA in humans and lead to a poor decision even with increased information. As with any major decision the benefits must outweigh the cons. Machines teammates that are able to explain their decision-making process and have an interface to maintain team SA have potential to tremendously benefit any command and control system.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

Other research that could be conducted would be to break this experiment into parts and focus on that part and manipulate a different variable to see its affect. For example, one could focus on the C-D and M-C-D portion and manipulate time (Table 2). Time could have three different levels: low, medium, and high. Time could be a critical factor in deciding to go with the machines analysis and further reinforcing a potential automation bias. Similarly, with the broken-down approach. One could manipulate a different variable of complexity in what you are asking the participants do. For instance, the task that you are asking the participants to do changes in complexity. The task could be broken down into two levels of simple and complex. It would be interesting to see if the level of difficulty changes the reliance or the effectiveness of the decision. Furthermore, if you changed the design to nearly orthogonal you may be able to combine several of these changes.

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