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A Cost-Effectiveness Analysis of Camouflage Patterns on USMC Plate Carriers

March 2025

Capt John A. Fiorelli, USMC

Thesis Advisors: Dr. Robert F. Mortlock, Professor
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Department of Defense Management

Naval Postgraduate School

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ABSTRACT

Current and emerging technologies provide an unprecedented ability to detect, track, and target forces on the modern battlefield. As a result, signature management plays an increasingly important role in both force protection and operational success. Although the Marine Corps Combat Utility Uniform (MCCUU) enables U.S. Marines to adequately blend in with their environments, the Marine Corps-issued infantry combat equipment–specifically plate carriers–does not. Coyote brown plate carriers worn over Marine pattern (MARPAT) MCCUUs negate much of the benefit of wearing camouflage uniforms. This research provides analysis of potential courses of action (COAs) the Marine Corps could take to reduce the salience of plate carriers worn over MARPATs.

This report quantifies the effectiveness of six courses of action, including the status quo, and estimates the costs associated to provide the related effectiveness-cost ratios. This research provides a framework that can be adjusted as necessary to reflect future decision-maker priorities. Results indicate that fielding plate carriers with matching MARPAT camouflage increases Marine effectiveness. The marginal cost changes according to the fielding strategy. COAs 3, 5, and 6 provide marginal effectiveness increases of 7%, 14%, and 34%, respectively, at marginal costs of $0, $117 million, and $153 million (in constant year 2025 dollars), respectively.

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ABOUT THE AUTHOR

Captain John Fiorelli was born in Virginia in 1995 and commissioned through the United States Naval Academy in 2019. In 2020, he graduated from The Basic School and Infantry Officer Course. In July 2020, Captain Fiorelli was assigned as First Platoon Commander, Company K, 3d Battalion, 5th Marines aboard Camp Pendleton, CA.

After reporting to 3d Battalion, 5th Marines, he attended Expeditionary Operations Training Group (EOTG) Fast Rope Master Course in September of 2020, and EOTG Raid Planners Course in March of 2021. Captain Fiorelli deployed in May of 2021 in support of the 31st Marine Expeditionary Unit, as part of Battalion Landing Team 3/5. He served as the alternate Sparrow Hawk Platoon Commander, and his platoon was handpicked to operate independently from the company on a separate ship for the duration of the 21.2 Patrol.

Upon returning to Okinawa from Camp Fuji, Japan in September 2021, Captain Fiorelli assumed the role of Company Executive Officer. He redeployed Company K from Okinawa, Japan to Camp Pendleton, CA. He served as Executive Officer for Company K, 3d Battalion, 5th Marines until May 2023 with a brief stint as Company Commander from November 2022 - January 2023.

Captain Fiorelli is currently a student at the Naval Postgraduate School. He is pursuing a Master of Science Management degree in the Defense Systems Analysis program. His thesis, *A Cost-Effectiveness Analysis of Camouflage Patterns on USMC Plate Carriers*, applies a common economic decision-making framework to address a perceived gap in Marine Corps personnel camouflage.

He lives in Seaside California and is married to Captain Eliza Fiorelli. Captain John Fiorelli holds a Bachelors of Science in History from the United States Naval Academy, and earned an award for the student with the highest cumulative Grade Point Average in History courses upon graduation.

His service in the fleet includes: Rifle Platoon Commander (2020-2021), Company Executive Officer (2021-2022, 2023), Company Commander (2022-2023), Company K, 3d Battalion, 5th Marines.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACU	Army Combat Uniform
AO	Area of Operations
BDU	Battle Dress Uniform
BLT	Battalion Landing Team
CADPAT	Camouflage Disruptive Pattern
CEA	Cost-Effectiveness Analysis
CER	Cost-Effectiveness Ratio
CDD	Capability Development Document
COA	Course of Action
CUU	Combat Utility Uniform
DBDU	Desert Battle Dress Uniform
DCU	Desert Camouflage Uniform
DEB	Deployer Equipment Bundle
DMDC	Defense Manpower Data Center
DoD	Department of Defense
ECR	Effectiveness-Cost Ratio
ERDL	Engineer Research Development Lab
FD2030	Force Design 2030
GWOT	Global War on Terror
IBA	Interceptor Body Armor
ICE	Infantry Combat Equipment
IMTV	Improved Modular Tactical Vest
IOTV	Improved Outer Tactical Vest
ISAPO	Interim Small Arms Protective Overvest
ISR	Intelligence, Surveillance, and Reconnaissance
JIC	Joint Inflation Calculator
KPP	Key Performance Parameter
K-W	Kruskal-Wallace
MARPAT	Marine Pattern
MCAGCC	Marine Corps Air Ground Combat Center

MCCUU	Marine Corps Combat Utility Uniform
MEB	Marine Expeditionary Brigade
MEU	Marine Expeditionary Unit
MOE	Measure of Effectiveness
MOP	Measure of Performance
MTV	Modular Tactical Vest
NDAA	National Defense Authorization Act
NIR	Near Infrared
OCIE	Organizational Clothing and Individual Equipment
OCP	Operational Camouflage Pattern
OEF-CP	Operation Enduring Freedom Camouflage Pattern
OG-107	Olive Green Shade 107
OMB	Office of Management and Budget
OTV	Outer Tactical Vest
PASGT	Personnel Armor System for Ground Troops
PC Gen III	Plate Carrier Generation III
POW	Prisoner of War
RBA	Ranger Body Armor
RIR	Round Impact Radius
ROMO	Range of Military Operations
SIGMAN	Signature Management
SLTE	Service Level Training Exercise
SMCR	Selected Marine Corps Reserve
SNR	Signal-to-Noise Ratio
SPC	Scalable Plate Carrier
SWIR	Short Wave Infrared
TMEABO	Tentative Manual for Expeditionary Advanced Base Operations
UDP	Unit Deployment Program
USMC	United States Marine Corps
USNI	United States Naval Institute
WWI	World War I
WWII	World War II

I. INTRODUCTION

> Tomorrow's fights will involve conditions in which "to be detected is to be targeted is to be killed." (Headquarters United States Marine Corps, 2016, p. 6)

A. PROBLEM IDENTIFICATION

Warfare is constantly evolving at the tactical level due to implementation of technology. Current and emerging technology, such as high-resolution satellite imagery, white phosphorous night vision devices with outline recognition technology, and long-range hypersonic cruise missiles, have made it increasingly easier to efficiently find, target, and destroy opposing forces. As a result, signature management (SIGMAN) plays an ever-larger role in both force protection and operational success (Smith, 2018). Visual camouflage is one small part of signature management, but it is also perhaps the most straightforward aspect to address and improve because there are sufficient materiel solutions available.

Due to the evolving nature of warfare, the United States Marine Corps (USMC) is currently undergoing a period of change in anticipation for the next fight. The *38th Commandant's Planning Guidance*, *Force Design 2030* (FD2030), *A Tentative Manual for Expeditionary Advance Base Operations* (TMEABO), and other recent publications provide guidelines and considerations for shaping current actions to reach future goals. Signature management is a common theme throughout, and the USMC has brought it to the forefront of doctrine and training. In his *Commandant's Planning Guidance*, General Berger (2019) states,

> Achieving this endstate [operating in complex environments] requires a force that can create the virtues of mass without the vulnerabilities of concentration…. Friendly forces must be able to disguise actions and intentions … through the use of decoys, signature management, and signature reduction. (p. 12)

Currently, the USMC equips its warfighters with two different uniforms depending on the environment. The Marine Corps Combat Utility Uniform (MCCUU) comes in woodland and desert variations of the Marine pattern (MARPAT) camouflage, as depicted in Figure 1.

Figure 1. Woodland and desert MARPATs. Adapted from Marine Corps University (2018).

Although the uniforms are efficiently designed to allow Marines to adequately blend in with their environments, the Marine Corps–issued infantry combat equipment (ICE) is not. Other services refer to this more broadly as organizational clothing and individual equipment (OCIE). Within the context of this research, the two terms are interchangeable, but for this research, ICE refers to Marine Corps equipment specifically and OCIE refers to equipment for the other military branches. ICE includes items such as the Plate Carrier Generation III, main pack, assorted pouches, chest rigs, sub-belts, and all other combat-related gear Marines need to train and fight. These items, and almost all other ICE items, are coyote brown in color. This analysis focuses specifically on the Plate Carrier Generation III, since Marines wear this virtually at all times while operating in hostile environments and they are the hardest item to conceal by other means. Figure 2 depicts a mortarman with Battalion Landing Team (BLT) 1/5 wearing the Plate Carrier Generation III while conducting live-fire training.

Figure 2. USMC mortarman wearing a Plate Carrier Generation III. Adapted from Helms (2024).

When wearing a solid coyote brown plate carrier over the MCCUU, Marines may be easier to detect and target because the coyote brown plate carriers are not camouflaged like the MARPAT uniforms. This negates some of the benefit of wearing camouflage uniforms. This is a problem on the modern battlefield that rapidly improving sensors will exacerbate. However, fielding camouflaged plate carriers in lieu of coyote brown plate carriers may have cost and logistical implications.

B. RESEARCH PURPOSE

The purpose of this research is twofold. The first objective is to provide decision-makers with an understanding of the effectiveness of the current USMC uniform and plate carrier configuration and its implications for force protection and mission effectiveness. The second, and primary, purpose is to provide decision-makers with an objective, quantifiable assessment of trade-offs associated with potential courses of action the USMC may undertake to improve Marine combat effectiveness at the best value for the taxpayer.

C. RESEARCH QUESTIONS

This thesis aims to answer the following questions:

- What are the trade-offs (advantages and disadvantages) associated with the USMC plate carrier camouflage options compared with the status quo?
- What are potential courses of action the Marine Corps could consider to address concealment vulnerabilities associated with plate carriers worn over the MCCUU with MARPAT camouflages?

D. METHODOLOGY AND SCOPE

This thesis answers the research questions using a cost-effectiveness analysis (CEA) of various plate carrier and uniform combinations following the guidance from the Office of Management and Budget (OMB) Circular A-94. First, this analysis provides sufficient background information to understand the science of camouflage and the current state of U.S. military personnel camouflage—with particular emphasis on the Army and Marine Corps. Then, this research uses data from recent Army camouflage testing to establish an objective hierarchy with appropriately weighted criteria and quantify benefits in terms of units of effectiveness. Next, the analysis identifies, categorizes, and quantifies costs associated with each course of action. This provides a measure of effectiveness (MOE) and effectiveness-cost ratio (ECR) for each course of action. Lastly, this analysis includes a sensitivity analysis and summary of findings.

This research is confined to evaluation of the combination of the existing MCCUU in woodland and desert MARPAT with existing coyote brown and Operational Camouflage Pattern (OCP) plate carriers and theoretical matching woodland and desert MARPAT plate carriers. While all USMC-issued ICE should be evaluated, this research is limited by existing test data that only involves plate carriers. Furthermore, this research does not attempt to address the effectiveness of current USMC uniforms or inform decisions regarding uniform updates or inclusion of a transitional camouflage uniform in the Marine Corps' repertoire. This research simply aims to quantify the effectiveness of the USMC's current uniform and plate carrier combination and other viable plate carrier camouflage options.

E. SUMMARY

Advances in battlefield technology necessitate examination and reevaluation of current equipment and operational practices. The USMC equips Marines with desert and woodland MARPATs to enable individual camouflage in various operating environments. Currently, Marines wear coyote brown plate carriers in all operating environments, regardless of the MARPAT variation worn underneath. This research provides an examination of the effectiveness of the status quo and the trade-offs associated with other plate carrier camouflage options. Chapter II provides a background of camouflage, plate carriers, and camouflage testing. Chapter III includes a literature review of scholarly work pertaining to this research. Chapter IV outlines the data and methodology used in this research. Chapter V provides the MOEs, costs, and ECRs associated with each COA, as well as sensitivity analysis. Chapter VI summarizes the findings, provides context, and highlights potential avenues worthy of future research.

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II. BACKGROUND

A. OVERVIEW

In order to comprehend the established measures of effectiveness and the potential need for change, one must first understand how camouflage works, the equipment Marines currently have and how it compares to that of peers, and recent developments in camouflage and camouflage testing. The following sections provide a basic summary of the science behind camouflage, define some significant terms, give a brief synopsis of the recent history of military camouflage and plate carriers, and outline key concepts of camouflage testing and the methodology behind the Army's rigorous testing that serves as the foundation of this analysis. It concludes with the current status of U.S. military uniform and plate carrier combinations, focusing specifically on the USMC and Army.

B. THE SCIENCE OF CAMOUFLAGE

To understand the importance of camouflage in relation to mission accomplishment and force protection, and the subsequent effectiveness data of the different uniform and plate carrier combinations, it is vital to first understand what camouflage is, why it is necessary in a biological sense, and how it works. In "Animal Camouflage: Current Issues and New Perspectives," the authors define camouflage as "meaning all strategies involved in concealment, including prevention of detection and recognition" (Stevens & Merilaita, 2009a, p. 424). It is important to note that the authors specifically address detection and recognition, as these are the key components in biological camouflage and these components inform the structure of the Army camouflage testing that is highlighted further in this research.

Among ecologists, the term *crypsis* corresponds to detection, as crypsis "should reduce the risk of detection when the animal is in plain sight" (Stevens & Merilaita, 2009a, p. 425). Crypsis is further broken down into two key attributes: background matching and disruptive coloration. Background matching refers to the degree to which the appearance of an object or animal matches the color, shading, and pattern of the environment in which it is found. Disruptive coloration refers to the degree to which that object or animal's markings mask its true outline and shape. It involves the use of false edges and boundaries within the outline of the object to do so (Stevens & Merilaita, 2009b). Background matching and disruptive coloration are the key mechanisms in preventing initial detection. The human eye is designed to detect anomalies and focus attention to bring more detail. In "How Camouflage Works," the authors state that initial functions in the visual process have two key components. The first is to acquire raw visual data for the brain to process, such as contours, edges, and shapes. The second is to detect and map saliency (Merilaita et al., 2017). Saliency is the degree to which visual anomalies are present. High saliency signals the brain to instruct the eyes to examine an object more closely. It is defined as "any feature … that stands out from the overall distribution" (Merilaita et al., 2017, p. 2). Merilaita et al. (2017) further declare, "the first and most basic role of background matching camouflage is to be coloured such that no features are salient and so detailed inspection does not occur" (pp. 2–4). As seen in the Army camouflage testing data, reducing the salience of an individual is the key to preventing initial detection, and the uniform and plate carrier combination worn by Marines drastically affects salience.

As previously stated, the purpose of camouflage is to prevent detection and recognition. Following an explanation of the detection, or crypsis, aspect, it is now important to address recognition. Among ecologists, the camouflage mechanism involving recognition is known as *masquerade*. Masquerade occurs when "recognition is prevented by resembling an uninteresting object, such as a leaf or a stick" (Stevens & Merilaita, 2009a, p. 424). In human visual perception, detection precedes recognition. In visual search, detection signifies presence and location, while recognition provides identification (T. Troscianko et al., 2009). To recognize an object, an observer must first detect background discontinuity, which cues the observer to focus on the area in which the discontinuity was detected. Again, this is known as salience and involves the crypsis mechanism of camouflage. Once the observer focuses on that area, a "distinctive region representing the object must be found" (T. Troscianko et al., 2009, p. 456). Only then can the observer's brain translate the two-dimensional picture into a three-dimensional object that it can recognize (T. Troscianko et al., 2009). Thus, even if an object is detectable, it must also be recognizable for the observer to comprehend what they are seeing. In photo-simulation tests that analyze eye movement data, detectability plays a larger role than discriminability does in camouflaged target search (Lin et al., 2014). This shows the recognition, or masquerade, mechanism of camouflage is secondary to initial detection, or crypsis, but still plays a vital role in human visual perception. In the Army testing data, the recognition aspect of camouflage is represented by the blending data gathered by the researchers (Mazz, 2015).

C. HISTORY OF MILITARY CAMOUFLAGE

The purpose of camouflage uniforms and equipment is to reduce salience in order to prevent detection and blend in with the background in order to prevent recognition. As stated in "Camouflage Combat Uniform," a case study published in the *Defense Acquisition Research Journal*, "Effective camouflage increases soldier combat effectiveness and improves force protection – saving soldiers' lives in battle" (Mortlock, 2020, p. 381). The use of camouflage by military forces dates back centuries. Thucydides' account of the Peloponnesian War and Homer's account of the sack of Troy both describe various instances of physical camouflage and deception. Military camouflage became increasingly important in World War I (WWI), when the use of aircraft for reconnaissance and strikes made it easier to detect, track, and strike opposing forces (Hicks, 2018). Figure 3 depicts a disruptive camouflage technique employed by ships during WWI to complicate tracking and targeting by surface and airborne enemy assets. This theme of increasingly advancing technology necessitating advances in camouflage for continued operational success is present in the study of military history from WWI to present and serves as the driving force for this research.

Figure 3. American dazzle-painted ship showing disruptive coloration techniques in WWI. Adapted from Behrens (2009).

The Marine Corps' first large-scale implementation of specifically designed camouflage uniforms occurred during World War II (WWII) at the Battle of Bougainville in November 1943. However, the uniforms were deemed ineffective at the subsequent Battle of Tarawa due to significant differences in terrain and foliage coloring, even though the two battles occurred in the same geographic region (Hicks, 2018). This anecdotal evidence highlights the importance of camouflage designed specifically with the environmental factors of the operating area in mind. Figure 4 depicts the standard sage green utility uniform worn by Marines throughout the Pacific theater.

Figure 4. Pattern 41 cotton-twill utility uniform worn during WWII. Adapted from Hicks (2018).

From 1950 to 2002, all four U.S. Service branches—Army, Navy, Marine Corps, and Air Force—used the same camouflage uniforms when operating ashore in combat environments. The U.S. Army led in uniform development and implementation, and there was no Service differentiation with respect to combat uniforms (Hicks, 2018). The Service branches did not use the same uniform throughout the entire period, but each Service adopted the necessary combat uniform designed by the Army as needed. Uniforms used from 1952 to 2002 included the Olive Green Shade 107 (OG-107), Tiger Stripe, Engineer Research Development Lab (ERDL) camouflage pattern or "leaf pattern," M81 Battle Dress Uniform (BDU) or Combat Utility Uniform (CUU), Desert Battle Dress Uniform (DBDU), and Desert Camouflage Uniform (DCU) (Hicks, 2018).

Figures 5 and 6 show side-by-side comparisons of the ERDL and BDU camouflage patterns and the DBDU and DCU camouflage patterns, respectively.

Figure 5. ERDL and BDU camouflage patterns used from 1967–2002. Adapted from Wharton (2017).

Figure 6. DBDU and DCU camouflage patterns used from 1981–2006. Adapted from Hicks (2018).

In 2002, the Marine Corps fielded a USMC-specific, two-pattern family of camouflage uniforms known as woodland and desert Marine pattern (MARPAT) camouflage. A side-by-side illustration of the woodland and desert patterns is depicted in Figure 7. MARPATs were the U.S. military's first digital camouflage pattern uniform and were developed from Canada's camouflage disruptive pattern (CADPAT) with permission from Canadian authorities (Farrell, 2022). Prior to fielding MARPATs, the

Marine Corps tested several variations of CADPAT at the USMC Scout Sniper Instructor School (Wharton, 2017). The Marine Corps' transition to MARPATs began in June 2002 and officially ended on September 30, 2006 (Hicks, 2018). Despite fielding two entirely new camouflage uniforms, the USMC chose to use coyote brown ICE, specifically plate carriers, for reduced production costs (Wharton, 2017). They believed the single coyote brown ICE adequately complemented both woodland and desert MARPATs. At the time, the USMC assessed that any increase in effectiveness gained by implementing matching ICE with each variation of MARPAT was outweighed by cost and logistical factors (Wharton, 2017).

Figure 7. Side-by-side visual of woodland and desert MARPAT MCCUU. Adapted from Hicks (2018).

It is important to note that after 2002, the Army, Navy, and Air Force pursued individual camouflage combat uniforms with varying success. Figure 8 shows the timeline of camouflage combat uniforms by service from 2002–2015. Although this research specifically evaluates the cost-effectiveness of potential courses of action to reduce the salience of the current USMC combination of MARPATs and plate carriers, it is important to gain insight into the Army's camouflage progression from the split in 2002 to present day. This is because the data used in this analysis is a byproduct of the Army's search for the optimal personnel camouflage solution.

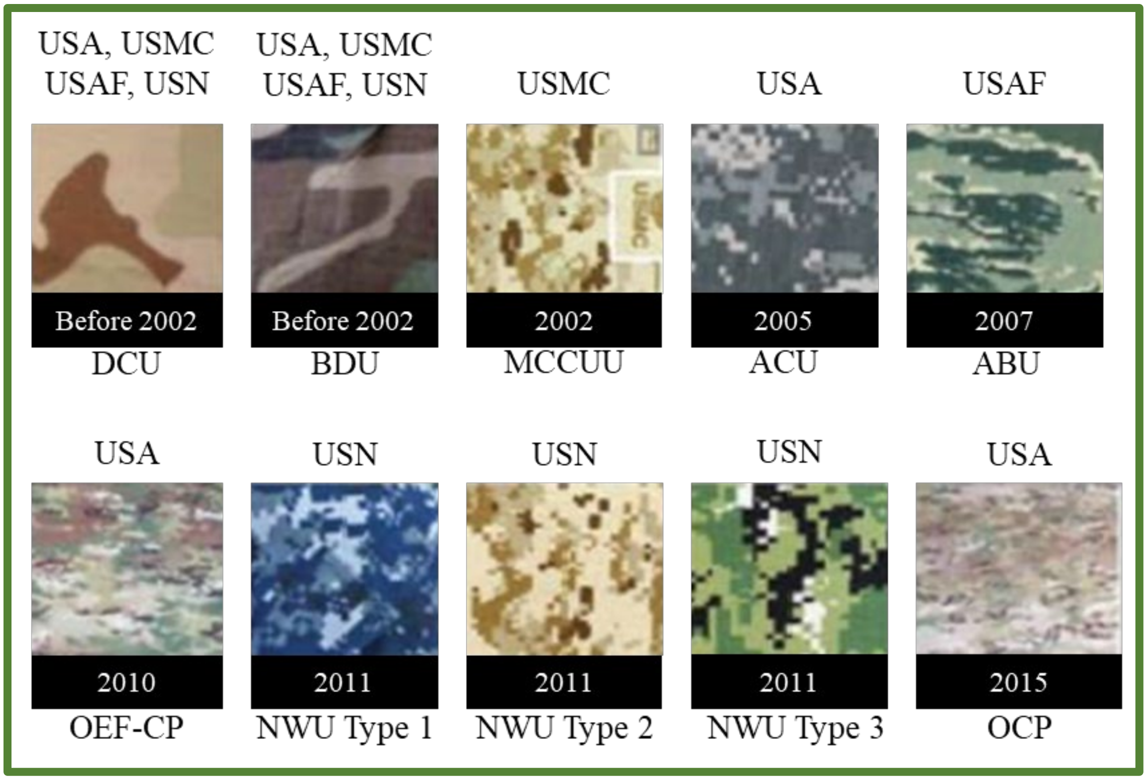

Figure 8. Timeline of recent U.S. military camouflage uniforms. Adapted from Wharton (2017).

The Army fielded the Army Combat Uniform (ACU) with the Universal Camouflage Pattern (UCP) in 2005 with the intent to use it as the sole camouflage uniform for any environment. However, by 2009, it became apparent that UCP was not sufficient for operations in Afghanistan because it did not blend in well with the specific environment. As a result, Congress directed the Department of Defense (DoD) to find a suitable solution for Soldiers deploying to Afghanistan (Government Accountability Office [GAO], 2012). Following this mandate, the Army began a four-phase Camouflage Uniform Improvement Project. The objective of Phases I–III was to provide a short-term solution for soldiers operating in Afghanistan. In July 2010, the Army fielded the short-term solution, which was to use the commercially developed MultiCam© pattern and rename it Operation Enduring Freedom Camouflage Pattern (OEF-CP) (Wharton, 2017).

While OEF-CP proved effective in Afghanistan, the objective of Phase IV was to "provide a long-term, Army-wide, camouflage-uniform solution to support the needs of the future fighting force" (Mazz, 2015, p. 1). In Phase IV, the Army sought to test and field a three-pattern family of camouflage uniforms with a single complementary OCIE pattern that would "maximize global reach at an affordable price" (Mazz, 2015, p. 1). The intent of the three-pattern family concept is to provide camouflage uniforms for use in environmentally specific terrain, with one OCIE camouflage pattern that performs sufficiently with all three uniform patterns. The three categories are transitional, woodland/jungle, and arid/desert. In support of the Camouflage Uniform Improvement Project, the Army Corps of Engineers conducted a global terrain assessment. They found the Army's operating environments consisted of terrain that was 44% transitional, 37% woodland/jungle, and 19% arid/desert (Mortlock, 2020). Figure 9 shows the effectiveness of camouflage patterns in these three different environmental classes.

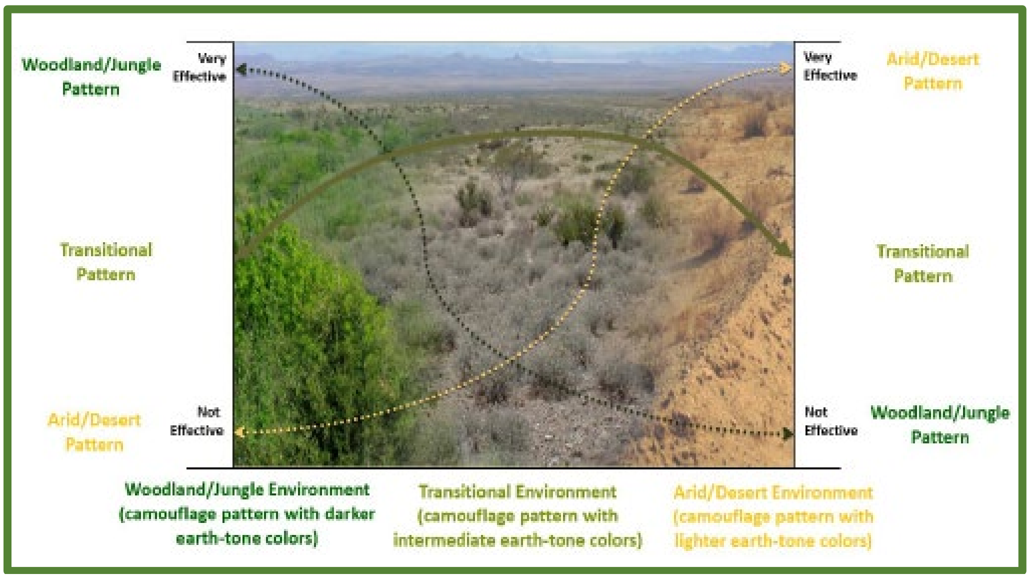

Figure 9. Visual representation of the effectiveness of the three-pattern concept. Adapted from Mortlock (2020).

Phase IV selection began in 2011 but was impacted by the 2014 National Defense Authorization Act (NDAA), which prevented funding for the development and fielding of new uniforms unless they were to be used by all four Services (Wharton, 2017). The Army's solution to a long-term replacement of UCP was to use a previously developed, but unused, camouflage pattern called Scorpion W2 and rename it the Operational Camouflage Pattern (OCP). The Army selected OCP as the transitional uniform and sole OCIE pattern in May 2014 (Mazz, 2015). To date, it is the only uniform of the three-family concept the Army has fielded.

Although the experiences of the Army and Marine Corps differ drastically in camouflage uniform development and fielding from 2002 to present, the Army's experience is vital in adequately addressing the research questions analyzed in this thesis. Those questions are: What are the advantages and disadvantages associated with the USMC plate carrier camouflage options? And what are potential courses of action the Marine Corps could consider to address concealment vulnerabilities associated with plate carriers worn over MARPATs? Due to the ineffectiveness of UCP in Afghanistan, and the subsequent involvement of Congress, the Army performed the most in-depth, intensive testing regarding camouflage uniforms and OCIE to date (Mortlock, 2020). Army leadership understood that mission accomplishment and the welfare of their Soldiers was on the line, and they exercised due diligence prior to fielding OCP. In doing so, they included both desert and woodland MARPATs and coyote brown plate carriers in their testing and analysis (Mazz, 2015). As a result, the Marine Corps can benefit from their experience, as the research translates Army camouflage uniform and equipment test data into quantifiable effectiveness measures that, when balanced against cost, can inform USMC senior leaders considering courses of action to improve the concealment of U.S. Marines in combat operations.

D. HISTORY OF MILITARY PLATE CARRIERS

Similar to camouflage, the use of body armor by military forces dates back centuries. However, modern day plate carriers trace their lineage to the Flyer's Vest, M1, which was developed by the Army Eighth Air Force during WWII and issued to pilots and aircrew in 1943 (Howard, 2020). The Flyer's Vest, M1 was designed to protect aircrew from exploding anti-aircraft shells, commonly referred to as flak, hence the still-prevalent nickname flak jacket. The M1 was constructed from steel plates sewn into canvas, and weighed 17 pounds, 6 ounces (Howard, 2020). Although a battle casualty study conducted by the Eighth Air Force showed a decrease in chest and abdominal wounds largely attributed to wearing the M1, the Army hesitated in developing body armor for ground troops due to its excessive weight and inherent restriction of movement (Howard, 2020). The Army Ordnance Corps eventually developed the M12, which weighed 12 pounds, 3 ounces, and was used in the early stages of the Korean War. The

M-1951 vest succeeded the M12. The Army and Marine Corps designed it in a joint effort, and both Services used it. The M-1951 was nicknamed the “Marine Vest” and weighed just under 8 pounds (Howard, 2020). Successors to the M-1951 included the M-1952, the M-1955, and the M-69 (Howard, 2020). These vests were similar in design, with successive layers of protection added to each new variant. As illustrated in Figure 10, the WWII– and Korean–era vests were typically brown in color, and later vests were primarily produced in olive-drab green to match the environment in Vietnam.

Figure 10. Left to right: Flyer’s Vest M1 with M3 Apron, M-1952, M-69. Adapted from Howard (2020).

In 1983, the Army fielded the Personnel Armor System for Ground Troops (PASGT), which was comprised of Kevlar soft armor in camouflage print. The PASGT was used in Grenada, Panama, and the Middle East (Howard, 2020). The Army implemented the PS-930 Ranger Body Armor (RBA) in the early 1990s, which built upon the design of the PASGT and included ceramic plates to protect the torso from small arms direct fire. Its effectiveness in the Battle of Mogadishu in 1993 led to the implementation of the Interim Small Arms Protective Overvest (ISAPO) in 1996 (Howard, 2020). The ISAPO was the first specifically designed plate carrier, with front and back ceramic plates, and was worn overtop the PASGT for a total system weight between 21 and 25 pounds (Howard, 2020). The RBA and the ISAPO marked the transition from flak jackets, or body armor designed to protect the wearer from shrapnel, to plate carriers, body armor specifically designed to protect the wearer from small arms direct fire.

The Interceptor Body Armor (IBA) succeeded the ISAPO and was fielded by the Army and Marine Corps in 1999. The IBA included Kevlar®-based inserts in the Outer Tactical Vest (OTV) and front and back ceramic Small Arms Protective Inserts (SAPI) plates. The OTV and SAPI combination provided protection from shrapnel and direct fire impacts. After September 11, 2001, the IBA was continuously upgraded to provide higher levels of protection, and the total weight rose from 16.4 pounds to 33 pounds (Howard, 2020). The IBA was primarily produced in BDU woodland camouflage print, which led to uniform incongruity in the early stages of the Global War on Terror (GWOT). Figure 11 shows the assortment of body armor used in the early stages of Operation Iraqi Freedom. The soldiers on either end of the front row are wearing RBA, the other three front-row soldiers are wearing IBA, the soldier in the back right is wearing the PASGT vest, and the captain in the center is wearing the Body Armor Load Carrying System (BALCS) (Howard, 2020).

Figure 11. Illustration of various types of body armor initially employed in Operation Iraqi Freedom, Mosul 2003. Adapted from Howard (2020).

Around 2006, the Marine Corps and Army parted ways on plate carriers. They both moved to modular designs in an effort to reduce weight, with the Army implementing the Improved Outer Tactical Vest (IOTV) and the Marine Corps fielding the Modular Tactical Vest (MTV). The implementation of the MTV marked the transition to fielding coyote brown plate carriers intended to be worn over both woodland and dessert MARPATs (DoD, n.d.). In an effort to increase modularity and further reduce weight, the Marine Corps fielded the Scalable Plate Carrier (SPC) in 2008, the Improved Modular Tactical Vest (IMTV), or Plate Carrier, in 2013, and the Plate Carrier Generation III (PC Gen III) in 2019 (Kelly, 2018). All three generations of the scalable plate carrier are coyote brown in color. Figure 12 shows a PC Gen III on display.

Figure 12. USMC PC Gen III. Adapted from Keller (2020).

E. CAMOUFLAGE TESTING

Camouflage testing provides the link between the scientific understanding of camouflage and the practical application to achieve desired results. In order to understand the effectiveness data presented in this research, one must have a basic understanding of camouflage testing and the specific methodology the Army used in its extensive testing from 2003–2015. Camouflage is broken down into crypsis and masquerade. Crypsis, a mechanism of both background matching and disruptive coloration, prevents detection. Masquerade, on the other hand, prevents recognition once an object has been detected. Crypsis and masquerade are both vital to overall camouflage effectiveness, and any testing conducted must take both into consideration. However, crypsis, or the initial detection of an object, precedes recognition, and therefore supersedes masquerade in priority. In “Quantifying Camouflage: How to Predict Detectability from Appearance,” the authors submit that results of their analysis show the measurement of disruptive coloration was a better predictor of capture times, or time until detection, than measurements of background matching were (J. Troscianko et al., 2017). Their finding is significant in the context of this research because it shows that disruptive coloration, or masking true edges, is arguably the most important aspect of avoiding detection. This revelation explains the Army's incorporation of a matching OCIE pattern in their testing against coyote brown OCIE and lends credibility to their eventual selection of OCP OCIE that matches the OCP uniform they selected.

Historically, military camouflage testing consisted of observers in specific settings visually assessing the performance of camouflage. In order to save time and money and increase the objectivity and validity of camouflage testing, modern camouflage tests have incorporated photo-simulation. The objective of photo-simulation camouflage testing is to "develop an image assessment algorithm consistent with subjective human visual judgment that has objectively quantified characteristics" (Lin et al., 2014, p. 1). The Army used both photo-simulation and operational field-testing in their Camouflage Uniform Improvement Project. Furthermore, they recognized that photo-simulation enables a tighter control of test variables, which in turn provides a more objective assessment (Mortlock, 2020). The Army's camouflage testing was comprised of four mutually supporting lines of effort that included both technical development testing and operational field-testing. The two methods of technical development testing were photo-simulation and spectral reflectance measurements. The two methods of operational field-testing were static observation tests and maneuver tests. Figure 13 shows the Army's camouflage test and evaluation strategy, in which they placed more relevance on photo-simulation testing contrary to ingrained beliefs that operational field-testing is supreme.

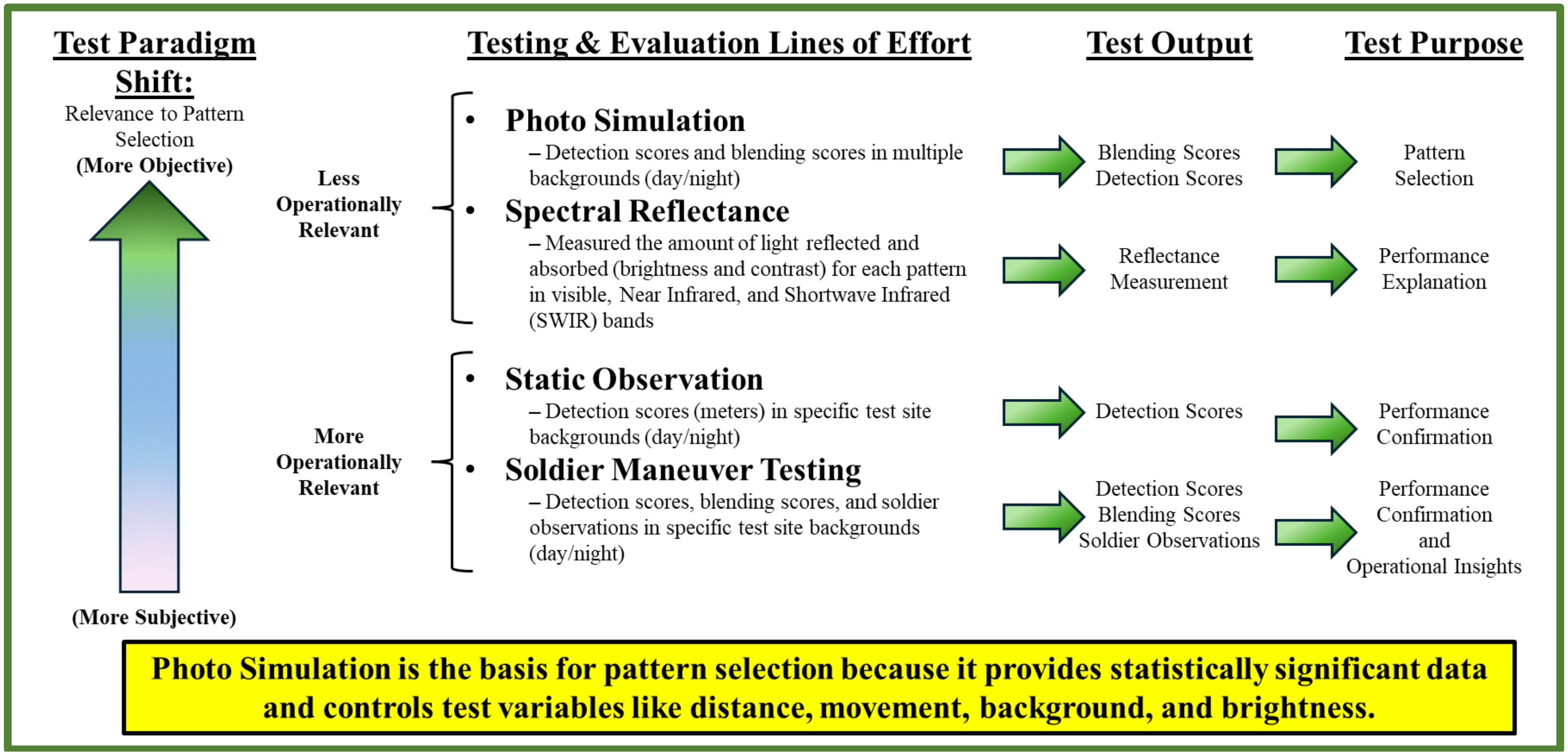

Figure 13. Army Camouflage Uniform Improvement Project test and evaluation strategy. Adapted from Mortlock (2020).

The Army conducted initial camouflage testing in Phase II when they were searching for the short-term solution to replace UCP on combat uniforms in Afghanistan. They used a combination of photo-simulation and operational feedback from soldiers in Afghanistan. One specific conclusion they drew from this testing was that a camouflage pattern called MultiCam performed better than other tested uniforms in detection and blending. A more general, but highly relevant, result of their evaluation was that terrain-specific camouflage patterns provided better concealment than a single transitional pattern did (Mortlock, 2020).

The objective of Phase IV of the Camouflage Uniform Improvement Project was to find the long-term solution regarding camouflage combat uniforms. In *Data Analysis for the Army Camouflage Uniform Improvement Project: Phase IV, Bookend Pattern Assessment*, John Mazz (2015) outlines the Army's research questions that served as a basis for their testing. Those questions were:

- Is there a benefit to the Army having a lighter-colored camouflage pattern than OCP for use in lighter-colored arid environments while wearing OCP OCIE?
- Is there a benefit to the Army having a darker-colored camouflage pattern than OCP for use in woodland environments while wearing OCP OCIE?
- Is there a benefit to the Army having matching OCIE for both arid and woodland camouflage patterns? (Mazz, 2015, p. 32)

It is important to note that the Army's third research question, which is directly relevant to this research, was not considered until after the test was designed (Mazz, 2015). Therefore, the Army did not have matching arid and woodland OCIE on hand for testing. However, they did test arid and woodland uniforms, to include MARPATs, without OCIE. The Army researchers made the assumption that not wearing OCIE is an accurate representation of the uniform's effectiveness with matching OCIE worn over it (Mazz, 2015). This appears to be a valid assumption within the context of this research, and the effectiveness evaluation derived from the Army data carries this assumption forward.

The two criteria used to evaluate the effectiveness of each camouflage pattern were *detection* and *blending*. Within the context of the study, detection is categorized as the ability to discern the object and was measured at different distances. Blending is categorized as an evaluation of how well the pattern matched the background once it was detected (Mortlock, 2020). Throughout the Phase IV testing, Army researchers collected over 137,000 data points from 12 different physical locations around the world and incorporated 85 different backgrounds in the photo-simulation testing. Additionally, the then U.S. Army Night Vision Laboratory conducted spectral reflectance measurements to assess pattern performance in visual, near-infrared (NIR), and short wave infrared (SWIR) wavelengths (Mortlock, 2020).

In the Army's study, researchers assessed detectability through photo-simulation and operational testing. Figure 13 shows the lines of effort and corresponding test output. The photo-simulation detection testing followed the North Atlantic Treaty Organization–recommended procedure. The observers were shown a sequence of five images depicting the target in the same uniform and OCIE configuration at ranges from 450 to 50 meters. The observers were shown the images in decreasing range order, and the maximum range at which the observer detected the target was noted to assess the detectability of the configuration (Mazz, 2015).

The operational detectability testing consisted of static detection testing and scenario testing. In the operational static detection testing, observers were given 30 seconds to view an area, detect the target, describe the target, estimate the range to the target, and specify what caused them to see the target. During daytime operational static detection testing, observers used any combination of unassisted eyesight, assigned weapon optic, or binoculars. During nighttime, they used assigned night vision devices, predominantly AN/PVS-14s (Mazz, 2015). The second method of operational detectability testing involved scenarios where soldiers conducted various infantry operations against an adversary force. The operating force and the adversary force wore different camouflage patterns, and both sides rated the camouflage effectiveness of their opponent's uniform at the conclusion of the scenario. They used an ordinal scale for effectiveness that included assessments of excellent, good, fair, poor, and terrible. Day and night methods of observation were the same as the static detection testing (Mazz, 2015).

Similar to detectability, blending was evaluated through photo-simulation and—to a smaller degree—operational testing. In the photo-simulation blending assessment, 49 observers evaluated the performance of each uniform and OCIE configuration in 46 daytime background scenes and 18 nighttime scenes (Mazz, 2015). The observers rated each configuration on its performance in blending with the background on a 100-point scale, with a rating of 1 meaning it stood out and a rating of 100 meaning it perfectly matched the background (Mazz, 2015). Figure 14 shows examples of the detection and blending photo-simulation procedure.

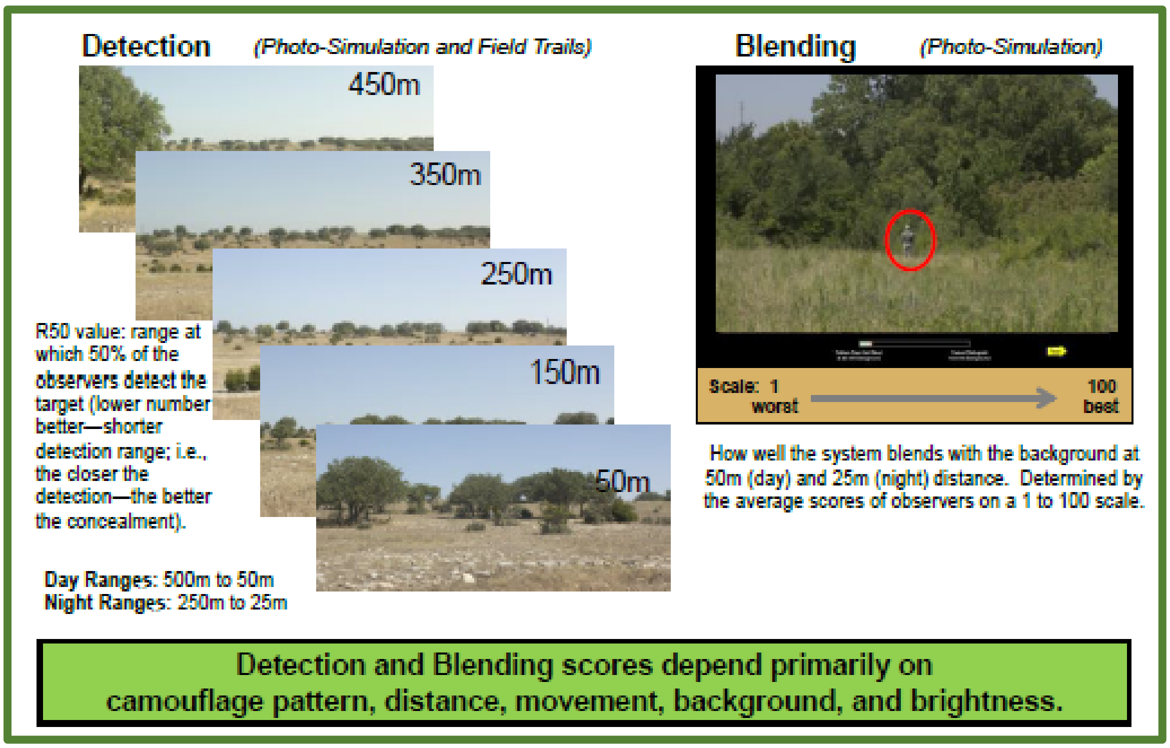

Figure 14. Photo-simulation testing procedure. Adapted from Mortlock (2020).

Unlike the detectability testing, the blending testing did not incorporate operational static blending assessments. However, the feedback ratings from the operational scenario testing were used to assess an operational blending score (Mortlock, 2020).

In analyzing the results of the photo-simulation blending assessment, the Army researchers used the Friedman Multiple Comparisons test with alpha set to 0.01. For both the photo-simulation detection testing and the operational testing, researchers used the

Kruskal-Wallis (K-W) test with alpha set to 0.01 (Mazz, 2015). Thus, Army researchers could say, with 99% confidence, that differences assessed in the performance of each camouflage configuration were not due to chance.

F. CURRENT STATUS OF U.S. MARINE CORPS AND ARMY UNIFORMS AND PLATE CARRIERS

Currently, Marines wear either desert or woodland MARPATs, depending on their operating environment, with the coyote brown Plate Carrier Generation III. Figure 15 shows these configurations.

Figure 15. Woodland and desert MARPATs with coyote brown plate carriers. Adapted from Mazz (2015).

Since 2015, U.S. Army Soldiers wear OCP ACUs with OCP Modular Scalable Vests (MSVs). The result of over 10 years of camouflage testing is that the Army's plate carriers, or MSVs, match the camouflage pattern of their transitional camouflage uniform. Figure 16 depicts a Soldier in OCP ACU and MSV. The Army plans on fielding additional camouflage uniforms for operations in woodland/jungle and arid/desert environments, but they have yet to do so. Although not discussed in this analysis, it is important to note that the Air Force has followed the Army's example and switched to OCP uniforms and plate carriers (Pawlyk, 2018).

Figure 16. U.S. Army Soldier in OCP ACU and MSV. Adapted from Program Executive Office Soldier (n.d.).

In the operating force today, infantry Marines employ principles of field craft to camouflage themselves and their gear. In order to camouflage their bodies and plate carriers, Marines use local vegetation and homemade camouflage shrouds, or ghillie suits, to break up edges and lines. Field craft is a necessary practice for Marines, but even well-employed camouflage practices sometimes fall short in reducing the salience of coyote brown plate carriers worn by Marines on the move. Now, more than ever before, decision-makers need a thorough, unbiased cost effectiveness analysis of the status quo and potential alternatives.

G. SUMMARY

Camouflage is a naturally occurring phenomenon that humans have studied and striven to emulate for centuries. As technology has improved, both the scientific understanding and the military application of camouflage have progressed. The objective of camouflage is to hinder both detection and recognition. Since WWII, the U.S. military has invested heavily in uniforms and plate carriers to enhance the combat effectiveness and survivability of Soldiers, Sailors, Airmen, and Marines. In recent years, the U.S. Army invested money, time, and energy into determining the optimal camouflage uniform solution for Soldiers. As a result of their testing and analysis, Soldiers now have the first uniform of the three-family concept with matching OCIE. The Marine Corps implements an effective two-family uniform concept on the MCCUU with either woodland or dessert MARPAT. However, unlike the Army, the Marine Corps continues to field and use coyote brown ICE worn with both MARPAT variations. Due in large part to the testing and analysis conducted by the Army, the Marine Corps now has a chance to evaluate the effectiveness of their standing uniform and plate carrier camouflage combination and compare it to other viable options that can be implemented in the future.

III. LITERATURE REVIEW

A. PURPOSE

The purpose of this literature review is to establish the context in which this research fits, identify adjacently related studies and analyses, and establish the gap in which this research falls. In addition, the literature review presents a discussion of the methods and approaches used in prior investigations to help construct the analysis framework used in this research. The literature review first provides the context into which this cost-effectiveness analysis fits; then it identifies related research, studies, and analyses on camouflage that are relevant to this research.

B. LITERATURE

1. Cost-Effectiveness Analysis

Cost-effectiveness analysis (CEA) and cost–benefit analysis (CBA) are common economic decision-support frameworks for evaluating trade-offs associated with changes in programs and policies when constrained by limited resources. The goal of CEAs and CBAs is to quantify marginal value and cost associated with any such change in an objective assessment. The OMB (2023) Circular A-94 provides guidance for CEAs and CBAs pertaining to evaluating implications from changes in taxpayer-resourced projects. The CEA and CBA frameworks are commonly used to assess impacts on all members with standing. While CEA "relates the costs of a program to its key outcomes or benefits … [CBA] takes that process one step further, attempting to compare costs with the dollar value of all (or most) of a program's many benefits" (Cellini & Kee, 2015, p. 493). CEA and CBA can be applied before (ex ante), during (in medias res), or after (ex post) a certain policy or change is enacted. As Cellini and Kee (2015) state, a CEA attempts to quantify the costs of a program in dollars, quantify the benefits in terms of units of effectiveness, and then "obtain a program's cost-effectiveness (CE) ratio by dividing costs by … units of effectiveness" (p. 493). Unlike CBA, where the benefits are quantified in monetary value, CEA quantifies effectiveness in units of effectiveness, which are "simply a measure of any quantifiable outcome central to the program's objective" (Cellini & Kee, 2015, p. 494). Two broad categories of CEA and CBA are social (or economic) and financial (Cellini & Kee, 2015). The Coquihalla Highway CBA outlined in *Cost-Benefit Analysis: Concepts and Practice* is an example of a social CBA (Boardman et al., 2006). Table 1 shows the summary of project benefits and costs for this example. In a CBA, benefits are quantified in dollars. Unlike the Coquihalla Highway example, this research falls under the mantle of economic CEA, as more than simply the monetary costs are considered, and benefits are quantified in terms of effectiveness rather than dollars.

Table 1. Coquihalla Highway CBA benefits and costs. Adapted from Boardman et al. (2006).

Coquihalla Highway CBA (1986 $ Million)

	No Tolls		*With Tolls*	
	A Global Perspective	*B Provincial Perspective*	*C Global Perspective*	*D Provincial Perspective*
Project Benefits:				
Time and Operating Cost Savings	389.8	292.3	290.4	217.8
Horizon Value of Highway	53.3	53.3	53.3	53.3
Safety Benefits (Lives)	36.0	27.0	25.2	18.9
Alternative Routes Benefits	14.6	10.9	9.4	7.1
Toll Revenues	—	—	—	37.4
New Users	0.8	0.6	0.3	0.2
Total Benefits	494.5	384.1	378.6	334.7
Project Costs:				
Construction	338.1	338.1	338.1	338.1
Maintenance	7.6	7.6	7.6	7.6
Toll Collection	—	—	8.4	8.4
Toll Booth Construction	—	—	0.3	0.3
Total Costs	345.7	345.7	354.4	354.4
Net Social Benefits	148.8	38.4	24.2	–19.7

2. Military Cost-Effectiveness Analysis

Governments around the world use CEA and CBA in assessing the impacts of policy changes (OMB, 2023). As part of the federal government, the U.S. military often undertakes CEAs before, during, and after policy changes or acquisitions. The goal is to inform decision-makers of the implications arising from program change and the associated trade-offs and risks. Although the evaluated program change is different, Paul Moreau (2022) provides an example of a CEA that aims to provide useful decision-making support. Moreau (2022) conducts a thorough, transparent CEA of two airborne intelligence, surveillance, and reconnaissance (ISR) systems to “determine the alternative with the best value” (p. v). Moreau’s (2022) objective hierarchy, and the means by which he establishes his overall measure of effectiveness (MOE), serve as an effective model despite the differences in systems analyzed. Moreau (2022) clearly defines the sub-objectives under overall effectiveness and nests the measurable attributes under the appropriate sub-objectives. Additionally, his value functions, justification of importance weights, and presentation of MOE versus cost informs the structure and presentation of this research.

Christian Diaz (2020) and B. Kelly et al. (2004) provide two additional CEAs that are similar in scope and methodology. Diaz’ (2020) cost estimation techniques, sensitivity analysis, and CEA methodology are particularly insightful and inform the methodology of this research. Similarly, B. Kelly et al.’s (2004) analytical framework and cost estimation techniques help guide the structure and methodology of this research. B. Kelly et al.’s (2004) presentation of CEA, particularly their means of assessing efficiency and computing effectiveness, inform the MOE calculations in this research. However, B. Kelly et al.’s (2004) research differs in the use of operational scenarios rather than COAs to determine a cost-for-effectiveness ratio. Both theses seek to inform military decision-makers through CEA and display a similar level of rigor to this research.

Hicks et al. (2018) provide a military CBA that also informs this research. Hicks et al.’s (2018) research is more informative in content than in structure, as their research is tangentially related to this CEA involving uniforms and plate carriers. Much of Hicks et al.’s (2018) background information on U.S. military uniforms, to include visuals, is incorporated into this research. While the topic is similar, the actual CBA structure does little to inform this research. While they are able to accurately assess potential costs, their assessment of benefits is vague due to data limitations, and their analysis results in a hybrid CBA/CEA. As Cellini and Kee (2015) state, a CBA “identifies and places dollar values on the costs of programs … [and weighs] those costs against the dollar value of program benefits” (p. 494). CBA is difficult due to the need to quantify benefits in dollars. In the context of this research, CEA is the appropriate method because it would be impractical to quantify the benefits of various plate carrier and uniform camouflage combinations in monetary terms. Furthermore, decision-makers will benefit from a precise MOE, as effectiveness in this context translates directly to mission accomplishment and Marine welfare.

3. Biological Study of Camouflage

In order to establish measures of effectiveness and an overall cost-effectiveness ratio, one must first attain a thorough understanding of camouflage from a biological perspective. In "Animal Camouflage: Current Issues and New Perspectives," Stevens and Merilaita (2009a) establish a baseline in camouflage terminology. Over the years, scientists have used different—and sometimes conflicting—terminology to describe camouflage mechanisms. Foundational camouflage vocabulary used in this research, such as crypsis, masquerade, background matching, and disruptive coloration, comes from the leveling research outlined by Stevens and Merilaita (2009a).

Over the past century, the scientific study of camouflage was limited by technology and the understanding of the human brain. As a result, past researchers focused on camouflage patterns themselves rather than the visual processes camouflage targets. In "How Camouflage Works," Merilaita et al. (2017) acknowledge pioneers in the field, such as Alfred Thayer and Hugh Cott. They seek to build on the works of Thayer and Cott, incorporate modern technology and ideas, and address how camouflage targets the perception and cognition of other animals (Merilaita et al., 2017). Merilaita et al. (2017) argue that "for understanding various mechanisms of camouflage, the concept of signal-to-noise ratio (SNR) provides a useful tool, and hence [they] identify the signal and the noise relevant to each camouflage mechanism" (p. 2). SNR is a measurement of useful information compared to irrelevant information, and the authors illustrate how camouflage minimizes SNR throughout the visual process (Merilaita et al., 2017). The ideas and methodology presented by Merilaita et al. (2017) indirectly contribute to this research by providing a better understanding of the Army camouflage testing data and the visual processes that camouflage targets to achieve successful results.

Recently, other researchers have studied the mechanistic functions of camouflage and methods to quantify effectiveness. In "Camouflage and Visual Perception," the authors analyze the impact of camouflage on visual search. They emphasize that detection precedes recognition in human visual search, and the brain's translation of a two-dimensional picture into a three-dimensional object it can recognize can only occur after detection cues the brain to focus on an area (T. Troscianko et al., 2009). In "Quantifying Camouflage: How to Predict Detectability from Appearance," the authors build on the previous concept and attempt to quantify detectability (J. Troscianko et al., 2017). They analyze background matching and disruptive coloration and quantify their impacts on camouflage through both established and novel methods. The results of their research show that disruptive coloration had the most significant impact on capture times, which highlights "the importance of false edges in concealment over and above pattern or luminance matching" (J. Troscianko et al., 2017, p. 1). These analyses are both informative and thorough, and they appear to corroborate the Army's camouflage research. The key conclusion is that detectability supersedes discriminability, and detectability can be quantified to provide a useful metric for comparison.

4. Military Study of Camouflage

The study and implementation of camouflage for military purposes has increased over the last 2 decades. Since the Marine Corps' MARPAT testing began in 2000, the DoD has invested millions of dollars and countless hours in developing, testing, and fielding camouflage patterns in an attempt to increase mission effectiveness and save American lives (GAO, 2012). One study that emerged as a byproduct of these recent camouflage developments is Robin Wharton's (2017) *Barriers to Implementing a Single Joint Combat Camouflage Uniform*. In his research, Wharton (2017) seeks to explore and understand barriers to implementing a single, joint camouflage combat uniform for all U.S. military branches. He uses the strategic analysis frameworks of strengths, weaknesses, opportunities, and threats (SWOT), and political, economic, social, and technological (PEST) as a means to understand the complex forces at work. Additionally, Wharton (2017) examines the requirements and role of each branch and compares the advantages and disadvantages of implementing a joint uniform. He concludes that "implementing a single joint camouflage uniform for all services will result in cost savings, effective concealment for all services, and logistical simplicity" (Wharton, 2017, p. v). While Wharton (2017) does not seek to quantify costs and benefits, his research serves as a basis for understanding the recent developments in U.S. military camouflage acquisition and the complicated social and political forces affecting those developments.

Improved military technology is one of the driving forces behind camouflage improvement efforts. However, improved technology has also been incorporated into the camouflage improvement effort itself through the use of photo-simulation testing. In "Developing and Evaluating a Target-Background Similarity Metric for Camouflage Detection," the authors seek to provide an objective assessment of camouflage effectiveness. Lin et al. (2014) compare and contrast the performance of several camouflage assessment algorithms. Their research includes in-depth analysis of military-specific photo-simulation camouflage testing. Additionally, they concur with previous assessments that detectability played a larger role than discriminability in camouflaged target search tests that analyzed eye movement (Lin et al., 2014).

Robert Mortlock's (2020) "Camouflage Combat Uniform" case study in the *Defense Acquisition Research Journal* highlights the Army's search for the optimal combat uniform since the Marine Corps fielded MARPATs in 2002. Mortlock's (2020) case study is targeted at defense acquisition professionals and is intended to provide context for those involved in project management. His narrative informs much of the context of this research, as these effectiveness evaluations are based on the same Army testing data he incorporates. Additionally, several of the visuals included in this research are adaptations of those included in "Camouflage Combat Uniform." Mortlock's (2020) research case history is informational in nature. He simply lays out the facts of the case and incorporates external factors that contributed to the chain of events. This research seeks to build on Mortlock's case study to identify potential courses of action the Marine Corps may take, quantify costs and benefits, and objectively present the results in a manner that will inform senior decision-makers.

The most closely related existing research to this thesis is John Mazz's (2015) technical report, *Data Analysis for the Army Camouflage Uniform Improvement Project: Phase IV, Bookend Pattern Assessment*. Mazz (2015) presents an analysis of several arid and woodland camouflage patterns incorporated in the Army's extensive testing. While his report is specific to the Army, the data included in the report forms the basis for the effectiveness data presented in this research. Mazz's (2015) third research question, regarding the benefit of having matching OCIE for both arid and woodland camouflage patterns, is an effective summation of this research's purpose. Although that question was not considered until after the testing was designed, Mazz (2015) makes the assumption that not wearing OCIE is an accurate representation of the uniform's effectiveness with matching OCIE. Thus, the detection and blending scores of uniforms worn without OCIE, compared to those same uniforms worn with coyote brown OCIE, provide a metric for this research's camouflage effectiveness quantification. Mazz (2015) concludes that matching OCIE can enhance the performance of camouflage uniforms designed for specific environments to different degrees. This research builds on Mazz's to specifically evaluate the effectiveness of USMC uniforms and various plate carrier options to provide a useful and objective MOE for each COA. It then incorporates cost estimates for each COA to provide effectiveness-cost ratios, marginal effectiveness, and marginal cost.

C. SUMMARY

This research adds to a growing body of academic and operational literature regarding camouflage. It uses the time-tested method of CEA to incorporate key performance metrics and forecasted costs into a quantifiable, objective metric that will inform key decision-makers. This analysis uses the research of scientists and academics in several related fields to illuminate the biological mechanisms of camouflage. It then builds on existing military camouflage testing data and links the science to the perceived effectiveness. Lastly, this research uses adjacently related narratives and analyses to provide insight that sheds light on the search for the optimal solution for adequately equipping the nation's warfighters.

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IV. METHODOLOGY

A. OVERVIEW

A CEA framework helps identify and quantify the costs of a program in dollars, then relate these costs to specific measures of program effectiveness (Cellini & Kee, 2015). As stated in the OMB (2023) Circular A-94, "CEA is appropriate when it is impractical to consider the dollar value of benefits provided by the alternatives under consideration" (p. 5). This technique is commonly employed in the DoD, where the quantification of benefits in terms of dollars for weapons and equipment is neither appropriate nor practical (OMB, 2023).

Figure 17 outlines the steps of a common CEA or CBA as laid forth by Cellini & Key (2015). Steps three through nine comprise the bulk of the CEA, and will be presented in detail in the following Analysis Chapter.

Steps in Cost-Effectiveness and Cost-Benefit Analysis

1. Set the framework for the analysis
2. Decide whose costs and benefits should be recognized
3. Identify and categorize costs and benefits
4. Project costs and benefits over the life of the program, if applicable
5. Monetize (place a dollar value on) costs
6. Quantify benefits in terms of units of effectiveness (for CEA), or monetize benefits (for CBA)
7. Discount costs and benefits to obtain present values
8. Compute a cost-effectiveness ratio (for CEA) or a net present value (for CBA)
9. Perform sensitivity analysis
10. Make a recommendation where appropriate

Figure 17. Steps in CEA & CBA. Adapted from Cellini & Kee (2015).

The scope of this analysis is appropriately narrow, as the potential change under consideration is restricted to plate carrier coloration. While all ICE should be considered in the future, this analysis serves as a starting point, and can be built upon if decision-makers desire more information regarding the potential benefits of additional equipment camouflage changes. Additionally, this analysis is not concerned with physical properties of plate carriers, such as size, weight, or ballistic properties. Typically, the only costs and benefits considered in CEA are "those that would occur over and above those that would have occurred without any action (under the status quo)" (Cellini & Kee, 2015, p. 496). In the context of this CEA, the change under analysis is the coloration of the plate carrier, thus any benefit of plate carriers not related to their coloration is disregarded. In order to be transparent and provide information relevant to decision-makers, this CEA will provide a MOE and effectiveness-cost ratio (ECR) for the status quo, so it can be compared to the other COAs under consideration. Additionally, after analysis, it may become apparent that some proposed courses of action are dominated by the status quo when all attributes related to plate carrier coloration change are considered. If this is the case, a complete analysis, MOE, and ECR will be calculated and shown prior to discarding the COA from future consideration.

This analysis focuses on the effectiveness of various plate carrier camouflage combinations when worn with woodland and desert MARPATs. This research seeks to answer the following two questions:

- What are the trade-offs (advantages and disadvantages) associated with the USMC plate carrier camouflage options, compared with the status quo?
- What are potential courses of action the Marine Corps could consider to address concealment vulnerabilities associated with plate carriers worn over the MCCUU with MARPAT camouflages?

The trade-offs associated with the various courses of action are broadly captured by the MOE established in the following analysis section. The specific advantages and disadvantages are highlighted in the objective hierarchy, and the value functions and importance weights assigned result in the final MOE (Moreau, 2022). The cost-effective solution then relates the MOE to the cost associated, and ECRs provide decision-makers with data points that encompass performance and cost tradeoffs to inform a decision.

The courses of action analyzed in this framework are as follows:

- COA 1: Status Quo. All Marines are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 2: OCP. All Marines are issued OCP plate carriers to be worn over both woodland and desert MARPATs.

- COA 3: Aligned with Area of Operations (AO). Marines aligned to woodland/tropic environments are issued woodland MARPAT camouflage plate carriers to be worn over both woodland and desert MARPAT uniforms. Marines aligned to desert/arid environments are issued desert MARPAT camouflage plate carriers to be worn over both desert and woodland MARPAT uniforms. Reservist Marines and Marines in non-deploying billets are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 4: Deployer Equipment Bundle (DEB). All Marines are issued coyote brown plate carriers when conducting operations in the continental U.S. (CONUS). Marines permanently stationed overseas and deploying Marines are issued woodland MARPAT camouflage plate carriers or desert MARPAT camouflage plate carriers dependent on their AO.
- COA 5: Prioritize Active Duty. Active duty Marines are issued both woodland MARPAT camouflage plate carriers and desert MARPAT camouflage plate carriers to be worn as the situation dictates. Reservist Marines are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 6: Two per Marine. All Marines are issued woodland MARPAT camouflage plate carriers and desert MARPAT camouflage plate carriers to be worn as the situation dictates.

Since the purpose of this research is to provide an objective analysis to inform key decision-makers, there will be no final recommendation regarding COA selection. The MOEs and ECRs are calculated to enable more informed decision-making, and any recommendations will highlight areas for further research.

B. COST FRAMEWORK

Cost-estimation needs to consider assumptions concerning future circumstances. Cost-estimation involves the approximation of probable worth "based on information available at the time" (Mislick & Nussbaum, 2015, p. 11). While a cost estimate does not need to be precise, it must be both reasonable and credible (Mislick & Nussbaum, 2015). This analysis uses historical cost data, the Joint Inflation Calculator (JIC), the Net Present Value (NPV) formula, and relevant USMC and Army organizational and deployment practices to present a reasonable and credible estimate.

The cost estimate in this thesis assumes the Marine Corps will conduct modernization through sustainment in the pursuit of any COA beyond the status quo. Rather than one up front purchase of new plate carriers, the USMC will use a staggered approach by replacing old, worn-out plate carriers with new plate carriers as described in the previously stated COAs. Using the standard life of a plate carrier, the average yearly turnover, the number of plate carriers prescribed by each COA, and the average unit cost (AUC) from historical data, this research estimates the 30-year life cycle cost in constant year 2025 dollars (CY2025$). This estimate then uses the NPV formula to account for the time-value of money and opportunity cost throughout the life cycle. The full cost estimation framework with values, formulas, and assumptions is presented in the following analysis chapter.

C. EFFECTIVENESS FRAMEWORK

1. Objective Hierarchy

This analysis uses an objective hierarchy to establish a measure of overall effectiveness (MOE). When multiple attributes capture overall effectiveness, multi-objective analysis is used “to allow for comparisons between alternatives with more than one attribute of effectiveness or with dissimilar attributes” (Moreau, 2022, p. 37). To account for each relevant attribute, analysts establish a hierarchy. Each additional level down captures specific attributes in more detail to provide objective measurement. Figure 18 depicts an example objective hierarchy of a sports car.

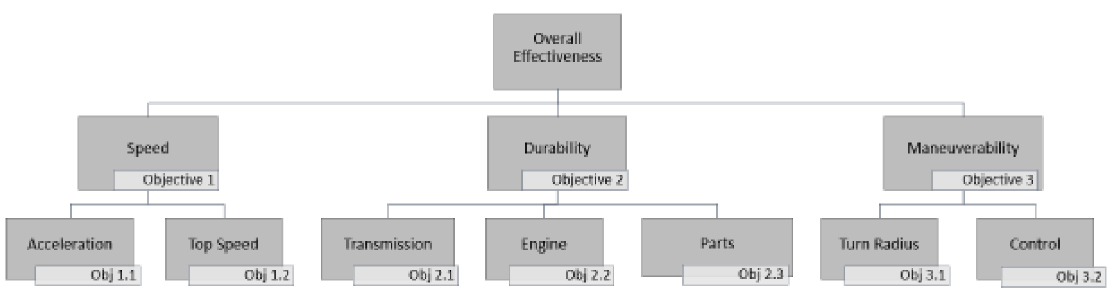

Figure 18. Example objective hierarchy of a sports car. Adapted from Moreau (2022).

The objective hierarchy presented in the following analysis section includes measures of effectiveness as determined by the camouflage of the plate carrier and the allocation method. The hierarchy includes both measures of the camouflage itself, as determined by detection and blending, and measures of additional attributes that are affected by the camouflage and the allocation method. All attributes captured in the objective hierarchy are pertinent to overall combat effectiveness.

2. Value Functions

In order to conduct multi-objective decision-making and establish a MOE, the individual attributes at the bottom of the hierarchy must be normalized (Moreau, 2022). If they are not normalized, they cannot be accurately composited, as different attributes will affect the MOE more than others based simply on the way they are measured. They will be normalized on a 0 to 1 scale, where higher is better. For some attributes, such as detection and blending, the method of measurement enables a clear and seamless normalization. For example, blending is evaluated on a scale from 1–100, so blending values can be divided by 100 to fit the 0 to 1 scale. Other attributes do not fit as neatly, and their methods of normalization will be clearly stated and justified in the analysis section.

3. Importance Weights

With normalized value functions, the last step for establishing a MOE score is assigning weights to each attribute. This is vital, as, "The importance weight assigns a relative value to each attribute between 0 and 1, based on the decision maker's assessment of the relative importance of each attribute to overall system effectiveness" (Moreau, 2022, p. 41). Put simply, weighting allows for differentiation between attributes in proportion to their significance to overall effectiveness. For clarity, individual MOEs will first be calculated without assigned weights, and then weights will be assigned based on a combination of research and subjective opinion. Since weighting is subject to decision-maker priority, this research will be transparent with assigned weights and it will later be subjected to sensitivity analysis. Additionally, future researchers can vary the weighting as needed when conducting additional analysis.

4. MOE Score

The overall MOE in this analysis is mission effectiveness. Each COA's MOE is the sum of the lowest attributes in the objective hierarchy after they have been normalized and multiplied by their corresponding importance weights. In the context of this research, the actual MOE score is irrelevant. The key contribution of this research is the marginal difference in effectiveness, as captured in the objective hierarchy. When combined with the estimated cost, each COA will have marginally different effectiveness for marginally different cost. This provides decision-makers with an initial estimate for each COA, and a framework they can adjust as necessary to capture differing priorities or circumstances.

5. Cost-Effective Solution

The outcome of a CEA is an estimated ratio that can be presented in two different formats. The first, and most common format, is a cost-effectiveness ratio (CER). A CER is calculated by dividing the program cost by its measure of effectiveness, as displayed in Figure 19.

$$\text{Cost-Effectiveness Ratio (CER)} = \frac{\text{Total Cost}}{\text{Measure of Effectiveness}}$$

Figure 19. Cost-effectiveness ratio formula

The second method is an effectiveness-cost ratio (ECR), in which the effectiveness measure is divided by the program cost, as shown in Figure 20.

$$\text{Effectiveness-Cost Ratio (ECR)} = \frac{\text{Measure of Effectiveness}}{\text{Total Cost}}$$

Figure 20. Effectiveness-cost ratio formula

When multiple programs or alternatives are considered, individual CERs or ECRs are calculated for each alternative. Typically, a cost-effective alternative has the "lowest costs expressed in present value terms for a given amount of benefits" (OMB, 2023, p. 5). However, since there is no underlying prescribed benefit threshold tied to this analysis, the results will be presented as marginal costs and marginal benefits. Each COA will have a unique ECR, and future decision-makers must determine the appropriate COA depending on the feasibility of attaining marginal benefit.

6. Assumptions and Sensitivity Analysis

Given the challenges of estimating future costs and effectiveness, determining a MOE and cost estimate for each COA requires starting assumptions. All assumptions must be clearly stated and justified as they are incorporated into the analysis. Key assumptions that have the potential to significantly affect the ECR will be subject to sensitivity analysis to inform decision-makers of the reasonable range for the expected cost effectiveness of the different COAs. These key assumptions include the discount rate (r), importance weights, and turnover rate. Sensitivity analysis will provide a range of outcomes dependent on the assumption made. This will allow decision-makers to better understand any risk and uncertainty inherent in the ex-ante analysis.

D. SUMMARY

CEA is the appropriate methodology for this analysis because it provides decision-makers with ECRs for each proposed course of action and allows them to compare marginal benefits and marginal costs. It is impractical to monetize the benefits of camouflage plate carriers, so measures of effectiveness are used instead (OMB, 2023). Since multiple attributes encompass mission effectiveness, this analysis uses multi-objective decision-making through an objective hierarchy. The lowest level attributes of the objective hierarchy are tied to measurable measures of performance (MOPs). After the MOPs are normalized, perceived decision-maker preference is incorporated through importance weights. The objective hierarchy provides one MOE for each COA, and the COAs can be compared to ascertain marginal benefits.

This CEA incorporates cost-estimation techniques to provide reasonable and credible cost estimates for each COA. The final cost estimates for each COA can be compared to determine marginal cost through inflation normalization and NPV. The MOEs and cost estimates provide ECRs that serve as data points for decision-makers. This allows decision-makers to compare marginal benefits and marginal costs associated with each COA and make an informed decision under future circumstances. All assumptions necessary to determine the ECR will be clearly stated, and key assumptions will be subject to sensitivity analysis. This will allow decision-makers to better understand the risks and uncertainty inherent in this analysis.

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V. ANALYSIS

A. OVERVIEW

This chapter focuses on steps 3–9 in Cellini and Kee's (2015) outline of a typical CEA shown previously. Specifically, this analysis identifies and categorizes costs and benefits, projects costs and benefits over the life of the project when applicable, quantifies benefits in terms of effectiveness, monetizes costs, discounts cost to obtain NPV, computes an ECR for each COA, and provides sensitivity analysis (Cellini & Kee, 2015). All assumptions will be stated and justified as they are presented through the analysis.

B. EFFECTIVENESS

The effectiveness attributes included in this analysis pertain to the specific courses of action outlined. The changes under consideration include the camouflage coloration of Marine's issued plate carriers, and the numbers of plate carriers required and their method of issue as prescribed by each COA. Any additional attributes of plate carriers outside the scope of this analysis, such as ballistic properties, size, weight, etc., are not included in the effectiveness analysis because the proposed changes do not affect these attributes (Cellini & Kee, 2015).

1. Objective Hierarchy

The top-level objective of *overall effectiveness* must be broken down to measurable attributes that provide for meaningful comparison. Typically, in a military CEA, sub-objectives and attributes are derived from key performance parameters (KPPs) found in the weapon, platform, or equipment's Capability Development Document (CDD) (Moreau, 2022). However, in the context of this research, the KPPs laid forth for plate carriers are not relevant in determining marginal effectiveness as a product of camouflage coloration. Therefore, this research relies on the scientific study of camouflage, previous testing, and simplified principles of production and supply to determine relevant sub-objectives and attain measurable attributes.

There are three objectives below the top-level objective that, when taken together, comprise overall effectiveness. These attributes are survivability, lethality, and suitability. The relationship is illustrated in Figure 21.

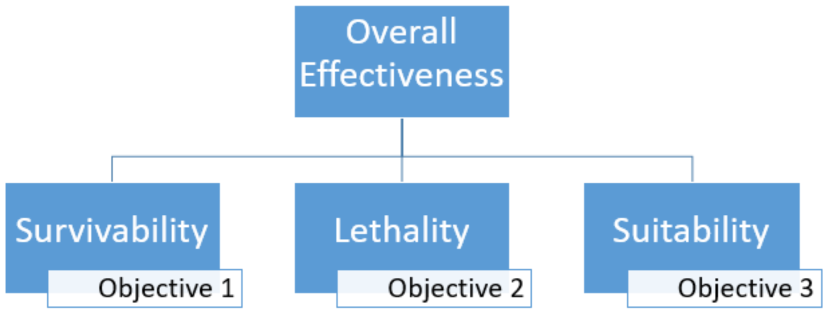

Figure 21. Objective hierarchy second-level objectives

Since none of these second-level attributes are yet measurable in a meaningful way, they must be further divided into sub-objectives and attributes (Moreau, 2022). In the context of this research, survivability means camouflage, which serves as objective 1.1. Camouflage can be further broken down to the attributes of detectability (objective 1.1.1) and blending (objective 1.1.2). Detectability and blending are measurable attributes, and their values are derived from the Army Camouflage Uniform Improvement Project results outlined in Mazz's technical report.

Lethality (objective 2) changes from the status quo as a result of the camouflage pattern prescribed in each COA. Accuracy is the measurable attribute tied to lethality, and serves as objective 2.1. The accuracy measurement stems from the round impact radius determined by the Minute of Angle (MOA) of the M27 Infantry Automatic Rifle (IAR) at the estimated range to target at detection, as derived from the 450-meter probability of detection highlighted in the Mazz technical report. A Marine wearing a plate carrier with a lower probability of detection can get closer to the target – resulting in increased accuracy and overall lethality.

Suitability (objective 3) seeks to capture the inherent differences in each COA as a result of the numbers and types of plate carriers acquired and issued to Marines that cannot be factored into the cost estimate. The four sub-objectives under suitability are flexibility (objective 3.1), uniformity (objective 3.2), production (objective 3.3), and logistics (objective 3.4). Flexibility is an approximate measurement of the scope of conflict supportable by Marines wearing plate carriers with camouflage that matches their intended environment. Uniformity is a binary variable that reflects whether all Marines can be uniformly equipped under each COA. Both production and logistics are measurements of the number of types of plate carriers required to be produced, and stored and supplied, respectively. Figure 22 shows the full objective hierarchy.

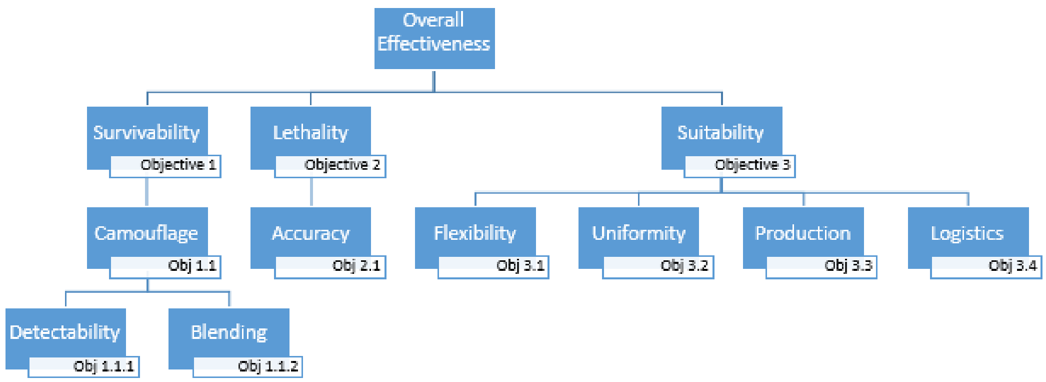

Figure 22. Objective hierarchy for camouflage plate carrier COAs

Each attribute in the bottom level of the objective hierarchy can be measured in a meaningful way that allows for comparison. The hierarchy has been derived down to the level where the question "what do you mean by that?" can be clearly answered for each attribute (Moreau, 2022, p. 48). The value functions and the underlying data for each attribute are presented in the following sections.

2. Survivability

Survivability is a critical aspect on the battlefield as it relates to people, weapons, equipment, and platforms. It serves as objective 1 and concerns the survivability of Marines on the battlefield wearing the MCCUU and different camouflage pattern plate carriers.

a. Camouflage

The principles of camouflage were previously articulated in Chapter II, Sections B and C when discussing the science of camouflage and the history of military camouflage. Camouflage is a naturally recurring phenomenon used to prevent detection and recognition that militaries have emulated for centuries in an attempt to protect their people and equipment. Detection precedes recognition in human visual perception, but both are necessary components in conducting visual search (T. Troscianko et al., 2009). The Army Camouflage Uniform Improvement Project tested various camouflage combinations of uniforms and plate carriers and assigned detection and blending scores relevant to this research (Mazz, 2015).

Figure 23 shows eight out of the 11 combinations tested. MPW stands for Marine pattern woodland, and MPD stands for Marine pattern desert. The –O denotes OCP plate carrier and the –C denotes coyote brown plate carrier. It is important to note the BDU and DCU are shown with OCP plate carriers, but were also tested without plate carriers, which represents the uniform worn with a matching plate carrier.

Figure 23. Uniform and plate carrier combinations included in the Army Camouflage Uniform Improvement Project Phase IV testing. Adapted from Mazz (2015).

As previously mentioned in Chapter II, Section E on camouflage testing, the Army underwent a paradigm shift in camouflage testing methodology. They placed more emphasis on photo-simulation testing than on operational field testing, as photo-simulation enabled the testers to more tightly control outside variables (Mortlock, 2020). Thus, they were able to more precisely attribute and measure the effectiveness of the camouflage pattern combinations in various environments. This analysis uses the daytime photo-simulation detection results and the day and night photo-simulation blending results as a basis for the detectability and blending attributes.

The Mazz (2015) technical report on the results of the Army Camouflage Uniform Improvement Project, Phase IV provides daytime detection scores and day and night blending scores at a range of 450 meters for woodland and desert MCCUUs with both coyote brown and OCP plate carriers worn over top. It also provides scores for DCU and BDU uniforms, worn in arid and woodland environments respectively, with OCP and "matching" plate carriers. This research carries forward the assumption made by the Army testers that DCUs and BDUs worn without plate carriers accurately represent those uniforms worn with plate carriers that have camouflage patterns that match the DCU and BDU patterns. The six COAs under consideration involve Marines wearing woodland and desert MCCUUs with either coyote brown, OCP, or matching camouflage plate carriers. As such, the results of the Army testing provide accurate metrics for evaluation of the various COAs.

(1) Detectability

Figure 24 represents the photo-simulation detection testing. Observers viewed an environment with a target wearing each combination of uniform and plate carrier at ranges decreasing from 450 meters to 50 meters until they correctly identified the target (Mortlock, 2020). This provided the testers with two related, yet distinct pieces of information: the range at which 50% of observers identified the target and the percentage of observers that identified the target at each range.

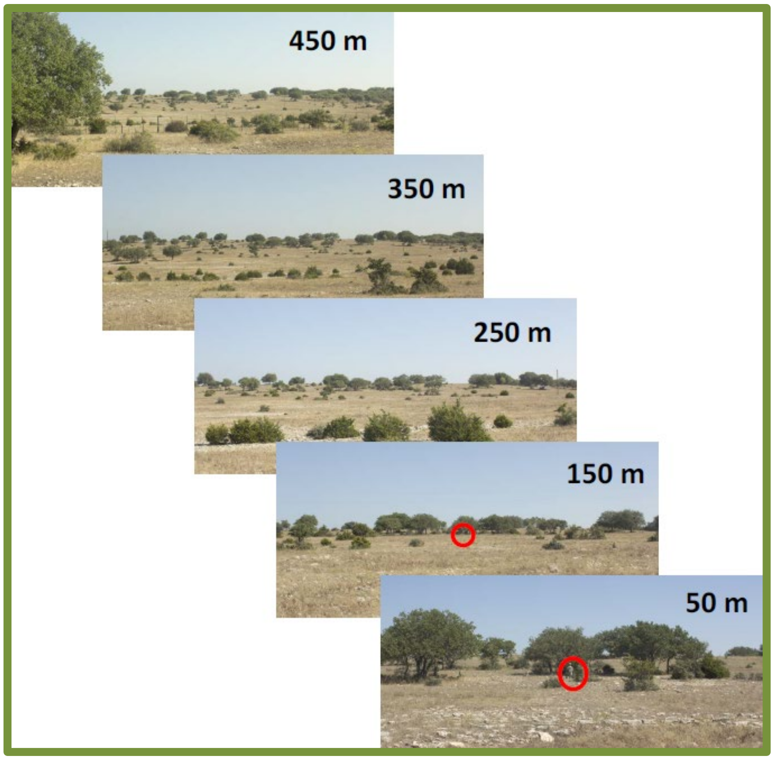

Figure 24. Photo-simulation detection testing methodology. Adapted from Mazz (2015).

This research uses the probability of detection at 450 meters to determine the detectability metric for the related attribute on the objective hierarchy. Table 2 displays the results of the arid detection testing, where a lower number is better, as it denotes a lower probability of detection. MPD stands for Marine pattern desert, or the desert MARPAT MCCUU. DCU is the desert combat uniform. C denotes a coyote brown plate carrier was worn over the uniform and O denotes an OCP plate carrier was worn over the uniform. N denotes that the uniform was worn without a plate carrier.

Table 2. Probability of detection in arid environments. Adapted from Mazz (2015).

Background	Pd at 450 meters for Day Arid Backgrounds			
	MPD-C	MPD-O	DCU-O	DCU-N
1	0.95	0.92	1.00	0.98
2	0.19	0.05	0.32	0.03
3	0.69	0.76	0.74	0.37
Average	**0.60**	**0.59**	**0.69**	**0.47**

In an arid environment, the desert MARPAT MCCUU worn with a coyote brown plate carrier has a slightly higher probability of detection than when worn with an OCP plate carrier. Additionally, a matching plate carrier results in a 22-percentage point lower probability of detection, as shown with DCU-O and DCU-N.

Table 3 shows the average probability of detection of woodland uniforms worn in woodland environments. MPW stands for Marine pattern woodland, or the woodland MARPAT MCCUU. BDU is the battle dress uniform.

Table 3. Probability of detection averages in woodland environments. Adapted from Mazz (2015).

	Pd at 450 meters for Day Woodland Backgrounds			
	MPW-C	MPW-O	BDU-O	BDU-N
Average	0.54	0.58	0.82	0.76

In a woodland environment, the woodland MARPAT MCCUU worn with a coyote brown plate carrier has a 4-percentage point lower probability of detection than when worn with an OCP plate carrier. The BDU data points show that a matching plate carrier results in a 6-percentage point lower probability of detection in woodland environments.

This data shows that the MCCUU worn with a coyote brown plate carrier is marginally more detectable than the MCCUU worn with an OCP plate carrier in arid environments. However, the MCCUU and coyote brown combination is less detectable than the MCCUU and OCP combination in woodland environments. Additionally, it shows that a perfectly matching plate carrier and uniform combination results in a 22-percentage point lower probability of detection in arid environments and a 6-percentage point lower probability of detection in woodland environments. This research assumes that the decrease in probability of detection from DCU-O to DCU-N and BDU-O to BDU-N translates to a decrease in probability of detection from the status quo, MARPAT MCCUUs worn with coyote brown plate carriers, to MARPAT MCCUUs worn with matching MARPAT camouflage plate carriers. Table 4 shows the probability of detection for each uniform in their intended environment with each combination of plate carrier. The averages at the bottom are the overall probability of detection of OCP, coyote brown, and matching plate carriers with the two-pattern USMC uniform family.

Table 4. Overall probability of detection of plate carrier and MCCUU combinations. Adapted from Mazz (2015).

Probability of Detection			
Uniform	**Plate Carrier**		
	OCP	**Coyote**	**Matching**
Desert	0.590	0.600	0.380
Woodland	0.577	0.540	0.480
Average	**0.583**	**0.570**	**0.430**

Probability of detection is on a 0 to 1 scale, where 0 means it is perfectly undetectable at that range and 1 means it is detected every time. Thus, lower is better. At 450 meters, a Marine wearing an OCP plate carrier is detected 58.3% of the time, a Marine wearing a coyote brown plate carrier is detected 57.0% of the time, and a Marine wearing a matching MARPAT camouflage plate carrier is detected 43.0% of the time. It is important to note that this signifies that OCP and coyote brown both have R50 ranges greater than 450 meters and matching has an R50 less than 450 meters. Since 450 meters was the furthest distance tested, there are no exact R50 values for OCP and coyote brown plate carriers. The data simply shows that over 50% of observers detect these combinations at 450 meters. This factors into the lethality attribute analysis.

(2) Blending

The various camouflage uniform and plate carrier combinations were evaluated for blending in day and night conditions. Blending affects recognition, which succeeds detection in human visual search (T. Troscianko et al., 2009). In Phase IV of the Army Uniform Camouflage Improvement Project, observers viewed a series of images with different uniform and plate carrier combinations in different backgrounds. The observers ranked each target on a scale of 0 to 100, where 0 perfectly stood out and 100 perfectly matched (Mortlock, 2020). Figure 25 shows an example of the blending methodology.

Figure 25. Photo-simulation blending testing methodology. Adapted from Mazz (2015).

The results of the day and night arid environment blending tests are shown in Table 5. The nomenclature remains the same.

Table 5. Arid environment blending scores. Adapted from Mazz (2015).

Arid Environment Blending Scores				
	MPD-C	**MPD-O**	**DCU-O**	**DCU-N**
Day	58	58	59	66
Night	58	59	60	67
Average	**58.0**	**58.5**	**59.5**	**66.5**

In arid backgrounds, desert MARPAT MCCUU with an OCP plate carrier performs marginally better than with a coyote brown plate carrier. As the table shows, the difference is in the average night blending score, where OCP performs one point better. The difference between DCU with OCP and DCU with matching is 7 percentage points.

Table 6 shows the results of the day and night woodland blending tests.

Table 6. Woodland environment blending scores. Adapted from Mazz (2015).

Woodland Environment Blending Scores				
	MPW-C	**MPW-O**	**BDU-O**	**BDU-N**
Day	55	55	51	53
Night	64	60	63	75
Average	**59.5**	**57.5**	**57.0**	**64.0**

In woodland backgrounds, woodland MARPAT MCCUU with a coyote brown plate carrier blends 2 percentage points better than with an OCP plate carrier. On average, woodland uniforms blend 7 percentage points better when worn with matching plate carriers, as is shown with BDU.

The difference in blending scores between coyote brown plate carriers and OCP plate carriers when worn over the MCCUU is minimal. OCP is marginally better in arid environments, while coyote brown is 2 percentage points better in woodland environments. However, it is clear that matching plate carriers positively impact the blending ability of Marines in MCCUUs in either environment, as matching blends 7 percentage points better in both environments. The overall blending results are highlighted in Table 7. Higher is better and scores are on a 0 to 100 scale.

Table 7. Overall blending scores of plate carrier and MCCUU combinations. Adapted from Mazz (2015).

Blending Scores			
Uniform	**Plate Carrier**		
	OCP	**Coyote**	**Matching**
Desert	58.5	58.0	65.0
Woodland	57.5	59.5	66.5
Average	**58.0**	**58.8**	**65.8**

Table 7 shows that coyote brown plate carriers worn over the MCCUU blend less than 1 percentage point better than OCP plate carriers. Similar to the detection results, this shows that OCP plate carriers worn over the MCCUU do not provide any camouflage benefit beyond the status quo of coyote brown plate carriers. Additionally, it shows a matching plate carrier will blend 7 percentage points better than the current status quo of Marines wearing coyote brown plate carriers over the MCCUU.

3. Lethality

Lethality is the second broad objective under overall effectiveness. In the context of this research, lethality is a function of the range at which a Marine is detected and the accuracy of their issued weapon at that range. Specifically, lethality changes based on the plate carrier worn, the resulting estimated distance from the Marine to the target at detection, and the round impact radius as determined by the Minute of Angle (MOA) of the M27 Infantry Automatic Rifle (IAR) at that range.

Accuracy is the measurable attribute under the lethality objective in the established objective hierarchy. If a Marine is harder to see, they can get closer to the target before engaging. Furthermore, if a Marine is closer to their target, they will engage the target with more accurate fire than they could if they were at a greater distance. There are multiple ways to capture this, and this research uses the estimated range to target at detection, derived from the 450-meter detection testing, and the round impact radius resulting from the MOA of the M27 IAR at that range.

As previously highlighted in the detectability section, 450 meters was the greatest distance at which the various uniform and plate carrier combinations underwent photo-simulation detection testing. The probability of detection for each relevant combination at 450 meters is highlighted again in Table 8.

Table 8. Probability of detection at 450 meters. Adapted from Mazz (2015).

Probability of Detection at 450 Meters			
Uniform	Plate Carrier		
	OCP	Coyote	Matching
Desert	0.590	0.600	0.380
Woodland	0.577	0.540	0.480
Average	**0.583**	**0.570**	**0.430**

Since 450 meters was the farthest range used in the photo-simulation detection testing, and Marines wearing OCP and coyote brown plate carriers were detected over 50% of the time at that range, the Army testing data does not provide exact R50 values for those plate carriers worn over the MCCUU. To establish an objective accuracy metric from the given data, this analysis uses the 57% probability of detection of the coyote brown plate carrier over the MCCUU as the baseline. The marginal difference in probability of detection at 450 meters from the baseline serves as the means for comparison. Table 9 shows the marginal differences in probability of detection at 450 meters from the baseline of the coyote brown plate carrier over the MCCUU.

Table 9. Marginal probability of detection at 450 meters from baseline

Marginal Probability of Detection at 450 Meters			
	Plate Carrier		
	OCP	Coyote	Matching
Average	0.583	0.570	0.430
Difference from Baseline	**-0.013**	**0.000**	**0.140**

Since coyote brown plate carriers are the status quo, it serves as the baseline for the accuracy analysis and the marginal difference in detection is 0. The marginal difference of OCP is negative because the detection rate of OCP is 1.3 percentage points higher than coyote brown plate carriers when worn over the MCCUU. Conversely, the detection rate of matching camouflage plate carriers is 14 percentage points lower than coyote brown plate carriers when worn over the MCCUU.

The marginal probability of detection is then multiplied by 450 to correlate probability of detection to range. This provides a marginal range tied to each plate carrier's probability of detection. When subtracted from 450 meters, that marginal range provides a range at detection based on the original probability of detection at 450 meters. Again, this is in lieu of the R50 ranges since the Army testing data could not provide exact R50 ranges for each camouflage combination. This relies on the assumption that probability of detection has a local linear relationship with range. Table 10 shows the range at detection for each camouflage combination. Lower is better.

Table 10. Range at detection derived from Pd at 450 meters

Range at Detection			
	Plate Carrier		
	OCP	Coyote	Matching
Average	0.583	0.570	0.430
Difference from Baseline	-0.013	0.000	0.140
Marginal Range (m)	-6	0	63
Range at Detection (m)	456	450	387
Range at Detection (yds)	**499**	**492**	**423**

The final range at detection for each type of plate carrier is then converted to yards to facilitate the incorporation of MOA. This establishes a linear approximation of detection ranges using the probabilities of detection at 450 meters and coyote brown's 57% probability of detection as the baseline.

Since the Marine Corps, or any branch for that matter, does not regularly test marksmanship precisely at the detection ranges established in Table 10, there is no data repository of Marine marksmanship that can connect the established detection ranges to an objective accuracy metric. Even if that data existed, there would be uncontrolled variables that could affect the outcomes. Therefore, this analysis uses Minute of Angle (MOA) to establish an objective accuracy metric dependent on the camouflage effectiveness of each type of plate carrier worn over the MCCUU.

MOA is a mathematical expression of a rifle's accuracy. There is a slight difference between Minute of Angle and Shooter's Minute of Angle, and this analysis uses Shooter's Minute of Angle when referencing MOA. Every rifle has a constant MOA, independent of range (Daniel Defense, 2022). Although a rifle's MOA is independent of range, the combination of a rifle's MOA and the range at which it is fired affects the accuracy of the round (Daniel Defense, 2022). If a rifle has one MOA at 100 yards, the round will impact within a 1-inch radius of the point of aim when it is fired accurately at a target 100 yards away. If the same rifle is fired at 200 yards, it will hit within 2 inches of the point of aim – again assuming the marksman is well-trained and their optic is zeroed properly. As the range increases, the MOA of 1 stays the same, but the circular area in which the round will strike increases by 1 inch in diameter per 100 yards.

The M27 IAR is the Marine infantryman's standard-issue rifle (South & Snow, 2019). The M27 averages 2.5 MOA at 100 yards with M855 ammunition when used in single fire mode (Heckler & Koch, n.d.). This means, when accurately fired at a target 100 yards away, the round will hit within 2.5 inches of the intended point. For every additional 100 yards, the diameter of the potential impact point increases by 2.5 inches.

The maximum effective range of the M27 IAR for an individual, or point target, is 500 meters (Marine Corps Systems Command, 2017). When converted, the maximum effective range for a point target is 547 yards. This means that a Marine taking well-aimed shots with an IAR on single fire mode at maximum range will consistently hit within 13.68 inches of the intended point. This analysis uses the ratio of the round impact radius resulting from the 2.5 MOA of the M27 IAR at the previously established detection ranges to the round impact radius at maximum range to establish a relevant accuracy metric. This metric is determined by the difference in camouflage effectiveness of each type of plate carrier when worn over the MCCUU. Table 11 shows the MOA ratios pertaining to each plate carrier. Lower is better.

Table 11. MOA ratio as determined by Pd at 450 meters

MOA Ratio Estimated from Pd at 450 Meters			
	Plate Carrier		
	OCP	Coyote	Matching
Average	0.583	0.570	0.430
Difference from Baseline	-0.013	0.000	0.140
Marginal Range (m)	-6	0	63
Range at Detection (m)	456	450	387
Range at Detection (yds)	499	492	423
Round Impact Radius	12.467	12.303	10.581
MOA Ratio	**0.912**	**0.900**	**0.774**

Since it is derived from the probability of detection differences, the difference in MOA ratio between OCP and coyote brown is minimal. Coyote brown is less than 2 percentage points better. The MOA ratio of matching plate carriers is significantly lower. This accounts for the impact that decreased detectability–through improved camouflage–has on a Marine's lethality, through increased accuracy. Not only are they harder to detect, but because they are harder to detect they can get closer and engage targets with greater accuracy.

4. Suitability

Suitability (objective 3) is comprised of flexibility, uniformity, production, and logistics. By including suitability as a measure of overall effectiveness, this research seeks to quantify less-obvious, yet still important, impacts associated with each COA. These attributes will likely concern future decision-makers and must be considered despite imperfect MOPs.

a. Flexibility

Flexibility serves as objective 3.1. It is measured by the approximate size of operation supportable by Marines wearing plate carriers with camouflage patterns that match the operating environment. For the purpose of this analysis, it is assumed that environments are either mostly woodland or mostly arid, since the USMC currently uses a two-family pattern of camouflage uniforms that are intended specifically for those two environments. Once again, the courses of action analyzed in this framework are:

- COA 1: Status Quo. All Marines are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 2: OCP. All Marines are issued OCP plate carriers to be worn over both woodland and desert MARPATs.
- COA 3: Aligned with Area of Operations (AO). Marines aligned to woodland/tropic environments are issued woodland MARPAT camouflage plate carriers to be worn over both woodland and desert MARPAT uniforms. Marines aligned to desert/arid environments are issued desert MARPAT camouflage plate carriers to be worn over both desert and woodland MARPAT uniforms. Reservist Marines and Marines in non-deploying billets are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 4: Deployer Equipment Bundle (DEB). All Marines are issued coyote brown plate carriers when conducting operations in the continental U.S. (CONUS). Marines permanently stationed overseas and deploying Marines are issued woodland MARPAT camouflage plate carriers or desert MARPAT camouflage plate carriers dependent on their AO.
- COA 5: Prioritize Active Duty. Active duty Marines are issued both woodland MARPAT camouflage plate carriers and desert MARPAT camouflage plate carriers to be worn as the situation dictates. Reservist Marines are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 6: Two per Marine. All Marines are issued woodland MARPAT camouflage plate carriers and desert MARPAT camouflage plate carriers to be worn as the situation dictates.

Under COAs 1 and 2, zero Marines can support an operation in which their plate carrier, coyote brown and OCP respectively, will match a woodland or arid operating environment. COAs 3–6 have differing numbers of Marines that could support an operation while equipped with camouflage plate carriers that match the environment and the MCCUU pattern they would wear in that environment. As such, each COA has a distinct level, or size, of operation supportable.

USMC doctrine identifies three levels that comprise the range of military operations (ROMO) (U.S. Marine Corps, 2017). The first level is military engagement, security cooperation, and deterrence, which are "ongoing activities that establish, shape, maintain, and refine relations with other nations" (U.S. Marine Corps, 2017, p. 1-5). This is the smallest level of operation in terms of the size of the Marine contingent required to mobilize in support. The medium level of operation within the ROMO is crisis response and limited contingency operations. Crisis response and limited contingency operations are "episodic operations conducted to alleviate or mitigate the impact of an incident or situation involving a threat to a nation, its territories, citizens, military forces, possessions, or vital interest" (U.S. Marine Corps, 2017, p. 1-5). Lastly, the largest level of operation within the ROMO spectrum is major operations and campaigns. Major operations and campaigns are "extended-duration, large-scale operations that usually involve combat" (U.S. Marine Corps, 2017, p. 1-6).

Table 12 shows the MOP for the flexibility attribute. Higher scores correspond to higher levels of the ROMO that can be supported by Marines wearing plate carriers with camouflage coloration that matches the operating environment. Thus, higher is better.

Table 12. Flexibility measures of performance

Flexibility Measures of Performance	
Score	**ROMO Supportable by Marines Wearing PC in Intended Environment**
0.00	Marines are not equipped with matching plate carriers
0.33	Ability to support military engagement, security cooperation and deterrence
0.66	Ability to support crisis response and limited contingency operations
1.00	Ability to support major operations and campaigns

b. Uniformity

Uniformity is objective 3.2 under the second-level objective suitability. By including the uniformity attribute, this research seeks to capture an aspect that is central to all uniformed services, and is of particular importance to the Marine Corps. Uniformity is essential to professional warfighters, as it physically sets them apart from non-professional combatants such as insurgents, gangs, and guerillas. In fact, Article Four of the Third Geneva Convention of 1949 includes uniformity as a requirement for combatants to be afforded the status of Prisoner of War (POW) (International Humanitarian Law Databases, n.d.).

Marines are uniform in the sense outlined in the Geneva Convention by their uniforms. The color of specific pieces of equipment, to include plate carriers, does not affect their characterization as uniformed combatants. However, uniformity is still an essential aspect of the Marine Corps that is drilled into every Marine from the moment they take their oath. One illustration of this point is that Marines even learn the proper way to lace their boots, that is, left over right, at entry level training to ensure uniformity and consistency (U.S. Marine Corps Field Medical Training Battalion, n.d.). Another practical reason for uniformity is to ensure positive identification in combat and prevent fratricide. Under COAs 3–5, there is potential that Marines could be equipped with different colored plate carriers in a major operation or campaign if it required full mobilization of active and reserve Marine forces.

The MOP for uniformity is a binary variable assuming the highest level of the ROMO. Assuming a major operation or campaign that requires full mobilization, the MOP is either 1, if all Marines can achieve uniformity in the plate carrier worn, or 0, if all Marines cannot achieve uniformity in the plate carrier worn. Table 13 shows the MOP for uniformity. Higher is better. This attribute is arguably less important than attributes such as detectability or lethality, but it is still an aspect that decision-makers must consider when comparing the COAs presented in this research.

Table 13. Uniformity measures of performance

Uniformity Measures of Performance	
Score	**Ability to Ensure Uniformity of PC Given Full Mobilization**
0.00	Unable to ensure uniformity of Plate Carriers
1.00	Able to ensure uniformity of Plate Carriers

c. *Production*

Production is objective 3.3, which captures the effect of the number of different types of plate carriers required under each COA. The number of different types of plate carriers ranges from one, under COAs 1 and 2, to three under COAs 3, 4, and 5. Cost-estimation principles such as complexity and differentiation show that cost generally increases as the complexity or variation of a product increases (Mislick & Nussbaum, 2015). Since it is not possible to quantifiably capture this attribute in the cost estimate to follow, it is included as an attribute in the effectiveness hierarchy.

The MOP for production is on a 0 to 1 scale, with 1 being the best and 0 being the worst. In terms of production, one type of plate carrier is best, and 3 different types of plate carriers is worst. Table 14 shows the MOP for production as it relates to the number of different types of plate carriers required to be produced for each COA.

Table 14. Production measures of performance

Production Measures of Performance	
Score	**Number of Different Types of PCs Produced**
0.00	3 Types
0.50	2 Types
1.00	1 Type

d. Logistics

Logistics is the last attribute under objective 3, suitability. In the context of this research, logistics refers to storage and supply. Like all ICE, plate carriers must be stored and supplied to Marines after they are produced. Principles of supply chain theory, such as inventory management, show that, in general, cost increases as variation of inventory increases (Gurtu, 2021). Similar to the production MOP, each COA requires a certain number of plate carrier variants to be stored and supplied. Generally, the lower the variation in inventory, the lower the cost. Thus, COAs that only require one type of plate carrier, such as the status quo, will have lower inventory management costs. Conversely, COAs that require two or three different types of plate carriers will have increasing inventory management costs.

This is separate, albeit similar, to the production attribute, and must be accounted for in addition to production to better capture the effects of the various COAs on overall effectiveness. Similar to production, the logistics attribute has cost implications. The inability to accurately capture and quantify the impact of additional inventory management costs, in terms of storage and supply, precludes this attribute from the cost estimate. Therefore, it is accounted for in the MOE to ensure it is not overlooked. Table

15 shows the MOP for logistics as it relates to the number of types of plate carriers stored and supplied in each COA. Higher is better, as it corresponds to less variation in inventory and lower inventory management costs.

Table 15. Logistics measures of performance

Logistics Measures of Performance	
Score	**Number of Different Types of PCs Stored and Supplied**
0.00	3 Types
0.50	2 Types
1.00	1 Type

5. Unweighted MOE Scores

Figure 26 depicts the objective hierarchy. Each lowest-level attribute has a quantified MOP normalized on a 0 to 1 scale. For some attributes, such as detectability and MOA at detection (round impact radius), the best score is 0 and the worst score is 1. After normalization, the MOP for these attributes is the inverse of the raw score. For all others, 1 is best and 0 is worst.

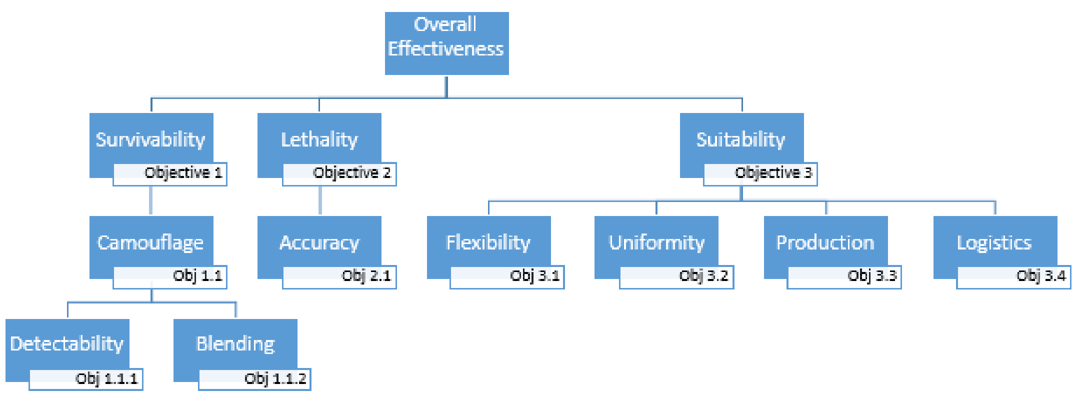

Figure 26. Objective hierarchy for camouflage plate carrier COAs

If all attributes are deemed equally important, none are weighted more than others, and the MOE score is simply the sum of the normalized lowest level attribute MOPs. Table 16 shows the unweighted MOE score calculations for each COA.

Table 16. Unweighted MOE scores

COA 1: Status Quo						
Level 1 Objective	**Level 2 Objective**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
Survivability	Camouflage	Detectability	0.00	0.57	0.43	1.00
		Blending	1.00	0.59	0.59	0.00
Lethality	Accuracy	MOA @ Detection (Round Impact Radius)	0.00	0.90	0.10	1.00
Suitability	Flexibility	ROMO Supportable	1.00	0.00	0.00	0.00
	Uniformity	Ability for 100% Uniformity	1.00	1.00	1.00	0.00
	Production	Production Variation	1.00	1.00	1.00	0.00
	Logistics	Storage & Supply	1.00	1.00	1.00	0.00
				Unweighted MOE Score:	**4.12**	
COA 2: OCP						
Level 1 Objective	**Level 2 Objective**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
Survivability	Camouflage	Detectability	0.00	0.58	0.42	1.00
		Blending	1.00	0.58	0.58	0.00
Lethality	Accuracy	MOA @ Detection (Round Impact Radius)	0.00	0.91	0.09	1.00
Suitability	Flexibility	ROMO Supportable	1.00	0.00	0.00	0.00
	Uniformity	Ability for 100% Uniformity	1.00	1.00	1.00	0.00
	Acquisition	Production Variation	1.00	1.00	1.00	0.00
	Logistics	Storage & Supply	1.00	1.00	1.00	0.00
				Unweighted MOE Score:	**4.09**	
COA 3: Aligned AO						
Level 1 Objective	**Level 2 Objective**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
Survivability	Camouflage	Detectability	0.00	0.43	0.57	1.00
		Blending	1.00	0.66	0.66	0.00
Lethality	Accuracy	MOA @ Detection (Round Impact Radius)	0.00	0.77	0.23	1.00
Suitability	Flexibility	ROMO Supportable	1.00	0.66	0.66	0.00
	Uniformity	Ability for 100% Uniformity	1.00	0.00	0.00	0.00
	Acquisition	Production Variation	1.00	0.00	0.00	0.00
	Logistics	Storage & Supply	1.00	0.00	0.00	0.00
				Unweighted MOE Score:	**2.11**	
COA 4: DEB						
Level 1 Objective	**Level 2 Objective**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
Survivability	Camouflage	Detectability	0.00	0.43	0.57	1.00
		Blending	1.00	0.66	0.66	0.00
Lethality	Accuracy	MOA @ Detection (Round Impact Radius)	0.00	0.77	0.23	1.00
Suitability	Flexibility	ROMO Supportable	1.00	0.33	0.33	0.00
	Uniformity	Ability for 100% Uniformity	1.00	0.00	0.00	0.00
	Acquisition	Production Variation	1.00	0.00	0.00	0.00
	Logistics	Storage & Supply	1.00	0.00	0.00	0.00
				Unweighted MOE Score:	**1.78**	
COA 5: Prioritize Active Duty						
Level 1 Objective	**Level 2 Objective**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
Survivability	Camouflage	Detectability	0.00	0.43	0.57	1.00
		Blending	1.00	0.66	0.66	0.00
Lethality	Accuracy	MOA @ Detection (Round Impact Radius)	0.00	0.77	0.23	1.00
Suitability	Flexibility	ROMO Supportable	1.00	1.00	1.00	0.00
	Uniformity	Ability for 100% Uniformity	1.00	0.00	0.00	0.00
	Acquisition	Production Variation	1.00	0.00	0.00	0.00
	Logistics	Storage & Supply	1.00	0.00	0.00	0.00
				Unweighted MOE Score:	**2.45**	
COA 6: Two Per Marine						
Level 1 Objective	**Level 2 Objective**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
Survivability	Camouflage	Detectability	0.00	0.43	0.57	1.00
		Blending	1.00	0.66	0.66	0.00
Lethality	Accuracy	MOA @ Detection (Round Impact Radius)	0.00	0.77	0.23	1.00
Suitability	Flexibility	ROMO Supportable	1.00	1.00	1.00	0.00
	Uniformity	Ability for 100% Uniformity	1.00	1.00	1.00	0.00
	Acquisition	Production Variation	1.00	0.50	0.50	0.00
	Logistics	Storage & Supply	1.00	0.50	0.50	0.00
				Unweighted MOE Score:	**4.45**	

The unweighted MOE scores in order from best to worst are: COA 6, COA 1, COA 2, COA 5, COA 3, COA 4. Figure 27 is a graphical representation of the unweighted MOE scores. It is important to note that COA 1, the status quo, has a higher MOE than all COAs other than COA 6, two matching camouflage plate carriers per Marine, when all attributes are considered equal.

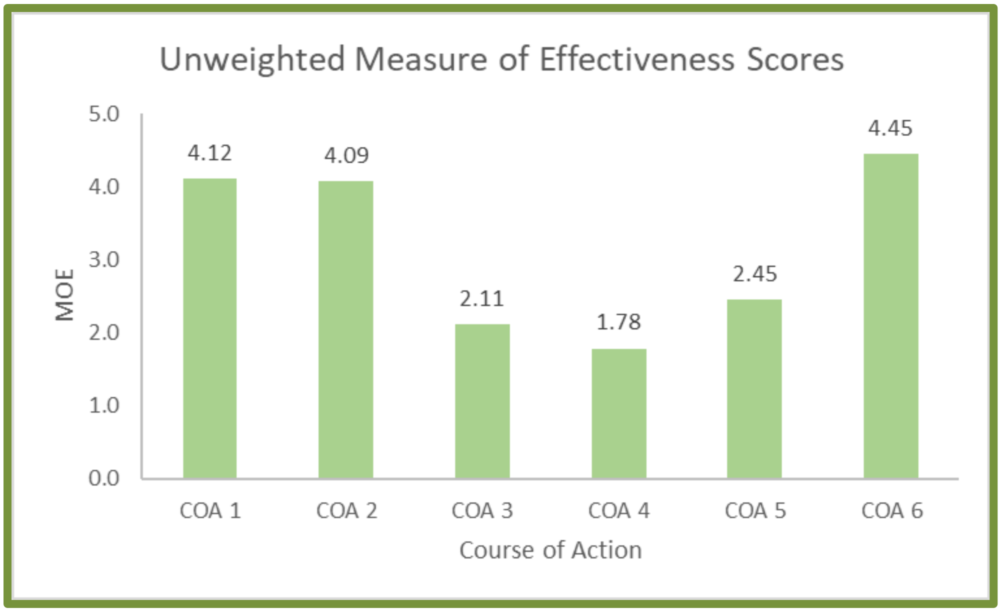

Figure 27. Unweighted MOE scores

6. Importance Weights

It would be an improper oversimplification to assign equal importance to all attributes. Although all attributes in the objective hierarchy affect the MOE of each COA, not all attributes are equally important. Each objective receives a weighting that corresponds to its importance within the scope of overall effectiveness as determined by the plate carrier and fielding strategy outlined in each COA. Each objective is weighted in comparison to the other objectives in the same level of the hierarchy. The sum of the weights of each objective's sub-objectives must equal 1. The three top-level objectives are survivability, lethality, and suitability. Due to the nature and purpose of plate carriers, and subjective assessment, the order of importance of the top-level objectives from most important to least important is survivability, lethality, suitability. Table 17 shows the top-level objective importance weights.

Table 17. Top-level objective importance weights

Importance Weights			
Level 1	**Survivability**	**Lethality**	**Suitability**
Weights	0.5	0.3	0.2

For singular sub-objectives, the importance weight is 1. The second-level of the objective hierarchy has two such sub-objectives. The importance weights for the attributes under the suitability objective in order of most important to least important are flexibility, logistics, uniformity, and production. The attributes under the camouflage sub-objective are detectability and blending. Since detection precedes recognition in human visual search, detectability is weighted heavier than blending (T. Troscianko et al., 2009). Table 18 shows the importance weights for each objective and sub-objective in the hierarchy.

Table 18. Importance weights

Importance Weights							
Level 1	**Survivability**		**Lethality**	**Suitability**			
Weights	0.5		0.3	0.2			
Level 2	**Camouflage**		**Accuracy**	**Flexibility**	**Uniformity**	**Production**	**Logistics**
Weights	1.0		1.0	0.4	0.2	0.1	0.3
Level 3	**Detectability**	**Blending**					
Weights	0.6	0.4					

7. Weighted MOE Scores

When calculating weighted scores, the MOP value is multiplied by the attribute importance weight. The sum of the weighted scores at each lower level is multiplied by the weight of the superior attribute. In this manner, the weighted MOE scores are a factor of the underlying MOP values and the sub-objective and objective weights. Table 19 shows the MOE score calculations for each COA.

Table 19. Weighted MOE scores

COA 1: Status Quo													
MOE Score	**Level 1 Scores**	**Weight**	**Objective**	**Level 2 Scores**	**Weight**	**Objective**	**Level 3 Scores**	**Weight**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
0.3966	0.25	0.5	Survivability	0.49	1.0	Camouflage	0.49	0.6	Detectability	0.00	0.57	0.43	1.00
								0.4	Blending	1.00	0.59	0.59	0.00
	0.03	0.3	Lethality	0.10	1.0	Accuracy	0.10	1.0	MOA @ Detection (RIR)	0.00	0.90	0.10	1.00
	0.12	0.2	Suitability	0.60	0.4	Flexibility	0.60	0.4	ROMO Supportable	1.00	0.00	0.00	0.00
					0.2	Uniformity		0.2	Ability for 100% Uniformity	1.00	1.00	1.00	0.00
					0.1	Production		0.1	Production Variation	1.00	1.00	1.00	0.00
					0.3	Logistics		0.3	Storage & Supply	1.00	1.00	1.00	0.00
COA 2: OCP													
MOE Score	**Level 1 Scores**	**Weight**	**Objective**	**Level 2 Scores**	**Weight**	**Objective**	**Level 3 Scores**	**Weight**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
0.3875	0.24	0.5	Survivability	0.48	1.0	Camouflage	0.48	0.6	Detectability	0.00	0.58	0.42	1.00
								0.4	Blending	1.00	0.58	0.58	0.00
	0.03	0.3	Lethality	0.09	1.0	Accuracy	0.09	1.0	MOA @ Detection (RIR)	0.00	0.91	0.09	1.00
	0.12	0.2	Suitability	0.60	0.4	Flexibility	0.60	0.4	ROMO Supportable	1.00	0.00	0.00	0.00
					0.2	Uniformity		0.2	Ability for 100% Uniformity	1.00	1.00	1.00	0.00
					0.1	Acquisition		0.1	Production Variation	1.00	1.00	1.00	0.00
					0.3	Logistics		0.3	Storage & Supply	1.00	1.00	1.00	0.00
COA 3: Aligned AO													
MOE Score	**Level 1 Scores**	**Weight**	**Objective**	**Level 2 Scores**	**Weight**	**Objective**	**Level 3 Scores**	**Weight**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
0.4232	0.30	0.5	Survivability	0.61	1.0	Camouflage	0.61	0.6	Detectability	0.00	0.43	0.57	1.00
								0.4	Blending	1.00	0.66	0.66	0.00
	0.07	0.3	Lethality	0.23	1.0	Accuracy	0.23	1.0	MOA @ Detection (RIR)	0.00	0.77	0.23	1.00
	0.05	0.2	Suitability	0.26	0.4	Flexibility	0.26	0.4	ROMO Supportable	1.00	0.66	0.66	0.00
					0.2	Uniformity		0.2	Ability for 100% Uniformity	1.00	0.00	0.00	0.00
					0.1	Acquisition		0.1	Production Variation	1.00	0.00	0.00	0.00
					0.3	Logistics		0.3	Storage & Supply	1.00	0.00	0.00	0.00

Table 19 (cont.)

COA 4: DEB													
MOE Score	**Level 1 Scores**	**Weight**	**Objective**	**Level 2 Scores**	**Weight**	**Objective**	**Level 3 Scores**	**Weight**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
0.3968	0.30	0.5	Survivability	0.61	1.0	Camouflage	0.61	0.6	Detectability	0.00	0.43	0.57	1.00
								0.4	Blending	1.00	0.66	0.66	0.00
	0.07	0.3	Lethality	0.23	1.0	Accuracy	0.23	1.0	MOA @ Detection (RIR)	0.00	0.77	0.23	1.00
	0.03	0.2	Suitability	0.13	0.4	Flexibility	0.13	0.4	ROMO Supportable	1.00	0.33	0.33	0.00
					0.2	Uniformity		0.2	Ability for 100% Uniformity	1.00	0.00	0.00	0.00
					0.1	Acquisition		0.1	Production Variation	1.00	0.00	0.00	0.00
					0.3	Logistics		0.3	Storage & Supply	1.00	0.00	0.00	0.00

COA 5: Prioritize Active Duty													
MOE Score	**Level 1 Scores**	**Weight**	**Objective**	**Level 2 Scores**	**Weight**	**Objective**	**Level 3 Scores**	**Weight**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
0.4504	0.30	0.5	Survivability	0.61	1.0	Camouflage	0.61	0.6	Detectability	0.00	0.43	0.57	1.00
								0.4	Blending	1.00	0.66	0.66	0.00
	0.07	0.3	Lethality	0.23	1.0	Accuracy	0.23	1.0	MOA @ Detection (RIR)	0.00	0.77	0.23	1.00
	0.08	0.2	Suitability	0.40	0.4	Flexibility	0.40	0.4	ROMO Supportable	1.00	1.00	1.00	0.00
					0.2	Uniformity		0.2	Ability for 100% Uniformity	1.00	0.00	0.00	0.00
					0.1	Acquisition		0.1	Production Variation	1.00	0.00	0.00	0.00
					0.3	Logistics		0.3	Storage & Supply	1.00	0.00	0.00	0.00

COA 6: Two Per Marine													
MOE Score	**Level 1 Scores**	**Weight**	**Objective**	**Level 2 Scores**	**Weight**	**Objective**	**Level 3 Scores**	**Weight**	**MOP**	**Best**	**Raw Score (MOP)**	**Normalized Value**	**Worst**
0.5304	0.30	0.5	Survivability	0.61	1.0	Camouflage	0.61	0.6	Detectability	0.00	0.43	0.57	1.00
								0.4	Blending	1.00	0.66	0.66	0.00
	0.07	0.3	Lethality	0.23	1.0	Accuracy	0.23	1.0	MOA @ Detection (RIR)	0.00	0.77	0.23	1.00
	0.16	0.2	Suitability	0.80	0.4	Flexibility	0.80	0.4	ROMO Supportable	1.00	1.00	1.00	0.00
					0.2	Uniformity		0.2	Ability for 100% Uniformity	1.00	1.00	1.00	0.00
					0.1	Acquisition		0.1	Production Variation	1.00	0.50	0.50	0.00
					0.3	Logistics		0.3	Storage & Supply	1.00	0.50	0.50	0.00

When the attributes and objectives are weighted according to importance, the order of COAs from most effective to least effective is: COA 6, COA 5, COA 3, COA 4, COA 1, COA 2. COA 6 has the highest MOE when both weighted and unweighted. COA 1, the status quo, is inferior with respect to effectiveness to all COAs other than COA 2 when the attributes are weighted according to importance. Figure 28 is a graphical representation of the weighted MOE scores.

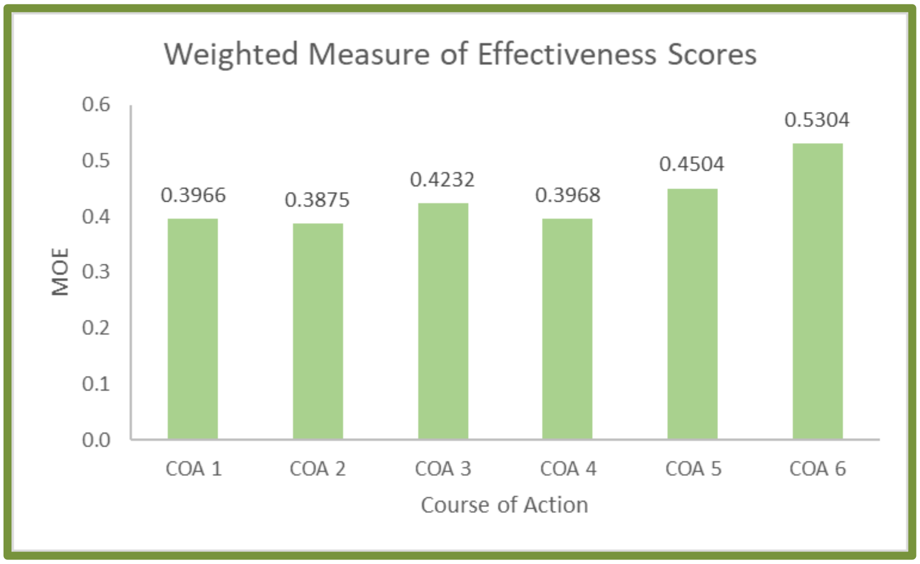

Figure 28. Weighted MOE scores

C. COST

1. Overview

This cost estimate uses historical data and the Joint Inflation Calculator (JIC) to compute the average unit cost for the Plate Carrier Generation III. Then, using current force strength and global disposition, this analysis estimates the numbers of each type of plate carrier required as outlined in the various COAs. Assuming modernization through sustainment, this estimate calculates the total thirty-year life cycle cost of each COA in CY2025$. Finally, this estimate calculates the NPV of future cash outflows to account for the time value of money; since a dollar today is worth more than a dollar tomorrow (Mislick & Nussbaum, 2015).

a. Average Unit Cost

In 2018, the Marine Corps awarded a $62,612,464 (CY2018$) firm-fixed-price, indefinite-delivery/indefinite-quantity contract to Vertical Protective Apparel, LLC to produce and deliver the Plate Carrier Generation III (Kelly, 2018). The contract included a maximum quantity of 225,886 plate carriers to be completed by September 2023 (Kelly, 2018). Using the JIC USMC procurement index, with an approximate inflation factor of 1.3, this equates to $78,204,874 (CY2025$) (Cost Assessment and Data Enterprise [CADE], n.d.). The AUC is then determined by dividing the total cost, in CY2025$, by the total number of plate carriers. The AUC for the Plate Carrier Generation III is $346.21 (CY2025$).

b. Force Strength

To determine the number and type of plate carriers required for each COA, and thus the estimated cost for each COA, this analysis uses the most recent Marine Corps force strength numbers and global disposition available from the Defense Manpower Data Center (DMDC) and U.S. Naval Institute (USNI). An abbreviated requirement summary for each COA is:

- COA 1: Status Quo. Inventory includes coyote brown plate carriers for all active duty and reserve Marines.
- COA 2: OCP. Inventory includes OCP plate carriers for all active duty and reserve Marines.
- COA 3: Aligned with AO. Inventory includes woodland camouflaged plate carriers for Marines aligned to woodland/tropic environments, desert camouflaged plate carriers for Marines aligned to desert/arid environments, and coyote brown plate carriers for reservists and Marines in non-deploying billets.
- COA 4: Deployer Equipment Bundle (DEB). Inventory includes coyote brown plate carriers for all Marines while operating in CONUS, and woodland camouflage plate carriers or desert camouflage plate carriers for Marines permanently stationed overseas and deploying Marines – dependent on their AO.
- COA 5: Prioritize Active Duty. Inventory includes woodland camouflage plate carriers and desert camouflage plate carriers for all active duty Marines and coyote brown plate carriers for all reserve Marines.

- COA 6: Two per Marine. Inventory includes woodland camouflage plate carriers and desert camouflage plate carriers for all active duty and reserve Marines.

As of August 31, 2024, there are 171,402 active duty Marines (Defense Manpower Data Center [DMDC], n.d.). In the context of this research, reserve Marines refers to the Selected Marine Corps Reserve (SMCR). As of July 31, 2024, there are 32,747 SMCR Marines (DMDC, n.d.). Thus, the total Marine force, encompassing active duty and SMCR Marines, is 204,149. This research uses a 10% safety stock in calculating the number of plate carriers required. With the safety stock, the total number of plate carriers required for every Marine to have one is 224,565. This is approximately the same as the number of Plate Carrier Generation IIIs ordered by the Marine Corps in 2018 (Kelly, 2018).

Of the standing Marine Expeditionary Units (MEUs) and Unit Deployment Programs (UDPs), approximately two-thirds are aligned with woodland/tropic environments and one-third are aligned with desert/arid environments (USNI News, 2024). This analysis uses this approximation to determine the number of each variation of plate carrier required for COA 3: aligned AO. Using this approximation, there are 114,268 Marines aligned to woodland/tropic environments, and 57,134 aligned to desert/arid environments. To approximate the number of plate carriers required for reservists and Marines in non-deploying billets, the sum of the previous two numbers is subtracted from the total number of Marines including the safety stock. This results in approximately 53,162 reservists and Marines in non-deploying billets.

To determine the number of each variation of plate carrier required for COA 4: DEB, this analysis uses the Marine Expeditionary Brigade (MEB) as a planning factor. A MEB is a "medium sized non-standing Marine Air Ground Task Force (MAGTF) that is task organized to respond to a full range of crises" and consists of up to approximately 20,000 Marines (U.S. Marine Corps Training and Education Command [TECOM], n.d.). COA 4 calls for equipping deploying Marines and Marines permanently stationed overseas with either woodland or desert plate carriers, depending on their AO. As of June 2024, there are approximately 24,000 Marines permanently stationed overseas (DMDC, n.d.). Of those 24,000, approximately 20,000 are stationed in woodland/tropic environments, and 4,000 are stationed in desert/arid environments (DMDC, n.d.). Thus, to account for a MEB and Marines permanently stationed overseas, COA 4 requires approximately 40,000 woodland camouflage plate carriers and 24,000 desert camouflage plate carriers in the inventory in addition to 224,565 coyote brown plate carriers. Table 20 shows the number of each variation of plate carrier required for each COA.

Table 20. Number and type of plate carrier required for each COA

Number and Type of Plate Carrier Required for Each COA					
	# Coyote PC Required	# OCP PC Required	# Woodland PC Required	# Desert PC Required	Total # PC Required
COA 1: Status Quo	224,564	0	0	0	224,564
COA 2: OCP	0	224,564	0	0	224,564
COA 3: Aligned AO	53,162	0	114,268	57,134	224,564
COA 4: DEB	224,564	0	40,000	24,000	288,564
COA 5: 2 Per Active Duty	53,162	0	171,402	171,402	395,966
COA 6: 2 Per Marine	0	0	224,564	224,564	449,128

c. Yearly Turnover

The U.S. Army estimates inventory turnover for durable OCIE, such as plate carriers, at 10% per year (Mortlock, 2020). This research carries that assumption forward for Marine Corps ICE – specifically the Plate Carrier Generation III. At a turnover rate of 10% per year, the number of plate carriers required per year is simply the total number of plate carriers required times 10%. The yearly cash outflow for plate carriers would then be the AUC multiplied by the yearly turnover as determined by each COA. Table 21 shows the relationship between yearly turnover and yearly cash outflow in CY2025$.

Table 21. Yearly turnover and cash outflow

Yearly Turnover and Cash Outflow			
	Total # PC Required	Yearly Turnover	Yearly Cash Outflow (CY25$)
COA 1: Status Quo	224,564	22,456	$ 7,774,714
COA 2: OCP	224,564	22,456	$ 7,774,714
COA 3: Aligned AO	224,564	22,456	$ 7,774,714
COA 4: DEB	288,564	28,856	$ 9,990,483
COA 5: 2 Per Active Duty	395,966	39,597	$ 13,708,890
COA 6: 2 Per Marine	449,128	44,913	$ 15,549,429

d. NPV Discount Rate

This analysis uses NPV to account for the time value of money and discount future costs, since, "Benefits and costs are worth more if they are experienced sooner, all else equal, and discounting is the way to reflect this" (OMB, 2023, p. 10). The Circular

A-94 recommends a 3.1% discount rate unless otherwise specified (OMB, 2023). This analysis uses the 3.1% discount rate to calculate the NPV of future costs.

2. Cost Estimates

This cost estimate uses the AUC in CY2025$ and the yearly turnover of Plate Carrier Generation IIIs to calculate the yearly cash outflows for the 30-year life cycle beginning in 2025. Table 22 reflects the yearly cash outflows and the total life cycle cost for each COA in CY2025$.

Table 22. Total life cycle cost (CY2025$)

Total Life Cycle Cost (CY25$)		
	Yearly Cash Outflow	Total Life Cycle Cost
COA 1: Status Quo	$ 7,774,714	$ 241,016,147
COA 2: OCP	$ 7,774,714	$ 241,016,147
COA 3: Aligned AO	$ 7,774,714	$ 241,016,147
COA 4: DEB	$ 9,990,483	$ 309,704,986
COA 5: 2 Per Active Duty	$ 13,708,890	$ 424,975,589
COA 6: 2 Per Marine	$ 15,549,429	$ 482,032,295

This estimate uses a discount rate of 3.1% to calculate the NPV of the total life cycle cost. Table 23 shows the NPV of the total life cycle cost with 2025 as year one. The results are shown as positive numbers with the understanding that they represent costs.

Table 23. NPV of total life cycle cost

NPV of Total Life Cycle Cost		
	Total Life Cycle Cost (CY25$)	NPV of Total Cost
COA 1: Status Quo	$ 241,016,147	$153,454,374
COA 2: OCP	$ 241,016,147	$153,454,374
COA 3: Aligned AO	$ 241,016,147	$153,454,374
COA 4: DEB	$ 309,704,986	$197,188,384
COA 5: 2 Per Active Duty	$ 424,975,589	$270,580,887
COA 6: 2 Per Marine	$ 482,032,295	$306,908,747

D. EFFECTIVENESS COST RATIOS

Figure 29 shows the MOE scores versus total life cycle cost for each COA in CY2025$M.

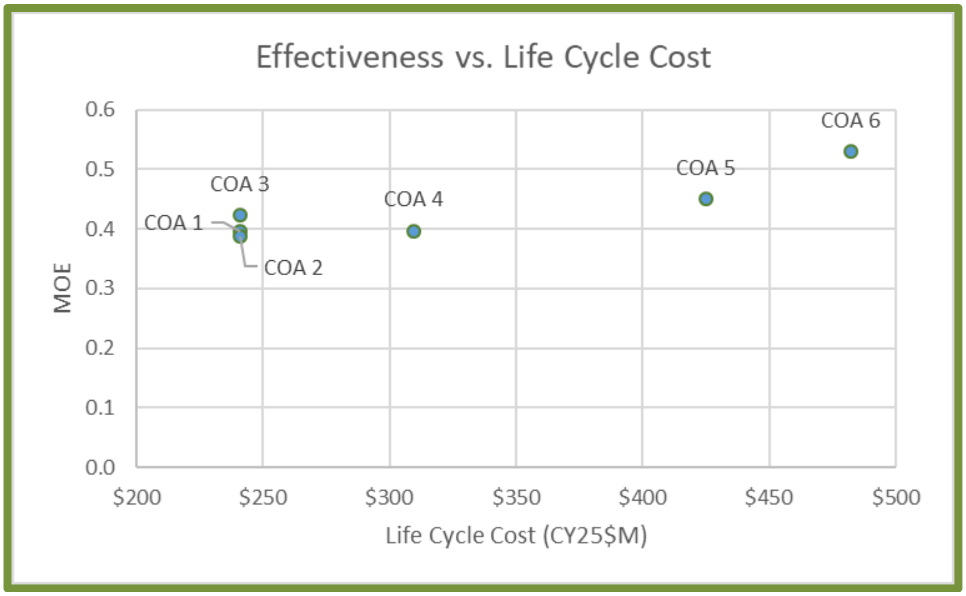

Figure 29. MOE vs. life cycle cost (CY2025$M)

Figure 30 shows the MOE scores versus the NPV of the life cycle cost for each COA.

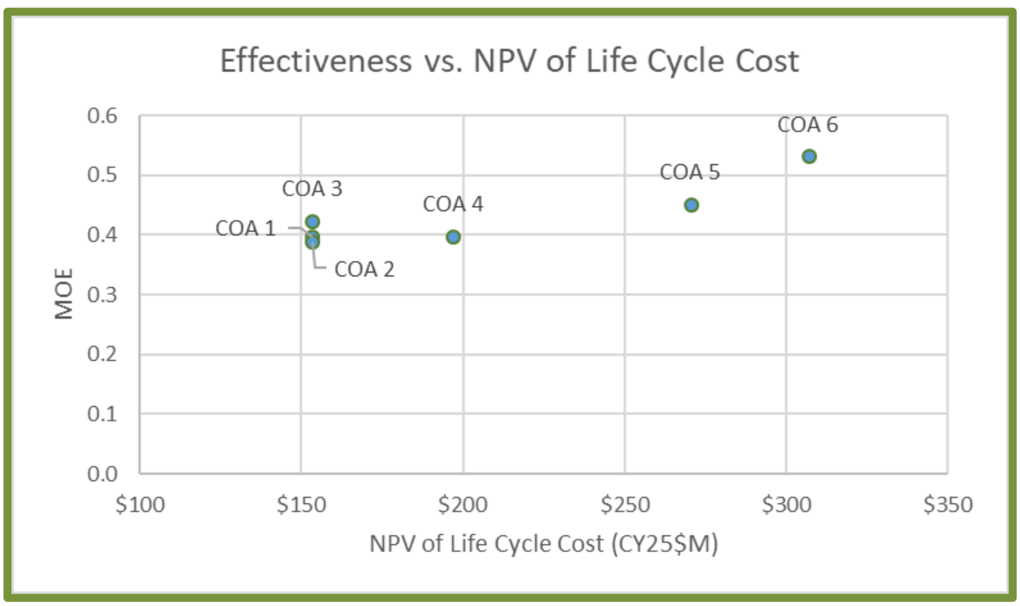

Figure 30. MOE vs. NPV of life cycle cost

Since the yearly cash outflows for each COA start in 2025 and end in 2055, the differences of the cost in CY2025$ and the NPV of the total cost for each COA are proportional. Thus, the data points in each graph are identical in their relationships to one another. As both figures show, COA 1 dominates COA 2, and COA 3 dominates both

COA 1 and COA 2. Additionally, COA 3 dominates COA 4. A dominant strategy is one that is more effective at the same or lesser cost (Boardman et al., 2006). Out of the six COAs, there is no superior solution. A superior solution is one that is most effective and least costly (Boardman et al., 2006).

The increase in effectiveness from COA 3 to COA 5 is due to COA 5's superior flexibility score. Under COA 5, the full ROMO is achievable while wearing plate carriers that are colored to match the operating environment. Under COA 3, only crisis response and limited contingency operations are possible. The substantially higher cost of COA 5 is due to the additional 171,400 plate carriers required to implement it.

The increase in effectiveness from COA 5 to COA 6 is a result of COA 6's higher uniformity, production variation, and storage & supply scores. All Marines can be uniform under COA 6, and it only requires two variations of plate carriers vice the three required by COA 5. The increase in price from COA 5 to COA 6 is a result of the additional 53,200 plate carriers COA 6 requires.

The ECR for each COA is computed by dividing the effectiveness by the cost. Since the effectiveness for each COA is a decimal between 0 and 1, and the cost is in millions of dollars, the ECR is scaled for readability. The ECRs shown in Figure 31 are effectiveness per $100 million (CY2025$).

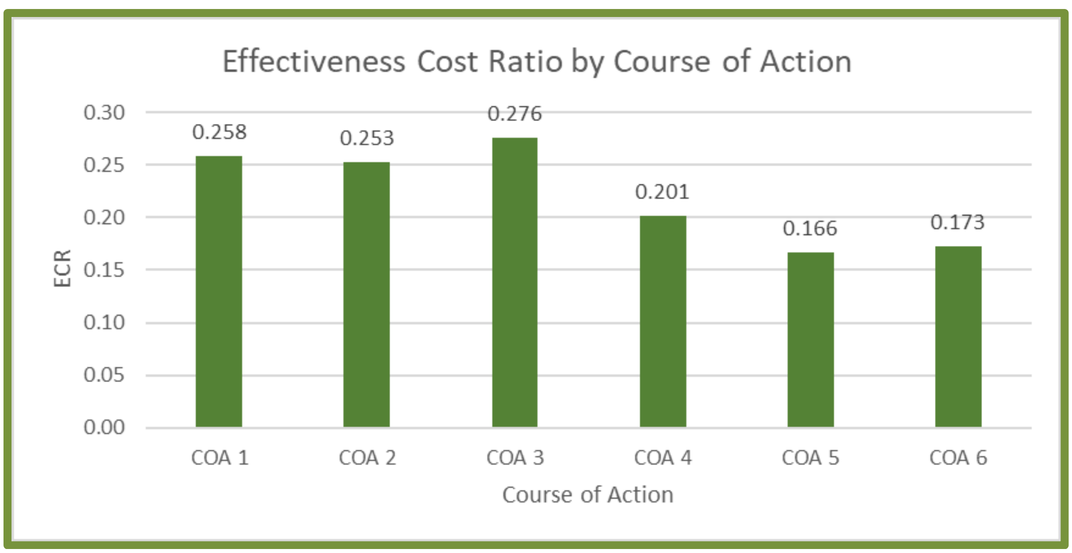

Figure 31. ECR by COA

When analyzed strictly through the ECR lens, COA 3 is best. COA 6, which has both the highest MOE and the highest cost, ranks fifth, and is followed by COA 5 which has the next highest MOE and cost.

E. SENSITIVITY ANALYSIS

Sensitivity analysis is vital to determine "how sensitive outcomes are to changes in major assumptions" (OMB, 2023, p. 13). These changes and assumptions include important inputs to effectiveness and cost, the discount rate, and importance weights (OMB, 2023). This research includes sensitivity analysis pertaining to the importance weights on the key variables in the objective hierarchy and their impact on the resulting MOEs and ECRs; as well as cost inputs and assumptions.

1. Measure of Effectiveness

Based on review of prior studies, experience, and judgement, the importance weights assigned to the top-level objectives of survivability, lethality, and suitability are 0.5, 0.3, and 0.2, respectively. However, if future decision-makers value these objectives differently, it will impact the MOE score of each COA. Due to the very nature of plate carriers, this research assumes that any changes in importance weights would increasingly favor survivability over lethality and suitability. To analyze the effect of increased emphasis on survivability, this research provides four MOE scores per COA, in addition to the base case previously outlined. Table 24 shows the importance weights assigned to the top-level objectives in the sensitivity analysis series.

Table 24. Sensitivity analysis importance weights

Sensitivity Analysis Importance Weights			
Series	**Survivability**	**Lethality**	**Suitability**
Basis	0.5	0.3	0.2
SA 1	0.6	0.3	0.1
SA 2	0.7	0.2	0.1
SA 3	0.7	0.3	0
SA 4	1	0	0

Figure 32 shows the resulting MOE scores for each COA with the changing importance weights.

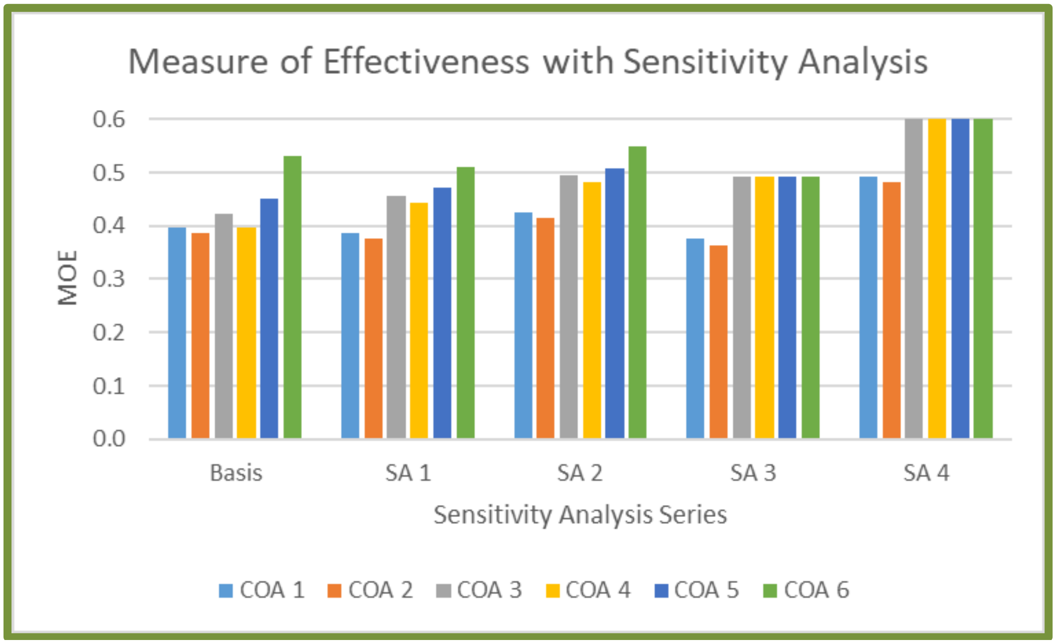

Figure 32. MOE per COA with increased emphasis on survivability

SA 1 and SA 2 result in the same general relationship between MOEs for each COA as the basis. That is, the order from most effective to least effective is COA 6, COA 5, COA 3, COA 4, COA 1, COA 2. In SA 3, the importance of the suitability objective is zero, thus it gets factored out of the MOE score. Once suitability is factored out, the MOEs of COAs 3–6 are the same. They continue to remain the same once lethality is factored out, as illustrated by SA 4. This makes sense, as COAs 3–6 all include woodland and desert camouflaged plate carriers, which provide more survivability than coyote brown (COA 1) or OCP (COA 2) as defined earlier in this research. The only differentiation between COAs 3–6 is the number and method of distribution for the camouflaged plate carriers, which is measured through the suitability variable and cost estimate. Figure 33 shows the variability of the MOE scores as a result of the five different weighting methods shown in Table 24.

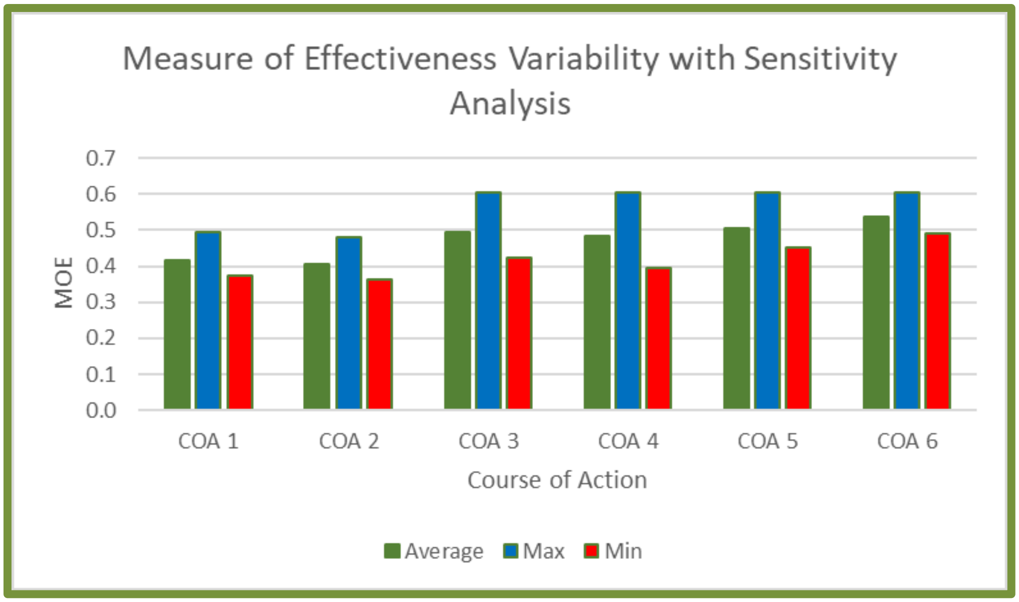

Figure 33. MOE variability with sensitivity analysis

The green bars depict the average MOE of the five different weighting schemes. The order of most effective to least effective is the same as the base case calculated previously. The blue bars depict the max value, which is the same for COAs 3–6 and is a result of the series in which survivability is assigned an importance of 1. The red bars depict the minimum effectiveness values for each COA when subjected to sensitivity analysis. The minimums follow the same order of most effective to least effective as the averages.

2. Cost

There are two major assumptions related to cost that will be subject to sensitivity analysis. The first assumption is the 10% turnover per year of plate carriers. The 10% turnover per year assumption comes from the Army's Camouflage Uniform Improvement Project (Mortlock, 2020). However, anyone familiar with the Marine Corps knows that Marines take exceptionally good care of their equipment, and the realized lifespan of Marine equipment often far exceeds the expected lifespan. For example, some units across the Marine Corps still carry the M16A4 rifle, which was originally fielded in 1997 and is a variation of the M16 rifle that entered DoD service in 1962 (Balestrieri, 2024). Furthermore, if each Marine is issued two plate carriers, they can switch back and forth depending on the operating environment, and each individual plate carrier may receive less wear and tear. Therefore, it is necessary to subject the 10% turnover per year assumption to sensitivity analysis to determine the impact on cost. Table 25 shows the NPV of total life cycle cost with 10% turnover per year and 5% turnover per year and the marginal difference.

Table 25. NPV of total life cycle cost subject to sensitivity analysis

NPV of Total Life Cycle Cost Subject to Sensitivity Analysis (CY25$)			
	NPV Total Cost (10%)	NPV Total Cost (5%)	Difference
COA 1: Status Quo	$ 153,454,374	$ 76,727,187	$ (76,727,187)
COA 2: OCP	$ 153,454,374	$ 76,727,187	$ (76,727,187)
COA 3: Aligned AO	$ 153,454,374	$ 76,727,187	$ (76,727,187)
COA 4: DEB	$ 197,188,384	$ 98,594,192	$ (98,594,192)
COA 5: 2 Per Active Duty	$ 270,580,887	$ 135,290,443	$ (135,290,443)
COA 6: 2 Per Marine	$ 306,908,747	$ 153,454,374	$ (153,454,374)

The costs for each COA halve when the turnover halves because the costs still occur on the same timeline, so the NPV does not affect the total costs relative to each other. This is of vital importance, because the cost of COA 6, the most effective COA, with a turnover rate of 5% per year is the same as COA 1, the status quo, under the 10% per year assumption. Thus, if Marines can prolong the useful life of their individual plate carriers to the extent that turnover halves, which may be easier with two plate carriers per Marine, they gain the benefits of increased effectiveness at no increase to marginal cost.

The second major assumption related to cost is the discount rate used to calculate NPV. In Appendix D, the Circular A-94 recommends a 3.1% discount rate (OMB, 2023). However, it allows for a 2% real discount rate if the costs reflect certainty-equivalent valuations (OMB, 2023). According to the Circular A-94, "A certainty-equivalent valuation can be thought of as the expected value of a benefit or cost less a premium... that reflects risk aversion" (OMB, 2023, p. 14). Although the 3.1% discount rate may be more appropriate, it is important to consider the NPV of the total life cycle cost of each COA at a 2% discount rate as well. Table 26 shows the NPV of each COA in CY2025$ with discount rates of 3.1% and 2%, as well as the marginal difference.

Table 26. Discount rate sensitivity analysis and its effect on the NPV of total cost

NPV of Total Life Cycle Cost (CY25$) with Different Discount Rates			
	3.1% Discount Rate	2% Discount Rate	Difference
COA 1: Status Quo	$ 153,454,374	$ 178,334,079	$ 24,879,705
COA 2: OCP	$ 153,454,374	$ 178,334,079	$ 24,879,705
COA 3: Aligned AO	$ 153,454,374	$ 178,334,079	$ 24,879,705
COA 4: DEB	$ 197,188,384	$ 229,158,726	$ 31,970,342
COA 5: 2 Per Active Duty	$ 270,580,887	$ 314,450,426	$ 43,869,540
COA 6: 2 Per Marine	$ 306,908,747	$ 356,668,158	$ 49,759,411

Reducing the discount rate from 3.1% to 2% results in a NPV total cost increase that ranges from approximately $25 million to $50 million (CY2025$) from COA 1 to COA 6.

3. Effectiveness Cost Ratio

Changing the importance weights, and thus the MOE of the COAs, is the only aspect of sensitivity analysis that may impact the ECR of each COA in relation to others. Changing the yearly turnover rate from 10% to 5%, and changing the discount rate from 3.1% to 2%, changes the ECRs of the COAs proportionally. Therefore, the order of highest ECR to lowest ECR remains COA 3, COA 1, COA 2, COA 4, COA 6, COA 5. However, when the importance weights change to reflect the increasing importance of survivability, the ECRs of the COAs change independently. Figure 34 shows the ECRs of each COA as a result of the MOE sensitivity analysis series in terms of effectiveness per $100 million (CY2025$).

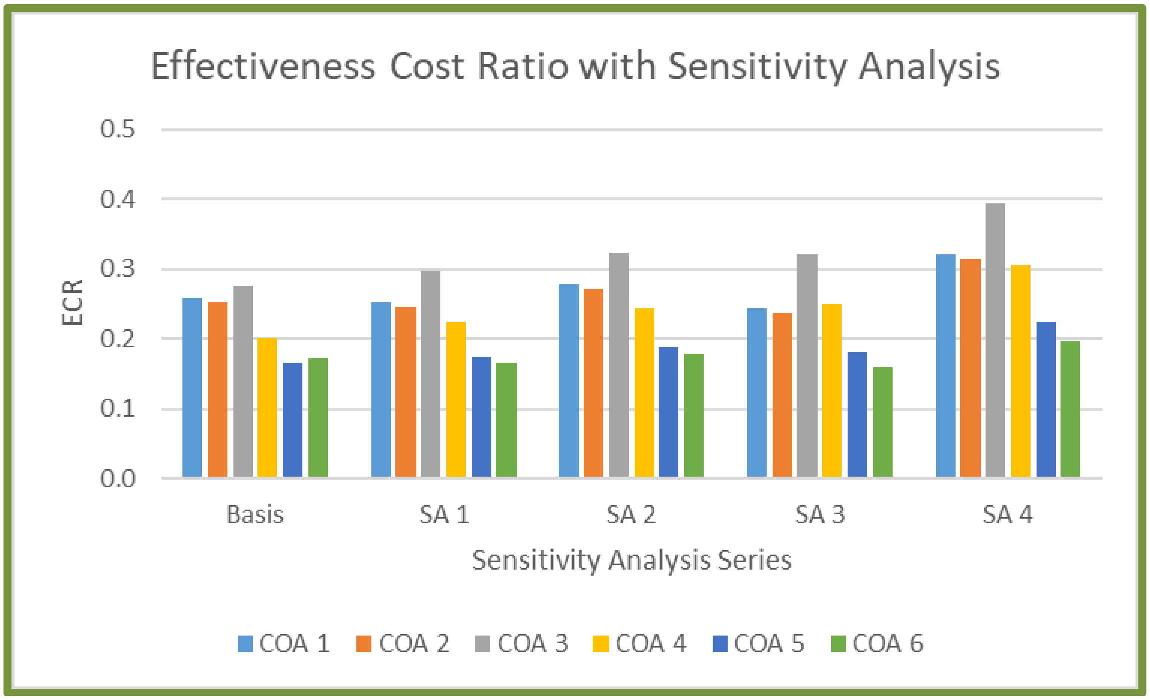

Figure 34. ECRs with MOE sensitivity analysis

There are two noteworthy changes in the ECR sensitivity analysis. The first is between COA 5 and 6. Initially, COA 6 has a higher ECR than COA 5, as depicted in the base case. However, as survivability gains importance, and the importance of lethality and suitability decrease to zero, COA 5 obtains a higher ECR than COA 6. This is shown in SA1 – SA4. The second important change concerns COA 4. Initially, COA 4 has a lower ECR than COA 1 and 2. However, in SA 3, with suitability factored out, COA 4 obtains a higher ECR than COAs 1 and 2.

This shows that the benefit of COA 6 over COA 5 is realized in the suitability measurement. Once the importance of suitability is decreased in the MOE scoring, the increased cost of COA 6 over COA 5 outweighs the gain in effectiveness, as realized in the ECR. Additionally, it shows the benefit of COA 1 and 2 over COA 4 is realized in the suitability metric. Once suitability is factored out, the increased benefit of COA 4 outweighs the increased cost from COA 1 and 2.

F. ASSUMPTIONS AND LIMITATIONS

Key assumptions in this research include:

- DCU/BDU worn without plate carriers in the detection and blending tests represents those same uniforms worn with matching camouflage plate carriers (Mazz, 2015).
- The marginal difference in blending and detection scores between DCU/BDU worn with OCP plate carriers and with "matching" plate carriers will be the same as MARPATs worn with the status quo of coyote brown plate carriers and theoretical matching camouflage plate carriers.
- Photo-simulation detection testing results have a local linear relationship at a distance of 450 meters which allows for the MOA ratio approximation.
- The order of importance of the top-level objectives is survivability (0.5), lethality (0.3), suitability (0.2).
- The turnover rate of plate carriers is 10% per year (Mortlock, 2020).
- Approximately 2/3 of active duty Marines are aligned to woodland/tropic AOs and 1/3 are aligned to desert/arid AOs (USNI News, 2024).
- The Deployer Equipment Bundle (DEB) should include enough plate carriers to outfit a MEB and the Marines permanently stationed overseas.
- The appropriate inflation rate for CY2018$ to CY2025$ conversion is reflected by the Joint Inflation Calculator (JIC) USMC Procurement Index (CADE, n.d.).
- The appropriate discount rate for plate carrier NPV calculations is 3.1% (OMB, 2023).

This research is limited by the Army's Camouflage Uniform Improvement Project methodology and findings outlined in the Mazz technical report. Although the Army testers conducted day and night detection and blending photo-simulation and operational testing, the technical report only included findings relevant to the Army's situation at the time. Therefore, only the day detection photo-simulation and day and night blending photo-simulation results could be used for the survivability metric in this research. Additionally, plate carriers were the only OCIE/ICE included in the Army testing, so this research could not draw any conclusions on the impact of camouflaging additional ICE components such as magazine pouches, radio pouches, sub-belts, main packs, etc.

This research is also limited by accessible cost data. The only data available for inclusion in the cost estimate is the AUC and number of plate carriers required to carry out each COA. The cost implications of producing, storing, and supplying multiple variations of plate carriers is not readily accessible or appropriate. Therefore, this research included production variation and storage & supply as measures of effectiveness components rather than cost estimate inputs.

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VI. CONCLUSION

A. SUMMARY OF FINDINGS

Marines wearing camouflage plate carriers that match their uniforms will be more effective, as defined by this research, than Marines wearing coyote brown or OCP plate carriers. Figure 35 displays the weighted MOE scores. Once again, the COAs analyzed in this research are as follows:

- COA 1: Status Quo. All Marines are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 2: OCP. All Marines are issued OCP plate carriers to be worn over both woodland and desert MARPATs.
- COA 3: Aligned with Area of Operations (AO). Marines aligned to woodland/tropic environments are issued woodland MARPAT camouflage plate carriers to be worn over both woodland and desert MARPAT uniforms. Marines aligned to desert/arid environments are issued desert MARPAT camouflage plate carriers to be worn over both desert and woodland MARPAT uniforms. Reservist Marines and Marines in non-deploying billets are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 4: Deployer Equipment Bundle (DEB). All Marines are issued coyote brown plate carriers when conducting operations in the continental U.S. (CONUS). Marines permanently stationed overseas and deploying Marines are issued woodland MARPAT camouflage plate carriers or desert MARPAT camouflage plate carriers dependent on their AO.
- COA 5: Prioritize Active Duty. Active duty Marines are issued both woodland MARPAT camouflage plate carriers and desert MARPAT camouflage plate carriers to be worn as the situation dictates. Reservist Marines are issued coyote brown plate carriers to be worn over both woodland and desert MARPATs.
- COA 6: Two per Marine. All Marines are issued woodland MARPAT camouflage plate carriers and desert MARPAT camouflage plate carriers to be worn as the situation dictates.

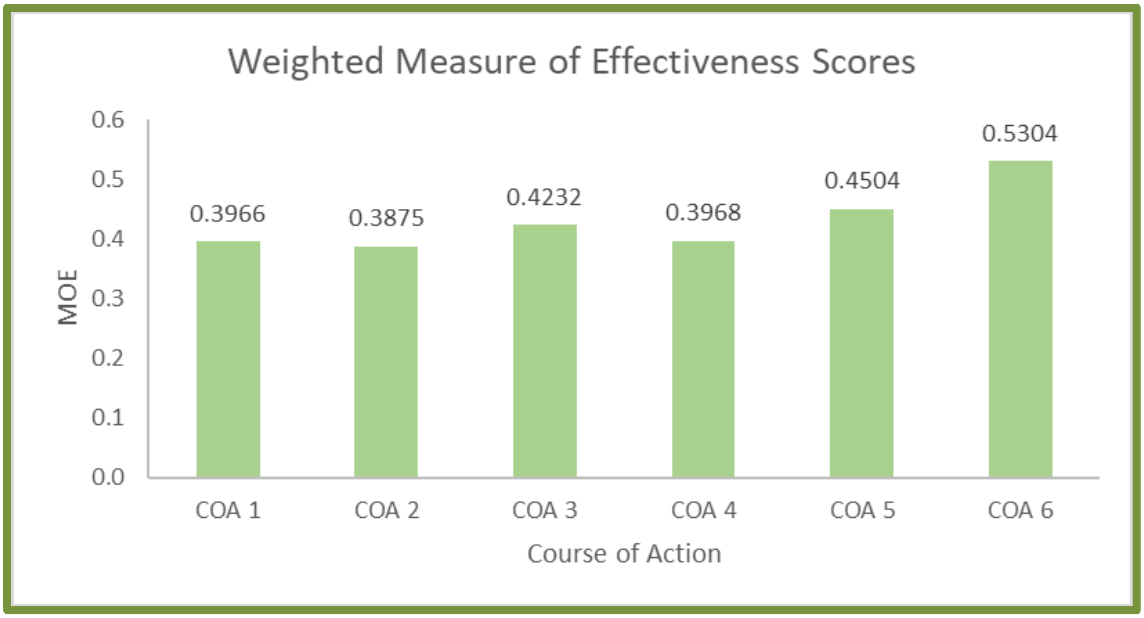

Figure 35. Weighted MOE scores

COA 6, fielding an inventory of plate carriers that includes one woodland/tropic and one desert/arid for each Marine in active duty and SMCR, is most effective both in the weighted and unweighted calculations. COA 2, fielding one OCP plate carrier per Marine, is less effective than the status quo of coyote brown plate carriers for all Marines and should be excluded from further consideration. For COAs 3–6, it then becomes a question of the monetary value of additional effectiveness. Table 27 shows the COAs in order from most effective to least effective and their marginal effectiveness, percent change, and marginal cost when compared to COA 1, the status quo.

Table 27. COA comparison, including marginal effectiveness and marginal cost, when compared to status quo

	COA Comparison					
	COA	MOE	Marginal MOE	% Change	Cost (CY25$M)	Marginal Cost
Most Effective	6	0.5304	0.1338	34%	307	153
	5	0.4504	0.0538	14%	271	117
	3	0.4232	0.0266	7%	153	0
	4	0.3968	0.0002	0%	197	44
	1	0.3966	0.0000	0%	153	0
Least Effective	2	0.3875	-0.0091	-2%	153	0

COA 6 is 34% more effective than the status quo at a marginal cost of $153 million and COA 5 is 14% more effective at a marginal cost of $117 million (CY2025$).

COA 3 is 7% more effective at zero additional cost from that already incurred by the status quo. Lastly, the marginal effectiveness of COA 4 over COA 1 is negligible at a marginal cost of $44 million (CY2025$).

One key finding of the sensitivity analysis is the implication of a reduced plate carrier yearly turnover rate. The 10% turnover per year assumption comes from the Army's Camouflage Uniform Improvement Project (Mortlock, 2020). Marines train how they fight and consistently wear plate carriers when conducting training and operations in rugged terrain. Although plate carriers are ruggedly designed, they tear and wear out with prolonged use. Thus, the 10% turnover rate per year makes sense. This research carried forward the 10% turnover rate per year in order to provide a reasonable and credible cost estimate. However, it stands to reason that issuing each Marine two plate carriers, one woodland and one desert, to be worn dependent on the operating environment, could decrease the individual wear of each plate carrier and reduce the overall turnover rate. If a Marine stationed in Camp Pendleton, Lejeune, or Hawaii wears their woodland plate carrier when conducting training on their home base, and their desert plate carrier when conducting a Service Level Training Exercise (SLTE) at Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, CA, then each plate carrier may receive less wear and tear than one coyote brown plate carrier worn for every exercise. Therefore, it is possible that doubling the number of plate carriers could halve the turnover rate. The NPV of the total life cycle cost of COA 1, the status quo, with a 10% turnover rate per year is $153 million (CY2025$). The NPV of the total life-cycle cost of COA 6, two matching plate carriers per Marine, with a 5% turnover rate per year is also $153 million (CY2025$). The real turnover rate would likely be somewhere in between 5% and 10%, but the implication is that the realized cost of COA 6 may be less than that calculated in this research.

B. APPLICATION

The purpose of this research is twofold. The first reason is to provide decision-makers with an understanding of the effectiveness of the current Marine Corps uniform and plate carrier configuration and its implications for force protection and mission effectiveness. The second is to provide decision-makers with an objective, quantifiable assessment of trade-offs associated with potential courses of action the USMC may undertake to improve Marine combat effectiveness at the best value for the taxpayer.

This thesis answers the following questions:

- What are the trade-offs (advantages and disadvantages) associated with the USMC plate carrier camouflage options compared with the status quo?
- What are potential courses of action the Marine Corps could consider to address concealment vulnerabilities associated with plate carriers worn over the MCCUU with MARPAT camouflages?

The potential courses of action the Marine Corps could consider to address concealment vulnerabilities associated with plate carriers worn over the MCCUU with MARPAT camouflages are presented in COAs 2–6. The trade-offs associated with the USMC plate carrier camouflage options, compared with the status quo, are quantified through effectiveness and cost. Those trade-offs that may have cost implications but could not be included in the cost estimate, such as production variation and storage & supply, were included in the MOE score for each COA. COAs 3–6 are more effective than the status quo is. Table 28 shows the percent change in effectiveness of COAs 3–6 and the marginal cost when compared to the status quo.

Table 28. COA 3–6 percent change in effectiveness and marginal cost compared to status quo

	COA Comparison		
	COA	% Change	Marginal Cost (CY25$M)
Most Effective	6	34%	153
↓	5	14%	117
	3	7%	0
Least Effective	4	0%	44

The marginal effectiveness of COA 4 is a fraction of a percent that equates to zero when rounded. Therefore, when comparing marginal effectiveness for marginal cost, COAs 3, 5, and 6 are the only ones worth further consideration. COA 3 is 7% more effective at zero marginal cost and should be considered at a minimum. COAs 5 and 6 are significantly marginally more effective but incur additional cost beyond the status quo. The marginal costs represented in Table 28 are calculated based on the 10% turnover per year assumption and should be considered maximum values. The actual marginal cost may be less if the realized turnover is less than 10% as previously mentioned.

COA 6 is the most effective, but also the most expensive. It is 34% more effective than the status quo at a marginal cost of $153 million (CY2025$). It is difficult to place the 34% increase in effectiveness into a context that can be compared to the marginal cost. Clearly, it stems from the objective hierarchy and the MOPs that fall under survivability, lethality, and suitability. Theoretically, if a 34% increase in effectiveness had a proportional linear relationship to lives saved, it can be quantified in dollars and compared to the marginal cost. There are approximately 90,000 Marines in a Marine Expeditionary Force (MEF) (TECOM, n.d.), so 34% of a MEF equates to 30,600 Marines. The most recent best-set average value of a statistical life (VSL) applicable to the DoD is $11.8 million (CY2021$) (Kniesner et al., 2024). Using the JIC general inflation index, this equates to approximately $13.9 million (CY2025$) (CADE, n.d.). Therefore, in the context of VSL, 30,600 Marines are worth approximately $424 billion (CY2025$). The VSL valuation of 34% of a MEF is approximately 880 times more than the marginal cost of implementing COA 6.

This research does not make the argument that a 34% increase in effectiveness would translate to a 34% increase in lives saved. The comparison is simply an attempt to understand potential implications of increased effectiveness when compared to marginal cost. The purpose of this research is to outline potential courses of action USMC leaders could consider to address concealment vulnerabilities inherent in the status quo and quantify their effectiveness and cost. Additionally, this research provides a framework that can be adjusted as necessary to better reflect decision-maker priorities and contribute to an informed decision.

This research finds that there are courses of action that USMC leaders can take to increase Marines' combat effectiveness at marginal costs ranging from $0 to $153 million (CY2025$). In COAs 3, 5, and 6, marginal effectiveness increases as marginal cost increases. It is up to the decision-makers to determine the appropriate trade-off between increased effectiveness and cost. This research simply provides the tools.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

This research focuses on the effectiveness and cost implications of camouflage plate carriers only. Plate carriers are only one component of a Marine's infantry combat equipment (ICE). Additional ICE components include magazine pouches, radio pouches, dump pouches, sub-belts, main packs, assault packs, etc. It is likely that Marines would benefit from a full complement of ICE that is camouflaged to match their operating environment. Future research could explore the effectiveness and cost implications of issuing Marines woodland/tropic and desert/arid ICE to match the two existing MCCUU MARPAT variants.

Five COAs were analyzed in this research in addition to the status quo. Due to the expeditionary nature of Marines, COA 4 (Deployer Equipment Bundle) called for enough plate carriers of each camouflage variation to equip a MEB and the Marines permanently stationed overseas. As a result, it scored lower in the suitability metric than COA 3 (Aligned AO) did. Future research could include another course of action that increases the inventory of each camouflage plate carrier variant to be issued in times of crisis. This could potentially result in a higher MOE score than COA 3 at a cost still lower than COA 5. It is worthy of consideration and future analysis.

The last recommendation for future research is the viability of a three-family uniform concept for the Marine Corps. The Marine Corps currently has a two-family concept. The MCCUU has a desert MARPAT variant and a woodland MARPAT variant. At the onset of the Camouflage Uniform Improvement Project, Army engineers conducted a survey in which they found Army global operating environments consist of terrain that is 44% transitional, 37% woodland/jungle, and 19% arid/desert (Mortlock, 2020). As a result, the Army initiated a plan to develop and field a three-family uniform concept that provides concealment in transitional, woodland/jungle, and arid/desert environments. Currently, the Army has only fielded their transitional uniform variant. Although the Marine Corps has a different mission set than the Army does, it is likely that Marines still operate consistently in transitional terrain. Therefore, future research should analyze the distribution of the Marine Corps' global operating environment and the implications of fielding a transitional camouflage uniform to complement the existing woodland and desert variants.

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