Reducing the Visual Signature of the M4A1 Rifle

Duke Choi, Kelvin Hockenbraugh-White, Jessica McAllister, Christian Mckenrick, and Paul Santamaria

Department of Systems Engineering
United States Military Academy
West Point, NY

Corresponding author's Email: Jessica.mcallister@usma.edu

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Abstract: The Maneuver Center of Excellence (MCoE) presented a directive to reduce the visual signature for small arms weapons by altering the color of the M4A1 rifle from its traditional black color. This research utilizes the Systems Decision Process (SDP) to develop and analyze alternatives to create a feasible and permanent solution to reduce the weapon's visual signature. The research consisted of an extensive stakeholder and functional analysis to develop a value model and framework that provides a values-based recommendation. The model establishes an optimal color change process that accounts for the design and performance characteristics of the weapon system and the stakeholder's values. The research also analyzes the potential integration of short wave infrared (SWIR) mitigation into the new color of the weapon. This analysis will establish a baseline methodology for weapon color change for all Army small arms weapons.

Keywords: Operational Camouflage Pattern (OCP), Short Wave Infrared (SWIR), M4A1 Rifle, Value Modeling

1. Introduction

1.1 Introduction

The M4A1, successor of the M16, is the primary weapon of the U.S. Army. The government does not currently own the Technical Data Package (TDP) for the M4A1 and must utilize outside vendors for the ongoing manufacturing of the traditionally black-colored weapon. Program Executive Office Soldier (PEO Soldier) is a Government organization responsible for development, procurement, and lifecycle management of equipment for all Soldiers, while Project Manager Soldier Weapons (PMSW)—a subordinate to PEO Soldier—is an entity that ensures that Soldiers on the battlefield have overmatch capabilities in individual and crew served weapons. The U.S. Army Capabilities Integration Center (ARCIC) identified a capability gap that small arms present visual and infrared signatures enabling the enemy to localize U.S. forces too readily. In order to counteract this gap, the Army and the Maneuver Center of Excellence (MCoE), i.e. "the user," desires to reduce the visual signature for small arms weapons by changing to a neutral (non-black) color. This alteration will provide a second order effect of enhancing operational security and Soldier survivability. PMSW is coordinating with Project Manager Soldier Clothing and Individual Equipment (PM-SCIE) to ensure the selected color range for weapons and associated supporting equipment compliments the new Army Operational Camouflage Pattern (OCP). The purpose of this study is to develop a framework by utilizing value-focused thinking and the Systems Design Process, to analyze potential manufacturing processes and determine the optimal solution to reduce the visual signature of the M4. The problem statement in section 1.2 forms the basis for this research and follows the methodology of the SDP.

1.2 Problem Statement

The problem statement for this research is to determine an optimal solution for PMSW and the Army to reduce the visual signature of the M4A1 weapon system by introducing a neutral (non-black) color with a flat-dull finish, through an implementation process focused on new production and previously fielded weapons. This solution must break up the Soldier's silhouette in both the visual and short wave infrared (SWIR) spectrums without altering the current specifications of the weapon or creating a substantial cost increase.

1.3 Research Goals and Objectives

Based on the problem statement listed above, the goals for this research include: 1) ensure the model accounts for all testing of the current M4A1, 2) develop value measures in accordance with PMSW and the M4 Test Operating Procedure (TOP), and 3) continue to research the possibility of SWIR integration. This study focuses on the new production and new memorandum for the current field weapons painting procedure. The scope of this research does not include depot/overhaul. The five critical objectives for this study are: 1) initial research and extensive stakeholder analysis, 2) an analysis of alternatives on the potential solutions, 3) a workable solution that addresses the problem statement and each of the requirements and constraints, 4) investigate the potential of reducing short wave infrared signatures radiating from the weapon, and 5) keep the overall cost per rifle < 7% added to the current manufacturing cost of the M4A1.

2. Background

The research for this study included the transition of military uniforms throughout the continual change of combat environments, the weapon's individual components and finishing, and SWIR integration. Each topic strategically synchronizes the research directly with the problem statement. With the information and assistance from many stakeholders and vendors, the research will provide PM Soldier Weapons with an in-depth analysis of alternatives to find the most optimal solution for M4A1 color change. To adapt to a rapidly changing environment, the Army has adopted a new operational camouflage pattern (OCP). OCP seeks to minimize color contrast and break-up the outline of the object by blending sharp edges with blurred patterns. The new OCP departs from the digital pattern popular over the last several years, but still adheres to the innovative rules used to design that pattern.

2.1 Manufacturing Processes and Weapon Components

The M4A1 rifle system is composed of nine main components displayed in Table 1. Each component undergoes a different manufacturing process depending on its material properties. Anodization of aluminum components (Upper/Lower Receivers, Forward Rails, and Magazine) is "a process to electrolytically coat a metallic surface with a protective or decorative oxide" (Superior Metals, 2015). The process consists of hydrated aluminum oxide and is considered resistant to corrosion and abrasion, making it an important attribute to the components of the M4 because the weapon must be capable of functioning in harsh conditions. Currently, the color options for this process include brass, bronze, and black and provide a more resistant coating (Superior Metals, 2015). Additionally, hard-coat anodize, another protective finishing process, uses an electrochemical process to apply a corrosion resistant coating in various bronze colors, black, gray, and clear (Superior Metals, 2015). Extensive stakeholder analysis showed that the steel barrel and forward sight undergoes a phosphate process to increase hardness penetration, toughness, and wear resistance. The specific process for these components are critical to this research because they make up 71 percent of the weapon's external surface area. Extensive stakeholder analysis on the manufacturing and coating processes helped the research develop alternatives to be analyzed later in the research's methodology.

Table 1. Weapon Components

Component	Material	Finish	Process
Buttstock	Plastic	Flat	Injection Dye
Pistol Grip	Plastic	Flat	Injection Dye
Upper & Lower Receiver	Aluminum	Flat	Anodize
Forward Rails	Aluminum	Matte	Anodize
Forward Sight	Steel	N/A	Phosphate
Barrel	Steel	N/A	Phosphate
Forward Pistol Grip	Nylon	Matte	Injection Dye
Rail Cover	Nylon	Matte	Injection Dye
Magazine	Aluminum	Flat	Anodize

2.2 Short Wave Infrared (SWIR) Capabilities

SWIR technology has become a growing market both commercially and militarily to account for threat detection beyond the visual spectrum in both day and night environments. SWIR uses electromagnetic radiation and provides imaging signatures based on the reflectivity of materials. SWIR mitigation research is necessary in order to understand the impacts of alternatives on SWIR based optics, camera, and imagers. The U.S. government conducted initial research for SWIR mitigation paint coatings and produced high temperature aerosol paints that mitigated the SWIR offender signature on weapons. The developmental effort included selecting and evaluating different pigments to neutralize the SWIR offender signature of the weapon across a variety of backgrounds representing potential combat environments. These pigments must be evaluated further as an addition to permanent solution in weapon color change (Roberts, 2015).

3. Methodology

This research utilized the Systems Decision Process, which is a “collaborative, iterative, and value-based decision process that can be applied in any system life cycle stage” (Parnell, 2011). The SDP is composed of four phases: problem definition, solution design, decision-making, and solution implementation. This research primarily focused on the first three phases of this process. The solution implementation phase was beyond the scope of the research but was still considered.

3.1 Problem Definition

During the problem definition phase, stakeholder analysis was conducted primarily through the means of literature reviews, interviews, site visits, and teleconferences. These interviews identified additional stakeholders as MCoE, i.e. “the user,” weapon vendors, coating companies, and other military services. MCoE’s influence in initiating a weapon color change was providing the overall objective for the study and needs of the Army. The interviews with each weapon vendor and coating company provided stakeholder research and information used to frame the problem and generate potential alternatives. Once the scope of this research was understood, a value hierarchy was developed and is illustrated in Figure 1. A value hierarchy is a pictorial representation of factors that influence the final value model, ultimately determining how well alternatives meet the stakeholder’s objectives (Parnell, 326). Once these value measures are identified, they are ranked and weighted by the stakeholder in an Analysis of Alternatives (AoA) matrix, which gives each measure a weight through the algorithm shown in Table 2. These value measures become the raw data that constitutes the quantitative value model.

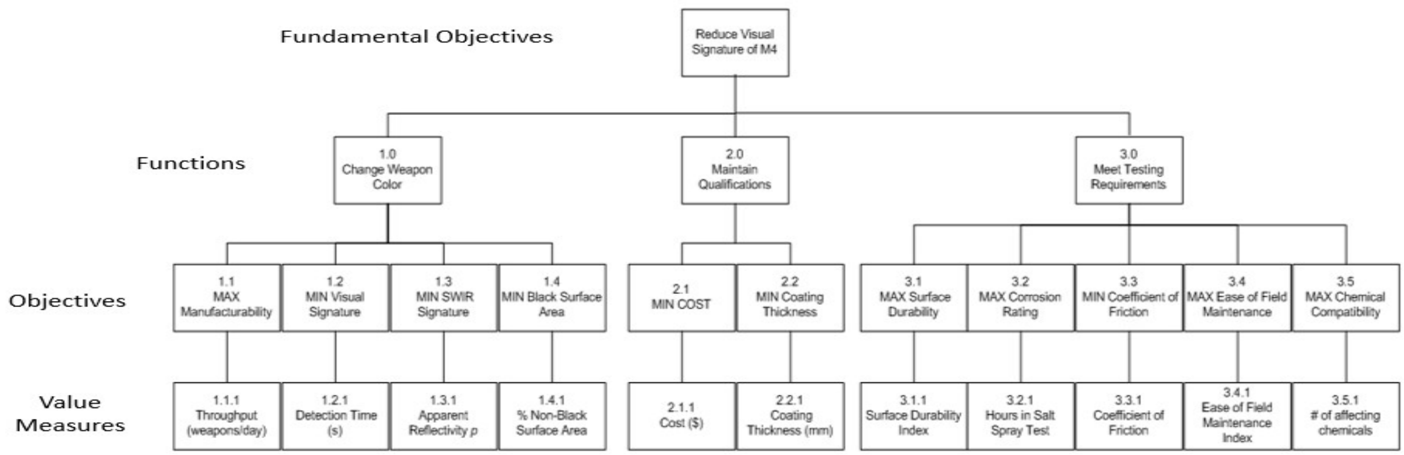

Figure 1. Value Hierarchy

Table 2. Analysis of Alternatives Matrix

	Manufacturability	Detection Time	Swirness	% Black Surface Area	Cost	Coating Thickness	Surface Durability	Corrosion Rating	Ease of Field Maintenance	Chemical Compatibility	Coefficient of Friction	TOTAL	WEIGHT
Manufacturability	0	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-8	1.82
Detection Time	1	0	-1	1	1	1	1	1	1	1	1	8	16.36
Swirness	1	1	0	1	1	1	1	1	1	1	1	10	18.18
% Black Surface Area	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	1	-8	1.82
Cost	1	-1	-1	1	0	1	-1	-1	1	-1	1	0	9.09
Coating Thickness	1	-1	-1	1	-1	0	-1	-1	-1	-1	-1	-6	3.64
Surface Durability	1	-1	-1	1	1	1	0	1	1	-1	1	4	12.73
Corrosion Rating	1	-1	-1	1	1	1	-1	0	1	1	1	4	12.73
Ease of Field Maintenance	1	-1	-1	1	-1	1	-1	-1	0	-1	1	-2	7.27
Chemical Compatibility	1	-1	-1	1	1	1	1	-1	1	0	1	4	12.73
Coefficient of Friction	1	-1	-1	-1	-1	1	-1	-1	-1	-1	0	-6	3.64

$$100 * \frac{(Total + Constant)}{(11 * Constant)}$$

3.2 Quantitative Value Model (QVM)

For the purpose of maintaining company security and protection of proprietary information within this study, the weapon coating companies are represented as Coating X, Coating Y, and Coating Z. The study's QVM is designed to evaluate potential solutions against a series of weighted evaluation factors. The input for this model is the raw data from market research, functional analysis, and test results. The model takes the raw scores for each alternative and converts them to comparable value on a scale of 0-100. For instance, a value of 0 does not meet any of the stakeholder's requirements while a value of 100 represents a perfect or ideal solution. Each value measure has a different function that converts raw scores to value. Two of the value functions can be seen plotted in Figure 2. The value function for "manufacturability" is a polynomial approximation, where value is derived from a line of best fit analysis. The value function for "percent non-black surface area" shows a direct linear relationship, where one percent of the surface area is equal to a value of one. These value functions are examples taken from the ten value measures and show how a baseline value is generated from varying inputs. Value measures increase usability by eliminating the differences in magnitude and units from the raw data input values.

Manufacturability	
Raw	Value
400	0
500	50
600	75
700	100

% Non-Black Surface Area	
Raw	Value
0	0
100	100

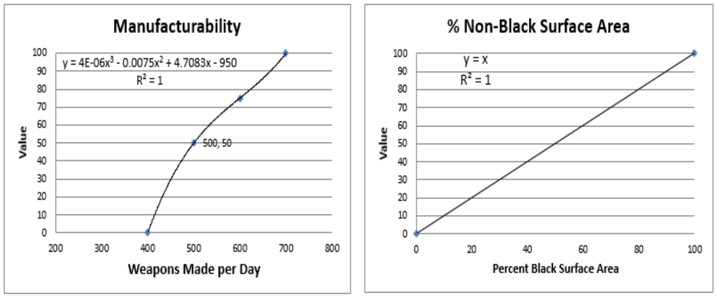

Figure 2. Example Value Functions

After converting the raw data scores to values, the values are weighted based on stakeholder importance derived from the AoA matrix. These final weighted values can be summed to get a total composite score for every alternative. The alternative with the highest score is the best fit for the stakeholder's needs, wants, and desires. Table 3 displays a modified screenshot of the model only including the two highest and two lowest of 13 scoring alternatives. There are four sections displayed, the raw data, raw value, weights, and weighted value. The composite score is in the table on the right labeled "Recommendation." This recommendation provides a singular representation of the alternative's ability to meet stakeholder objectives. This produced a methodology to easily rank order the alternatives and identify the optimal solution for the color change process.

The model prompts the user, in the "raw data matrix section," to input their desired specifications or requirement for each value measure in the qualitative value model. These value measures—manufacturability, detection time, reflectivity, percent of black surface area, cost, coating thickness, surface durability, and corrosion rating—were the most important to consider when determining each alternative. From the model, Alternative 2 and 5 had the highest total value scores.

Table 3. Quantitative Value Model

	Raw Data Matrix-USER INPUT									
Alternatives	Manufacturability (Throughput)	Detection Time*	*Apparent Reflectivity**	% non-black surface area	cost*	Coating Thickness	Surface Durability	Corrosion Rating	Ease of Field Maintenance	Chemical Compatibility*
2	600	0	100	100	4.84	0.001	18000	2034	5	2
5	600	0	100	94.219	4.56	0.001	18000	2034	4	2
9	600	0	100	75.068	5.83	0.00075	9000	500	2	4
12	700	0	100	100	5.83	0.001	1500	1000	4	5

	Value Matrix									
Alternatives	Manufacturability (Throughput)	Detection Time	*Apparent Reflectivity*	% non-black surface area	cost	Coating Thickness	Surface Durability	Corrosion Rating	Ease of Field Maintenance	Chemical Compatibility
2	75	0	0	100	51.6	50	80	97	100	66.66666667
5	75	0	0	94.219	54.4	50	80	97	80	66.66666667
9	75	0	0	75.068	41.7	62.5	70	25	40	33.33333333
12	100	0	0	100	41.7	50	50	50	80	16.66666667

	Weights										
	Manufacturability (Throughput)	Detection Time	*Apparent Reflectivity*	% non-black surface area	cost	Coating Thickness	Surface Durability	Corrosion Rating	Ease of Field Maintenance	Chemical Compatibility	Total
Swing Wt	3.19	16.81	18.75	1.25	9.03	5.14	12.92	12.92	7.08	12.92	100.01
VM Wt	0.03189681	0.168083192	0.187481252	0.01249875	0.090290971	0.051394861	0.129187081	0.129187081	0.070792921	0.129187081	1.00

	Weighted Value Matrix									
Alternatives	Manufacturability (Throughput)	Detection Time	*Apparent Reflectivity*	% non-black surface area	cost	Coating Thickness	Surface Durability	Corrosion Rating	Ease of Field Maintenance	Chemical Compatibility
2	2.39	0.00	0.00	1.25	4.66	2.57	10.33	12.53	7.08	8.61
5	2.39	0.00	0.00	1.18	4.91	2.57	10.33	12.53	7.08	8.61
9	2.39	0.00	0.00	0.94	3.77	3.21	9.04	3.23	2.83	4.31
12	3.19	0.00	0.00	1.25	3.77	2.57	6.46	6.46	5.66	2.15

Recommendation	
Alternatives	Total Score
2	49.43
5	49.61
9	29.72
12	31.51

4. Results and Analysis

4.1 Results from Quantitative Value Model

The results of the quantitative value model are displayed in the stacked value chart in Figure 3. Each bar clearly shows where the cumulative value score originates, allowing the reader to visually identify which value measures are most influential in determining the optimal solution (closest to a value of 100). The stacked bar chart shows the dispersion of value measures across each alternative. As indicated by the left two arrows on the graph, Alternatives 2 and 5 are the most valuable options, whereas the two arrows on the right, above alternatives 9 and 12, point to the least valuable. Therefore, before conducting any sensitivity analysis or cost-benefit analysis, the research suggests implementing Alternative 5 since it is valued slightly higher than Alternative 2. Alternative 5 is to apply Coating X to the entire weapon exterior, except for the barrel due to difficulty altering the phosphate coloring process to a non-black color as explained in the introduction. Alternative 2 is to apply Coating X to the entire weapon exterior, including the barrel. These two alternatives scored very well in the surface durability and corrosion rating measures. The lowest scoring alternatives are Alternative 9 and Alternative 12. Alternative 9 was to apply Coating Z to everything but the barrel and the buttstock of the weapon. Alternative 12 was to hard-coat anodize the aluminum parts, change the dye of the plastic parts, and leave the barrel untouched. These alternatives did not score well in the surface durability or corrosion testing measures and did not change the percentage of black surface area.

4.2 Sensitivity Analysis and Weapon Color Validation

The purpose of sensitivity analysis is to see if a change in the assumption changes the preferred solution (Parnell, 2011). Therefore, a parameter is sensitive if the decision maker's preferred solution changes as the parameter is varied over a range of interest. If the lines intersect, the weights are considered to be sensitive. Sensitivity analysis was conducted to validate the results of the model. The weights of each value measure were altered by ±25% and graphed to observe the change of each alternative based on its individual measure. This process presented the significance of each value measure and the subsequent effect on the best alternative. For each value measure, a graph is produced with each weight and value score on the x and y axis, respectively. Based on the sensitivity analysis, the best alternatives are 2 and 5. Figure 4 shows one graph from the sensitivity analysis. The intersecting lines at the bottom graph show that the value measure "Ease of Field Maintenance" is sensitive. After analyzing all of the graphs, both Alternative 2 and Alternative 5 maintained the highest value scores. The sensitivity analysis ultimately validated the quantitative value model and confirms the optimal solution to be Alternative 5.

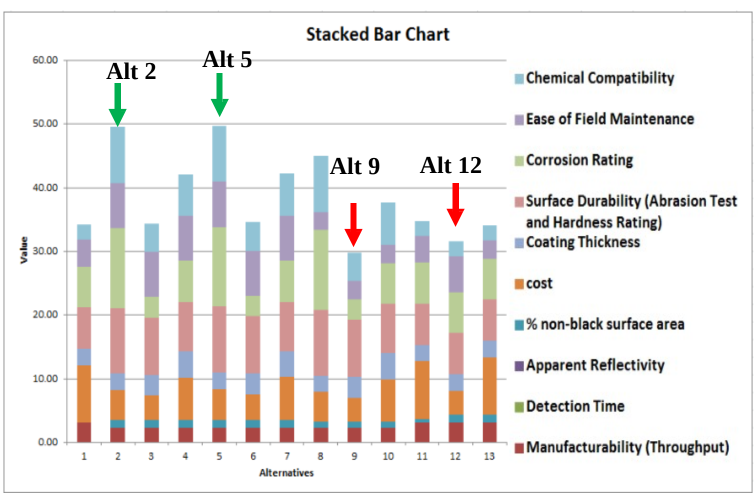

Figure 3. Stacked Bar Chart of Value

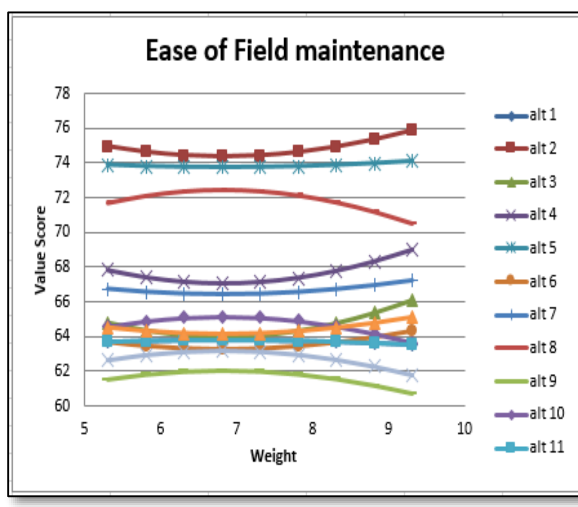

Figure 4. Example of Sensitivity Analysis

Section 1.1 introduced ARCIC and the capability gap that small arms present visual and infrared signatures which enables the enemy to easily locate U.S. forces. The client's initial brief recommended a specific color range to reduce the visual signature for small arms weapons. A portion of this research was the validation of this color range. An equation to find the color difference between varying colors against the weighted average of the current OCP was published by Ramsley (1979). The color analysis runs a series of available colors on the OCP against a weighted average of those same colors based on the percentages of repeat in the uniform. The ΔE values are calculated based on Equation 1. Equation 1 accounts for the difference in individual L*a*b* values of presented colors against the weighted average color of the OCP uniform (represented by the delta U, V, and W variables). The differences in values are weighted by the Angular Subtense, which measures the distance, color, and pattern sizing of a specific pattern and color, represented by the kU, kV, and kW variables. When calculating the ΔE, a lower value (typically under 1) is desired to determine the lowest color difference. With a lower color difference, the color implemented into the weapon will complement and break-up the visual outline of the weapon. This analysis allowed the researchers to provide objective measures in determining the best color range for the M4A1 against a weighted color average of the OCP background. In doing so, it will provide the optimal mitigation process within visual spectrum.

Concerning the alternatives for SWIR mitigation of the M4A1, little research for a permanent alternative for spectral mitigation was found; however, a temporary alternative exists that can complement a permanent color change to the M4A1. Other service agencies have provided their research on the temporary alternative to spectral mitigation of the system. Though a temporary alternative for spectral mitigation does not fit the scope of this research, the application method of the temporary solution share some similarity with the recommended solution in this paper. The research concludes that the process of anodizing or phosphate coating is not yet viable and therefore yields an unfavorable SWIR assessment. More research and testing is needed to incorporate SWIR mitigation to the recommended solution's process.

5. Recommendations and Conclusion

This research showed that the best solution for implementing a new manufacturing process to alter the M4A1 from black to a neutral color is to apply Coating X to the exterior of the weapon, excluding the barrel. Coating X meets this research's color, cost, and manufacturability requirements, without changing the tolerance or qualifications of the weapon. Coating X also provides the most durability and corrosion protection for the weapon and allows for Soldiers in the field to apply and remove additional temporary customization over the base coat. This coating can be applied by licensed applicators both in the manufacturing process and after the weapon has been fielded. Implementing Coating X will reduce the visual and SWIR signature of the weapon. Reducing the visual signature of the weapon increases the effectiveness of soldiers by increasing their ability to remain undetected in combat environments. Currently, black weapons starkly contrast with the colors of the new OCP on both visible and non-visible spectrums. The new, non-black weapon will have less visual and SWIR contrast, reducing the likelihood of detection for U.S. Soldiers and increasing the rate of mission success. The M4A1 color change will serve as the foundation for implementing color change across all of the Army's individual weapons. Many components across different weapon systems are composed of the same materials and finishes and Coating X can be applied to most of these weapons. As the Army moves forward in the weapon color change process, PMSW can utilize and adjust this model to fit a new scenario.

Figure 5. Alternative 5

6. Acknowledgement

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