# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# THESIS

**PROMOTING MISSION SUCCESS FOR THE USMC DISTRIBUTED OPERATIONS SQUAD THROUGH EFFICIENT EQUIPMENT SELECTION**

by

Shawn M. Charchan

September 2006

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| REPORT DOCUMENTATION PAGE | | | *Form Approved OMB No. 0704-0188* |
|---|---|---|---|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503. | | | |
| **1. AGENCY USE ONLY *(Leave blank)*** | **2. REPORT DATE** September 2006 | **3. REPORT TYPE AND DATES COVERED** Master's Thesis | |
| **4. TITLE AND SUBTITLE**: Promoting Mission Success for the USMC Distributed Operations Squad Through Efficient Equipment Selection | | | **5. FUNDING NUMBERS** |
| **6. AUTHOR(S)** Shawn M. Charchan | | | |
| **7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)** Naval Postgraduate School Monterey, CA 93943-5000 | | | **8. PERFORMING ORGANIZATION REPORT NUMBER** |
| **9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)** N/A | | | **10. SPONSORING/MONITORING AGENCY REPORT NUMBER** |
| **11. SUPPLEMENTARY NOTES** The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. | | | |
| **12a. DISTRIBUTION / AVAILABILITY STATEMENT** Approved for public release; distribution is unlimited. | | | **12b. DISTRIBUTION CODE** |

**13. ABSTRACT (maximum 200 words)**

The Marine infantryman is carrying too much weight in combat. This thesis analyzes the trade-offs between individual load weights and the value that a Distributed Operations squad receives from the equipment its members carry. We use multiple objective decision analysis principles to help determine the coefficients for an integer linear programming model. The optimization model prescribes equipment assignment to individual positions that maximizes squad mission success while meeting target weights for the individual Marine. Our findings indicate that significant improvements can be made to the Marine's combat load weight and equipment composition. The optimization model provides the squad with a more efficient combination of equipment while reducing the average weight of the combat load by more than 19 percent for both the assault load and the approach march load. Also, by balancing the loads across the members of the squad, the model reduces the variation of weight across the squad positions from as much as 38 percent to less than 2 percent for all loads. By examining the trade space between equipment weight and equipment value, we assist in the creation of future Marine Corps doctrine by providing senior Marine leaders a starting point analysis for addressing this difficult problem.

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| **14. SUBJECT TERMS**: Value-Focused Thinking, Multiple Objective Decision Analysis, Multiple Attribute Utility Theory, Decision Analysis, Equipment Selection, Distributed Operations, Squad Equipment. | | | **15. NUMBER OF PAGES** 79 |
| | | | **16. PRICE CODE** |
| **17. SECURITY CLASSIFICATION OF REPORT** Unclassified | **18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified | **19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified | **20. LIMITATION OF ABSTRACT** UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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# PROMOTING MISSION SUCCESS FOR THE USMC DISTRIBUTED OPERATIONS SQUAD THROUGH EFFICIENT EQUIPMENT SELECTION

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN OPERATIONS RESEARCH**

from the

**NAVAL POSTGRADUATE SCHOOL**
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# ABSTRACT

The Marine infantryman is carrying too much weight in combat. This thesis analyzes the trade-offs between individual load weights and the value that a Distributed Operations squad receives from the equipment its members carry. We use multiple objective decision analysis principles to help determine the coefficients for an integer linear programming model. The optimization model prescribes equipment assignment to individual positions that maximizes squad mission success while meeting target weights for the individual Marine. Our findings indicate that significant improvements can be made to the Marine's combat load weight and equipment composition. The optimization model provides the squad with a more efficient combination of equipment while reducing the average weight of the combat load by more than 19 percent for both the assault load and the approach march load. Also, by balancing the loads across the members of the squad, the model reduces the variation of weight across the squad positions from as much as 38 percent to less than 2 percent for all loads. By examining the trade space between equipment weight and equipment value, we assist in the creation of future Marine Corps doctrine by providing senior Marine leaders a starting point analysis for addressing this difficult problem.

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# LIST OF ACRONYMS

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|---|---|
| BRAC | Base Realignment And Closure |
| C4 | Command, Control, Communications, and Computer Systems |
| CDD | Capabilities Development Document |
| DO | Distributed Operations |
| DOD | Department Of Defense |
| FM | Field Manual |
| GAMS | General Algebraic Modeling System |
| HE/DP | High Explosive / Dual Purpose round |
| IFAKs | Individual First Aid Kits |
| ILBE | Integrated Load Bearing Equipment |
| MAGTF | Marine Air-Ground Task Force |
| MBITR | Multiband Inter/Intra Team Radio |
| MCCDC | Marine Corps Combat Development Command |
| MCWL | Marine Corps Warfighting Lab |
| MODA | Multiple Objective Decision Analysis |
| MSBS | Modular Sleeping Bag System |
| NBC | Nuclear, Biological, and Chemical warfare |
| OEF | Operation Enduring Freedom |
| OIF | Operation Iraqi Freedom |
| PRR | Personal Role Radio |
| SAPI | Small Arms Protective Inserts |
| SAW | Squad Automatic Weapon |
| SMAW | Shoulder-Launched Multipurpose Assault Weapon |
| USAF | United States Air Force |
| USMC | United States Marine Corps |
| VFT | Value Focused Thinking |

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ACKNOWLEDGMENTS

As my thesis advisor, Major Lee Ewing taught me, directed my research efforts, and helped me to get over stumbling blocks.  More importantly, he provided guidance and mentorship through the duration of my research that bettered me as both a student and a military officer.  Thank you for the time and effort you dedicated.

Professor Nita Lewis Miller helped me find this thesis topic and spent many months searching for the right sponsor for my research.  Her instruction along the way was instrumental to the completion of my thesis and ensured that my work contributes in the manner I desire.  Thank you for your guidance and assistance.

Mark Richter supplied key information and helped to coordinate travel opportunities that increased my understanding of how to ensure my research aids the Marine Corps.  Thank you for helping me make my research relevant.

Professor Rob Dell and Colonel Bill Tarantino both helped refine my research.  Thank you for your advice and for helping me to present this material in a structured manner.

Finally, I thank my wife Amy for her incredible support throughout my time at NPS.  I have been a student for as long as we have known one another, and I am very excited about the prospect of spending time with her rather than with my research!  Amy has been patient and understanding throughout the duration of my studies while she was working and maintaining an equally busy schedule herself.  Thank you for helping me keep my center, encouraging me, and providing me so much love.

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# EXECUTIVE SUMMARY

In July 2005, the Commandant of the Marine Corps approved the concept for Distributed Operations (DO) to promote discussion and generate ideas concerning the new concept. DO is the Marine Corps' answer to the battlefield of the future, where Marines will fight an adaptive and decentralized enemy with infantry units that can operate independently while providing a coordinated effort toward a common goal. A primary challenge to the implementation of DO is the additional weight Marines must carry due to the sustainment requirements, new technologies, and advanced weaponry required for DO missions.

We explore the trade-offs between individual combat loads and the value an infantry squad receives from the equipment its members carry. Our analysis examines two different loads, the assault load and the approach march load. Though our focus is on loads containing equipment that will be employed by the DO infantry squad, this research may be generalized to provide insights that are applicable throughout the Marine Corps.

We first examine the literature regarding appropriate equipment weights for the two loads to understand the human factors issues. We use decision analysis principles to determine the coefficients for an integer linear programming model. The optimization model maximizes the equipment's contribution to the squad's mission success, while limiting the weight carried by the individual Marine. We discuss the feasibility of a Marine infantry squad obtaining weight limits recommended in DOD literature. We examine the two biggest contributors of weight on the assault load, body armor and weaponry. Finally, we investigate the affect the additional equipment and supplies required during the approach march has on combat load weight.

Our findings indicate that significant improvements can be made to the Marine's combat load weight and equipment composition, as shown in Figure 1. By evaluating the value gained by issuing every piece of equipment to each individual, the optimization model provides the squad with a more efficient combination of equipment. Also, by balancing the loads across the members of the squad, the model greatly reduces the variation of weight carried by the individual Marines in the squad.

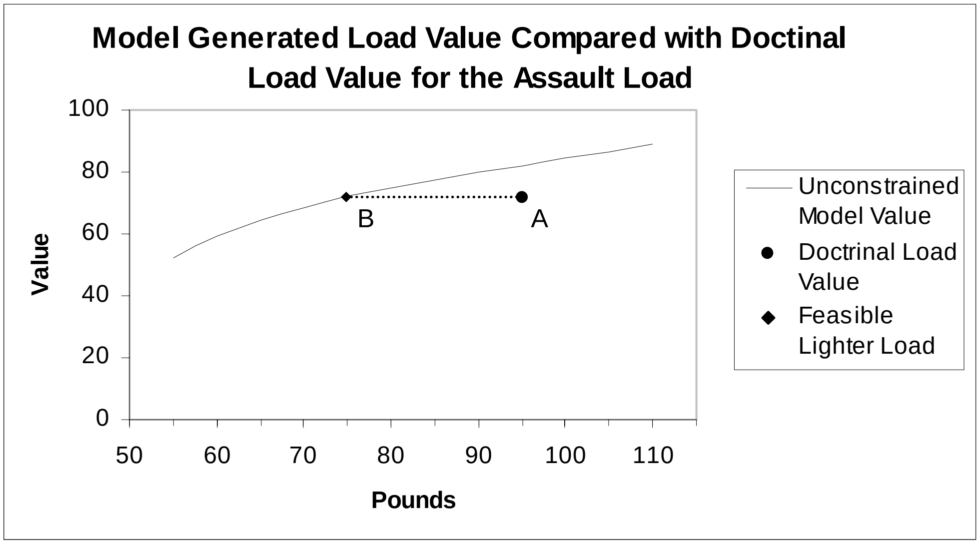


Figure 1. Graphical depiction of the value curve generated by our optimization model. Point A represents the value achieved at the average individual weight of the doctrinal assault loads. The line represents the value that can be achieved by the squad when weight limits for individual loads are constrained. For example, point B represents a more efficient assault load that achieves the same value as the doctrinal load but weighs 20 pounds less.

Our analysis shows potential gains in efficiency over current doctrinal equipment loads and reveals key points that decision-makers should consider when creating doctrinal loads. We also provide example loads for each member of the squad that maximizes the squad's potential for mission success while limiting the weight that the members of the squad must carry in combat. By examining the trade space between equipment weight and equipment value, this thesis assists in the creation of future Marine Corps doctrine by providing senior Marine leaders a starting point analysis of this difficult problem. Though we focus on the equipment available to the Marine DO squad, this research provides insight that can be applied to other foot-mobile units throughout the DOD. Further, we provide an analytical framework that can be used for future analysis of other military equipment selection problems.

# I. BACKGROUND

> On the field of battle man is not only a thinking animal, he is a beast of burden. He is given great weights to carry. But unlike the mule, the jeep, or any other carrier, his chief function in war does not begin until the time he delivers that burden to the appointed ground…In fact we have always done better by a mule than by a man. We were careful not to load the mule with more than a third of his weight.
>
> S.L.A. Marshall, The Soldier's Load and the Mobility of a Nation, 1950

## A. PURPOSE

The Marine Corps infantryman is carrying too much weight in combat. Marine infantry squads fighting in Iraq in Operation Iraqi Freedom and in Afghanistan in Operation Enduring Freedom are carrying more specialized equipment than has ever been carried by an infantry squad in the past. Marines in Afghanistan carry extremely large combat loads, as they have to operate for long durations without resupply. Conversely, Marines in Iraq conduct shorter patrols and security operations with more frequent resupply and vehicle assets at their disposal. Marines in both theaters must carefully select what equipment they carry in their packs. Their goal is to find the optimum balance between the weight they must bear and the capabilities their equipment will provide so they may effectively accomplish the mission.

This is not a new issue. As the mission for the Marine Corps has expanded through time, so has its equipment inventory. As the mission expands, Marines are provided added capabilities but also require additional training and possibly additional equipment.

In July 2005, the Commandant of the Marine Corps approved the concept for Distributed Operations (DO) to promote discussion and generate ideas concerning the new concept. DO is the Marine Corps' answer to the battlefield of the future, where Marines will fight an adaptive and decentralized enemy with infantry units that can operate independently while providing a coordinated effort toward a common goal. It expands current maneuver warfare doctrine by allowing commanders to decentralize decision-making and distribute their forces on the battlefield. The Marine Corps Combat Development Command defines DO as [MCCDC, 2005, p. 1]:

> Distributed Operations describes an evolving concept that seeks to maximize the MAGTF commander's ability to employ tactical units across the depth and breadth of a nonlinear battlespace, in order to achieve favorable intelligence-driven engagements as part of the Joint Force Commander's overall campaign. A robust and easily accessible C4 backbone and prompt, responsive joint fires enable this capability. The first step, however, in developing this capability is to provide better education, training and equipment to the individual Marine, his fire team, squad, and platoon.

DO is designed to augment the Marine Corps' current doctrine, training, and equipment, not replace it. The DO implementation plan requires future Marine Corps infantry squads to receive more training to perform the additional DO missions. Although DO will increase the combat capability of the Marine infantry squad by providing additional training and equipment, the current implementation plan requires that the foot-mobile DO squads carry an excessive amount of weight. DO squads will carry additional batteries, ammunition, food, and water to allow them to operate over longer periods of time without resupply. Along with the additional sustainment requirements, the Marine squad must also carry enhanced weaponry and communications to accomplish its DO mission.

The Distributed Operations Experimentation After Action Report (AAR) indicates that the expected combat loads that the DO squad must bear may hinder mission accomplishment, "The weight issue regarding the "soldiers load" has affected mission effectiveness. For every additional capability we desire to have, some piece of gear has to accompany it, and soon we find out that the average man carries approximately 90-lbs worth of mission essential gear, water, and ammunition; not including the sustainment load. This has greatly reduced our mobility as a light infantry." The AAR goes on to state that there is concern about the weight of the sustainment equipment that will be required on a DO mission, "Could the DO unit carry adequate mission equipment and logistics to operate for a minimum of 72 hours when operating dismounted, mounted, or inserted by helicopter and operate dismounted?" [MCWL, 2005, p. 27]

This thesis addresses this issue by analyzing the trade-offs between the individual combat load weights and the value that the DO squad receives from the equipment its members carry. By examining the trade space between equipment weight and equipment value, this thesis provides senior Marine leaders a starting point for further analysis in the development of future Marine Corps doctrine. Although we focus on the equipment available to the Marine DO squad, this research may provide similar insights to non-DO Marine infantry, Army light infantry and other Department of Defense foot-mobile units. Further, our work may be generalized to provide an analytical framework for analysis of other military equipment selection problems.

## B. HISTORY

In September 2003, the Marine Corps Combat Development Command Materiel Requirements Division commissioned a study to determine optimum combat loads for the Marine Corps infantryman [MCCDC, 2005]. The study established the combat loads that a Marine should bear in combat from a strictly physiological standpoint. The researchers found a steady increase of the combat loads carried on the march by various infantry units throughout history. As communication equipment, weaponry, and other technology have continued to be developed, the infantryman carries more equipment in an effort to increase his combat effectiveness. The result is a warfighter that has increased capability, but may also result in a decrease in mobility.

The increased amount of equipment currently available provides the infantry squad with more capability than ever before. Unfortunately, the squad members may shed vital pieces of equipment in an effort to reduce the weight he must bear in battle [Castaneda, 2005]. The haphazard elimination of equipment from the combat load may have unintended consequences such as reduced capabilities, reduced personal comfort and health, and could even result in reduced mission success. Conversely, carrying excess equipment can result in fatigue and reduced mobility, which can bring about the very same consequences. Prescribed equipment lists must address this issue by ensuring the combat loads do not endanger the Marine and best outfit the squad for combat.

Current Marine Corps doctrine for infantry combat loads requires every member of the squad to carry the same base equipment. While there are some benefits to uniformity, standardization of the equipment that every infantryman is required to carry may result in overly redundant equipment at the squad level. A Marine infantry squad is designed to work as a synergistic unit, therefore, its members should be able to rely on one another for equipment. Our analysis addresses this issue by examining the equipment the squad carries as an aggregated unit while taking into account the weight the individual must bear.

In the military's efforts to increase the squad's combat effectiveness through technology, we may have degraded the ability of the individual by weighing him down with too much equipment. Current Marine doctrine dictates combat loads for some positions within the squad that are too heavy. Consequently, small unit leaders must deviate from doctrinal loads and tailor them to each individual within their squad. We examine that process analytically to determine how the combat load can be improved.

## C. SCOPE OF THE THESIS

This research provides an analysis that will assist decision-makers in better understanding how the doctrinal loads can be changed to best prepare the DO squad for combat. It provides insight to help create future published doctrinal loads, both for the DO squad and for the non-DO infantry squad.

To assist with concept development for the DO implementation plan, we focus on the assault load and the approach march load as they are defined in the 2005 Marine Corps Combat Development Command Integrated Load Bearing Equipment Capabilities Development Document (MCCDC ILBE CDD). The study cannot cover the entirety of scenarios that the DO squad will encounter. Consequently, we consider two loads, the assault load and approach march load, in broader, more general scenarios that can be used to help establish doctrine rather than focusing on a particular mission or climate. Small unit leaders will still have the ultimate responsibility of tailoring the equipment within the squad to the mission at hand. The goal of this thesis is not to replace tactical level leadership, but rather to gain an understanding of what we can reasonably ask Marines to carry and to suggest issues for consideration when developing the doctrinal combat loads for the DO squad.

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# II. CONTRIBUTING LITERATURE

This chapter presents previously conducted research and published literature that is relevant to this thesis. The first section reviews the studies that have been conducted regarding maximum combat load weights for the infantryman and also looks at several texts regarding the subject. The second section introduces previous research regarding Value-Focused Thinking [Keeney, 1992] and the construction and use of multiple objective decision analysis (MODA) models. The final section presents the literature that provides the foundation for the optimization model that is employed in this thesis.

## A. COMBAT LOAD WEIGHTS AND TODAY'S INFANTRYMAN

The Marine Corps Combat Development Command (MCCDC) has conducted several studies on the combat load of the individual Marine performing the infantry mission. In the 2005 ILBE CDD, three standard combat loads are "defined with respect to operational need, human factors, and level of sustainment" [MCCDC, 2005]. These combat loads provide a basis to determine what items should be carried in a particular mission. We focus on two loads from this study; the assault load and the approach march load. We list the ILBE CDD definitions of the two loads below to provide a basic understanding of how they are used within the literature, then augment these definitions in Chapter III for use within our study.

- Assault Load - The assault load is the load needed during the actual conduct of the assault. It will include minimal equipment beyond water and ammunition. From the human factors perspective, the maximum assault load weight will be that weight at which an average infantry Marine will be able to conduct combat operations indefinitely with minimal degradation in combat effectiveness.
- Approach March Load - The approach march load is defined as that load necessary for the prosecution of combat operations for extended periods with access to daily re-supply. The approach march load is intended to provide the individual infantry Marine with the necessities of existence for an extended period of combat. From the perspective of human factors, the

> maximum weight of the approach march load will be such that the average infantry Marine will able to conduct a 20-mile hike during a time frame of eight hours with the reasonable expectation of maintaining 90% combat effectiveness.

The IBLE CDD lists maximum weights of 75 pound for the assault load and 100 pounds for the approach march load. It then provides specific equipment lists for the two loads that show how the infantry rifleman can meet the target weights. The doctrinal loads include clothing, ballistic protection, the M-16 rifle, night vision, the M-40 gas mask, food and water, and other equipment. Unfortunately, the equipment lists do not meet the aforementioned weight restrictions for those Marines who are carrying weapons that are heavier than the M-16 rifle. Replacing the M-16 rifle with the M-240G light machine gun adds over 15 pounds from the weapon alone, and another 20 pounds is gained if you exchange six M-16 magazines for 500 rounds of M-240G ammunition. When combined, the weight of the replacement weapon and ammo results in a combat load that exceeds the standard contained in the ILBE CDD by 35 pounds.

Though the ILBE CDD sets the target weights at 75 and 100 pounds for the two combat loads, other Department of Defense literature suggests even lighter weights. Much of the published literature recommends target weights based on a percentage of body weight to determine how much that individual can be expected to bear during a given scenario. An example of this is The Department of Defense “Design Criteria Standard: Human Engineering” document published in 1999 that states, “The total load carried by an individual, including clothing, weapons and equipment for close combat operations, should not exceed 30% of body weight and, for marching, 45% of body weight.” [MIL-STD-1472F, p. 162]

The five DOD publications below all list the optimal combat loads to be 30 percent of bodyweight for the assault load and 45 percent of bodyweight for the approach march load.

- MIL-STD-1472F: Design Criteria Standard: Human Engineering
- DOD-HDBK-743A: Anthropometry of US Military Personnel

- MIL-HDBK-759C: Handbook for Human Engineering Design Guidelines
- FM-21-18: Foot Marches Army Field Manual
- FM 7-10: The Infantry Rifle Company Army Field Manual

The May 2004 Combat Load Report [MCCDC, 2004], published by the Marine Corps Combat Development Command, contains the most recent published Marine Corps research concerning combat load weight and provides information regarding the current anthropometrical data for height and weight within the Marine Corps. This report also states that the assault load should weigh no more than 30 percent of bodyweight and the approach march load should weigh no more than 45 percent. The report acknowledges that the ILBE CDD, published by the same command, recommends higher weights for each load. The authors suggest that the reduced weight can be achieved by removing certain items, such as the M40 gas mask, from the combat load. While eliminating some items can reduce the weight of the rifleman's equipment to appropriate levels, it does not do so for the other members of the squad who are required to carry heavier weapons or communications equipment.

The Combat Load Report states that the average Marine weighs 169 pounds, and uses the 30 percent and 45 percent standards to establish a maximum weight of 51 pounds for the assault load and 76 pound for the approach march load. Because these weights are based on the percentages found most prevalently in the literature, they serve as the starting point for our analysis. However, some of the weapons the DO squad members carry are extremely heavy, and when combined with only 8 pounds from a basic uniform they exceed the 51 pound maximum. Thus, the bulk of the analysis focuses on keeping to a minimum the amount by which we exceed these weights. As stated in Battlefield Mobility and the Solder's Load, "Although no load is the ideal load for fighting efficiency and every pound an infantryman carries cuts down his mobility and the tactical mobility of his unit, the solution of the load carrying problem will be a compromise between what the individual must carry to do his job and the ideal." [Ezell, 1992, p. 3]

While it may be necessary to prescribe doctrinal loads for the DO squad that exceed the recommended maximum weights, we can still mitigate the excess weight carried by each individual by tailoring his combat load based on the weapon and equipment needed for his position. This enables the Marines who are carrying the lightest weapons to carry equipment that is easily distributed and shared throughout the squad when it is needed, such as entrenching tools, batteries, and supplemental ammunition. To ensure that the squad is provided the optimum combination of equipment, we must first determine what constitutes the optimal combination.

## B. VALUE-FOCUSED THINKING AND A MULTIPLE OBJECTIVE DECISION ANALYSIS MODEL

We approach this problem through the use of Value-Focused Thinking which formalizes preferences regarding equipment composition within the loads. This analytical process first examines where stakeholders' values or objectives lie, and then determines how much each piece of equipment contributes to the overall goal of mission success.

Keeney [1992, p. 3] describes how values should be used to improve decisionmaking. He states that,

> The premise is that focusing early and deeply on values when facing difficult problems will lead to more desirable consequences, and even to more appealing problems than the ones we currently face. In short, we should spend more of our decisionmaking time concentrating on what is important: articulating and understanding our values and using these values to select meaningful decisions to ponder, to create better alternatives than those already identified, and to evaluate more carefully the desirability of the alternatives.

If we begin our analysis by examining possible equipment configurations, this would constitute alternative focused thinking; however, by conducting a thorough analysis of our true goals, we are using value focused thinking. Keeney believes that creating alternatives using value-focused thinking is superior to evaluating preset alternatives using alternative-focused thinking. While alternative-focused thinking is aimed at solving decision problems, value-focused thinking allows us to explore decision opportunities. Specifically, value focused thinking assists us in truly focusing on what we are trying to accomplish rather than trying to decide between existing alternatives.

Evaluating known alternatives based on multiple desires, or objectives, is called multiple objective decision analysis (MODA). MODA is an operations research technique used to determine the best alternative when we have multiple, conflicting objectives and significant uncertainties [Parnell, 2005]. We separate the MODA model into two models: a qualitative model composed of an objective and supporting attribute hierarchy, and a quantitative model that measures the degree to which we accomplish the objectives.

The creation of a thorough and accurate qualitative value model is very important to this research. All too often, decision makers and stake holders do not pay sufficient attention to accurately reflect the problem that they are trying to solve [Keeney et al,. 2004]. Neglecting the problem analysis may result in a misrepresentation of the true objectives or a poor link between the attributes and how they affect the objectives. The qualitative value model is the foundation that our results are built upon, and the objective hierarchy and importance (weights) given to each attribute must represent the preferences of both the decision-maker and the Marine that will be using the equipment. As stated in Parnell [2005, p. 7], "Qualitative value modeling is critical to the success of a [Value Focused Thinking] analysis. If we do not get the decision-makers' and stakeholders' values qualitatively right, they will not (and should not!) care about our quantitative analysis."

The quantitative model is composed of both natural and constructed scales. Both were created based on the direction provided by Ewing et al., [2006]. We relied on the published doctrinal combat loads that were previously mentioned as well as consumption rates from various Marine Corps publications to create the measures for the quantitative model. We use subject matter expert input as well as after-action reports and "lessons learned" reports from Operation Iraqi Freedom and Operation Enduring Freedom to construct both the qualitative model and the quantitative model.

## C. THE CREATION OF AN OPTIMAL ALTERNATIVE USING AN INTEGER LINEAR PROGRAMMING MODEL

Much of the academic literature related to decision analysis suggests that the evaluation of alternatives is accomplished by substituting the known or predetermined alternatives into a constructed multiple objective decision analysis model to determine which alternative provides the best value. The decision analysis process is frequently composed of the following sequential steps [Clemen, 1996]:

- Identify the decision and understand objectives.
- Identify alternatives.
- Decompose and model the problem.
- Choose the best alternative.

For example, consider the two-part MODA model that Ewing et al. [2006] use in their analysis of Army's Base Realignment and Closure (BRAC). They first create a qualitative model outlining the key concepts that impact an installation's military value. They then use a quantitative model to measure the military value of an installation for attributes such as airspace, maneuver area, and housing availability. The Army's installations serve as the alternative and each alternative is then evaluated using the MODA model to determine its military value.

Parnell et al. [1998] conducts a similar analysis of future air and space systems. A value hierarchy is created based on USAF objectives for the future. Forty-three system concepts are evaluated as alternatives in a multiple attribute decision analysis model containing 134 attributes to determine which provides the highest score from the model.

Rather than establish set combat loads, i.e. alternatives, to be evaluated into a MODA model, this thesis employs an integer linear programming model to explore all possible combat loads for each member of the squad. The value the squad receives from combining all of the individual combat loads is assigned based on the MODA model.

This cumulative value is calculated by summing the value gained from each piece of equipment held by all of the members of the squad.

We are unaware of any documented research that exists at this time involving the use of Value-Focused Thinking and an integer linear programming model to generate optimal alternatives. The use of Value-Focused Thinking to generate alternatives is in use though, as can be seen in Parnell's [2005] discussion of the use of two types of alternative generation tables to develop better alternatives than those that are already known.

Exploring the alternatives through an integer linear programming model allows for a more thorough analysis by evaluating all feasible combat loads for each individual to determine which combination provides the highest value to the squad as a unit. It also permits the exploration of a minimum feasible combat load weight and provides a means of performing a tradeoff analysis between the weight of an infantryman's equipment and the value his equipment provides to the squad.

The integer linear programming model displays similarities to an integer knapsack model. In the knapsack model, we are given a set of items from which we are to select several to be carried in a knapsack. Each item has an associated weight (or size) and value that are both gained by placing items in the sack. The objective is to choose the set of items that fits in the knapsack and maximizing the value received. This concept can, however, be extended beyond physical items and a volume constraint. Brown, Dell and Newman [2004] use a similar approach to maximize the value that they received while not exceeding budgetary constraints in their optimization of military capital planning. They define an embellished knapsack problem in their analysis that serves as the basis for our integer linear programming model.

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# III. THE MULTIPLE ATTRIBUTE DECISION ANALYSIS MODEL

## A. CONSTRUCION OF THE OBJECTIVE HIERARCHY

To construct the multiple attribute decision analysis (MODA) model, we first create an objective hierarchy. This explicitly states both the primary and supporting goals of the model, called the overall objective and sub-objectives. We then decompose the sub-objectives until quantifiable measures are developed to support the lowest level sub-objectives.

The decision analysis literature refers primarily to two types of objectives: fundamental objectives and means objectives. Fundamental objectives are important because they state the essential reasons for interest in a problem. Conversely, means objectives simply contribute to higher-level objectives, i.e., a lower-level means objective provides a means to accomplish one or more higher-level objectives. For example, fundamental objectives answer the question, “what do we want?” whereas means objectives answer the question, “how do we accomplish this?” We use fundamental objectives throughout our objective hierarchy because they decompose easily and doing so provides the necessary conditions for an additive value model [Kirkwood, 1997].

The top-down approach is the most appropriate method for constructing a fundamental objectives hierarchy. We use the top-down approach for the creation of the majority of the fundamental objectives, then reference the list of available equipment once we reach the alternatives. This ensures that we account for all of the ways in which the equipment contributes to mission success.

The first step in the creation of the objective hierarchy is to identify the overall fundamental objective. In many cases the overall fundamental objective is obvious from the decision context. Ultimately, this study examines the effects the equipment carried by the DO squad in combat has on the squad’s ability to successfully complete the mission, thus revealing the overall fundamental objective to *promote mission success* of the DO squad through proper equipment allocation.

After we establish the overall fundamental objective, we begin developing fundamental sub-objectives (called fundamental objectives from this point on). Per Keeney [1992, p. 78], "The higher-level objective is defined by the set of lower-level objectives directly under it in the hierarchy. These lower-level objectives should be mutually exclusive and collectively should provide an exhaustive characterization of the higher-level objective." It is imperative that we capture every aspect of the promotion of mission success in clear, concise fundamental objectives, as they have a tremendous impact on the results of the study.

We conclude that the objective *promote mission success* can be decomposed into three fundamental sub-objectives: the *enhancement of warfighting ability*, the *increase of force protection*, and *providing physical sustainment*. A squad's warfighting ability enables it to carry out the warfighting element of the commander's intent for a particular mission, whether it is an ambush of an enemy convoy or to call for indirect fire support on an enemy position. Force protection protects the squad from injury and discomfort, thereby ensuring the squad can focus its combat power to accomplish the mission. This sub-objective captures our desire to ensure that every member of the squad returns safely, as mission success is frequently defined by both the accomplishment of the task and the safe return of our troops. Finally, by providing physical sustainment through food and water we can ensure that the members of the squad have the energy required to successfully carry out the mission. Figure 2 provides a graphical representation of the first two levels of the fundamental objective hierarchy.

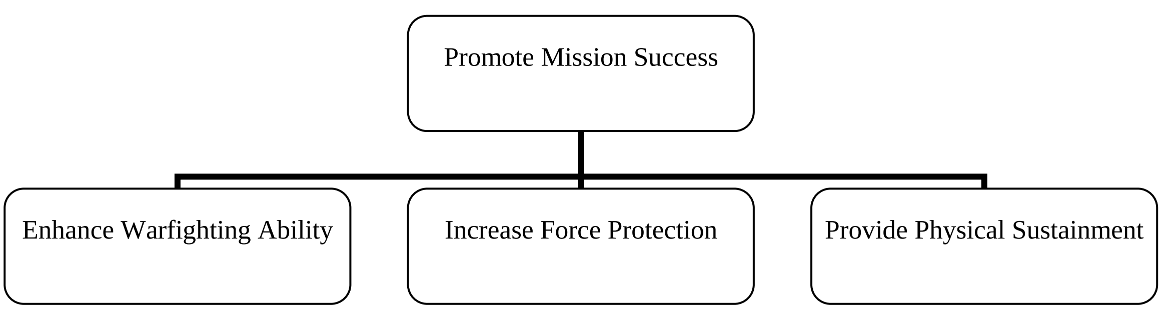


Figure 2. Fundamental objective hierarchy, level one and level two

We continue to decompose the fundamental objective hierarchy by examining each of the sub-objectives to determine what contributes to their accomplishment. Consider, for example, the sub-objective *enhance warfighting ability*. A unit's warfighting ability frequently hinges upon its ability to conduct three specific tasks: move, shoot, and communicate. In the context of this decision problem, *increasing engagement of the enemy*, *improving the squad's movement abilities*, and *enabling successful communication* are all fundamental objectives that contribute to the sub-objective of *enhancing warfighting ability*.

The remaining two fundamental sub-objectives are similarly decomposed. By continuing to decompose the objectives into sub-objectives we eventually reach a point at which each objective allows for a measurable attribute can be associated with it. As introduced in Chapter II, an attribute is a means by which we measure the achievement of an objective. This allows us to evaluate the value associated with each alternative i.e. equipment combination.

The resulting fundamental objective hierarchy is shown in Figure 3. This hierarchy represents the "top-down" flow of the qualitative model, illustrated from left to right, where the left-most objective is the overall fundamental objective. As we move from left to right in the hierarchy we move from the overall fundamental objective to the three fundamental sub-objectives, then on to the more fundamental sub-objectives.

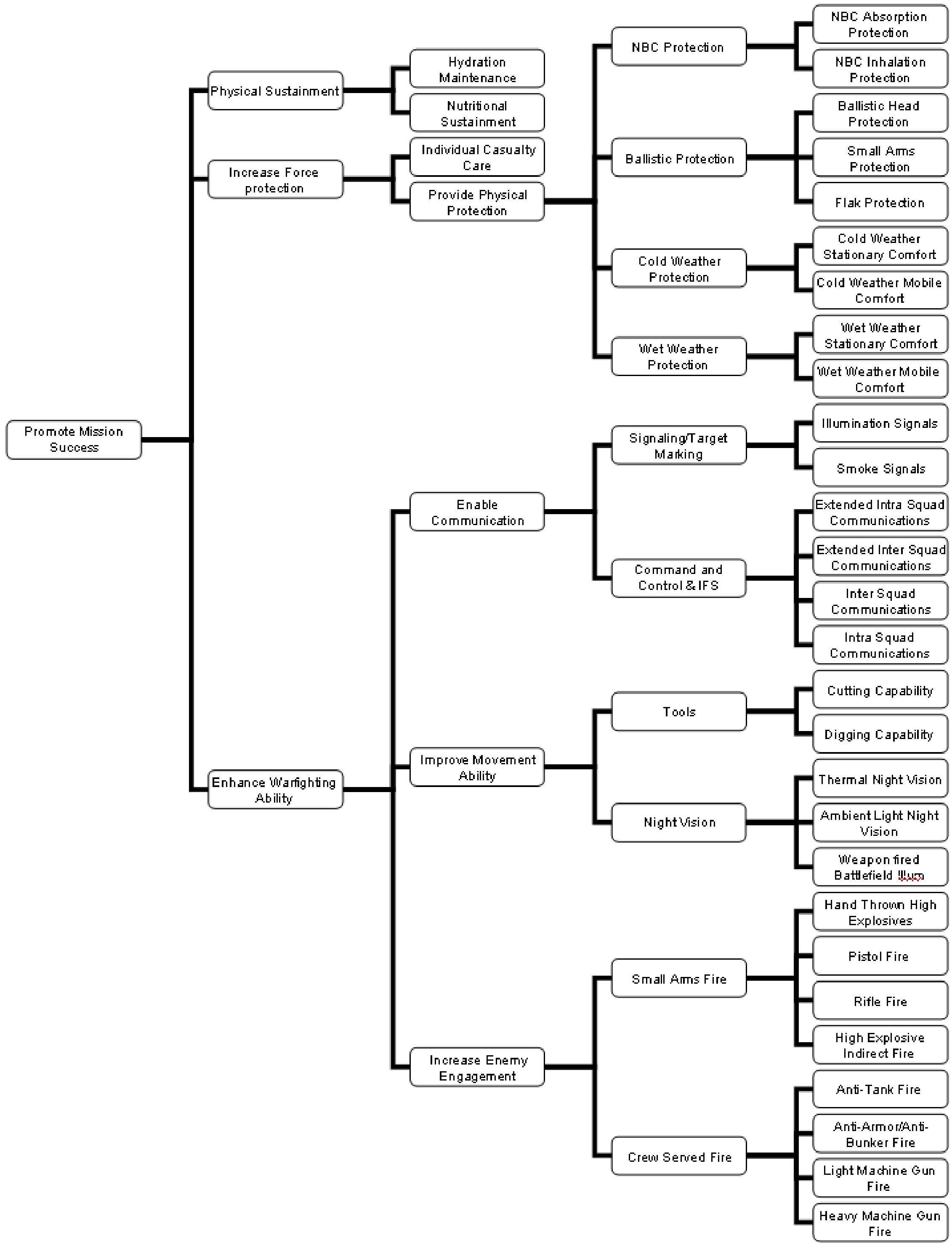


Figure 3. Fundamental objective hierarchy

## B. CONSTRUCTION OF VALUE FUNCTIONS

Now that we have identified the attributes, we begin construction of the value function for each attribute. These functions reflect the returns to scale over the relative range of the measures used for the attributes. The attributes fall into one of two categories: natural or constructed. We use natural measures for attributes that are contributed to by one type of equipment. For example, the attribute *digging capability* is composed of a measure based on the number of entrenching tools within the squad. We use piecewise linear functions for all of the natural measures.

Some attributes measure the contributions of several types of equipment, requiring construction of two or more measures to capture the possible *interactions* of two or more items. For example, the attribute *wet weather protection* uses a constructed measure based on the number of ponchos, Gore-Tex tops, and Gore-Tex bottoms in the squad, as they all contribute to the level of squad wet weather protection. We also use constructed measures to capture the difference in value that would be achieved if a particular member was provided a specific piece of gear. For example, the squad receives more value if a member of the machine gun team receives machine gun ammunition than if the squad rifleman receives the ammo. In another example, the squad receives more value if the squad leader or one of the team leaders is issued communication assets than if the automatic rifleman or assistant gunner is issued the radio. The use of constructed measures allows us to capture the importance of *position* in assessment of the value functions.

The measures are all created on a zero to ten point scale, where the squad gets no value if they receive no equipment and ten if they receive all possible equipment that composes that attribute. Each scale was created in two steps:

1. We examine an attribute and determine whether the measure is natural or constructed.
    - If the measure is constructed, we construct a function representing the interaction between the equipment that compose the measure.

- If the measure is natural, we begin by assuming a linear value function for the measure.

2. We use the value increment approach to evaluate the value function, and deviate from a linear function if it necessary to capture decreasing returns to scale of adding more items to the squad combat load.

The following two examples should help to provide a better understanding of the value function assessment:

Example 1: Digging capability

1. Only one piece of equipment contributes to the attribute *digging capability*: the entrenching tool. Therefore, the measure is based solely on the number of entrenching tools that can be issued to the squad. A maximum of thirteen entrenching tools can be issued to the squad. We assume a linear value function that provides no value if no entrenching tools are issued and a value of 10 if all 13 entrenching tools are issued.
2. We look at the value increment along the scale of the measure and determine that the incremental value that is gained in the first four entrenching tools is greater than that achieved in the last nine and the value function is adjusted. We then evaluate the value increments again and determine that the incremental value that is gained from the fourth through the seventh is greater than that from the eighth through the thirteenth, and the value function is adjusted again. See Figure 4 below for a graphical representation of this measure.

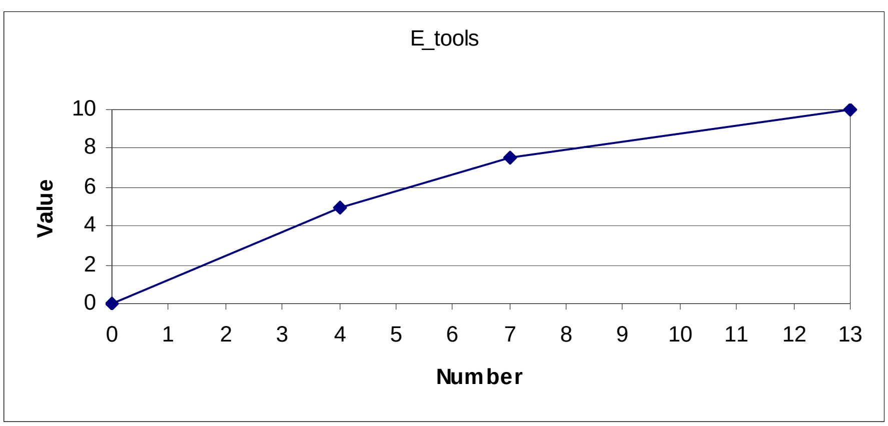


Figure 4. Graphical representation of the value measure for the digging capability attribute

Example 2: Cold weather stationary/sleeping comfort

1. Three types of equipment contribute to the attribute *cold weather stationary/sleeping comfort*: the modular sleeping bag systems (MSBS), poncho

liners (blankets), and the foam isopor mat. Each of these contributes to the objective, but the MSBS provides the greatest level of comfort, followed by the poncho liner, and finally the isopor mat. Further, the squad could carry a maximum of 13 of each of the items. A value function, seen below, was created to construct this measure.

2. No additional adjustment is needed, as the value increment is equal throughout the relevant range of the measure.

| |
|---|
| Cold weather sleeping/stationary value = $(w_1x_1+w_2x_2+w_3x_3)/13$ |
| Where $w_1$=2, $w_2$=5, $w_3$=3 |
| $x_1$= number of ISO-mats in squad |
| $x_2$= number of MSBSs in squad |
| $x_3$ = number of Poncho Liners in squad |

Figure 5. Functional representation of the value measure for the wet weather sleeping/stationary comfort attribute

As a further explanation, it is clear that the squad achieves a maximum value of 10 on for this attribute if each of the 13 members of the squad receives a MSBS, a poncho liner, and an isopor mat. Conversely, a value of 3 will be received if each member receives only a poncho liner.

We use this process to create the measures for all of the 31 attributes using each of the items listed in Appendix B.

## C. CREATION AND ASSIGNMENT OF SWING WEIGHTS

The final stage in the creation of the MODA model is the assessment of swing weights for the value model. The swing weights represent trade-offs among the attributes, which is mathematically equivalent to the trade-offs among the objectives [Kirkwood 1997]. We employ non-hierarchical weighting, meaning that weights are defined for the attributes only. Weights provide us the ability to compare the desire to achieve each objective with that of all the other objectives.

The technique we use in this study is based on that which Ewing et al. [2006] use, in which a swing weight matrix is created. By using a matrix, we are able to assign weights based on two dimensions of importance, in this case, the degree by which an attribute is required for mission success, and a combination of discrimination and military judgment. We performed the following four steps to create a swing weight matrix and assign global weights to the attributes:

Step 1. *Define the two dimensions.* How much an attribute is required for mission success is based on the literature stating the potential use of the DO squad. We define the columns as, "essential for mission success", "contributes to mission success", and "not required for mission success" to allow consideration for how vital each attribute is to mission success. We define the rows using a combination of military judgment and discrimination among the attributes, thereby allowing us to delineate items within the same column. An example in Step 2 provides clarification of the delineation by rows.

Step 2. *Place the attributes in the matrix.* Each item was first evaluated by placing it in a column, then by placing it in a row. For example, the attributes *small arms protection* and *NBC inhalation protection* both fall into the column "contributes to mission success", but based on our assumption that the squad is more likely to encounter small arms fire than an NBC attack, the first was placed in the top row while the latter was placed in the bottom row.

Step 3. *Assess the swing weights.* We represent the importance of each attribute using swing weights from 10 to 100 to ensure they vary by an order of magnitude. Weights decrease from top to bottom and from left to right. We place 100 in the upper left hand corner of the matrix and 10 in the lower right hand corner. Numbers between 10 and 100 are placed in the remaining positions according to the importance level of the attributes contained in each cell. The resulting matrix can be seen in Table 1.

| | Essential for Mission Success | Contributes to Mission Success | Not Required for Mission Success |
|---|---|---|---|
| | Light Machine Gun Fires<br>Anti-Armor/Anti-Bunker Fires<br>Anti-Tank Fires<br>Intra Squad Communications<br>Extended Intra Squad Communications<br>100 | Ballistic Head Protection<br>Small Arms Protection<br>Flak Protection<br>Inter Squad Communications<br>Extended Inter Squad Communications<br>HE Indirect Fire<br>70 | Smoke Signals<br>30 |
| **Discrimination/ Military Judgment** | Automatic Rifle Fires<br>Rifle Fires<br>Individual Casualty Care<br>90 | Hand Thrown HE<br>Hydration Maintenance<br>Weapon Fired Battlefield Illumination<br>Thermal Night Vision<br>60 | Nutritional Sustainment<br>Cutting Capability<br>Digging Capability<br>Wet Weather Mobile Comfort<br>Cold Weather Mobile Comfort<br>20 |
| | Ambient Light Night Vision<br>80 | NBC Inhalation Protection<br>NBC Absorption Protection<br>Pistol Fire<br>50 | Cold Weather Stationary and Sleeping Comfort<br>Wet Weather Stationary and Sleeping Comfort<br>Illumination Signals<br>10 |

Table 1. Swing weight matrix

Step 4. *Calculate the global weights.* The weight for each attribute is the "matrix weight" for the attribute divided by the sum of all matrix weights. This *global weight* is represented in the following equation:

$$w_i = \frac{f_i}{\sum_{w_i}^{31} f_i}, \text{ where } f_i = \text{ matrix swing weight corresponding to attribute i.}$$

Once we have successfully assigned swing weights, we are able to combine the qualitative results from the objective hierarchy with the quantitative results from the creation of the attributes to create the coefficients for the MODA model. The coefficients representing the value gained by the squad when issued a particular piece of equipment is determined by multiplying the value achieved from the value function by the associated attribute's global weight. The structure of the qualitative model and the value increment assessment cause the resulting measures to be additive, meaning that the squad receives positive additional value for each piece of equipment that a member is issued. This ensures that the resulting value model is also additive.

# IV. INTEGER LINEAR PROGRAMMING MODEL CREATION AND IMPLEMENTATION

## A. THE INTEGER LINEAR PROGRAMMING MODEL

This chapter explains the construction of the mathematical model that we use to generate and evaluate various combat loads. The model is a collection of logical and mathematical relationships called an integer linear program that represents different aspects of the selection of combat loads for the squad. The first section of this chapter explains the creation of the integer program, the second section explains integration of the multiple attribute decision analysis model results with the integer linear program, and the final section presents the formulation of the integer linear program.

A typical integer linear program consists of a single linear objective function, representing either a profit (or value) to be maximized or a cost to be minimized, and a set of integer variables that bound the decision space. The objective function evaluates alternative solutions while the constraints restrict the solutions to those which are feasible.

The capital budgeting problem [Lorie and Savage, 1955], is a specific example of a integer linear program that is used to ration available resources among competing investment opportunities. The formulation can be represented as:

$$
\begin{aligned}
\max \quad & \sum_{j=1}^{n} c_j x_j \\
\text{S.T.} \quad & \sum_{j=1}^{n} a_j x_j \le b \\
& x_i \in \{0,1\} \\
& i = 1,\ldots,n
\end{aligned}
$$

In this case, the objective function seeks to maximize the total capital received while the first constraint prevents the investments from exceeding the budget. This problem has also been referred to a knapsack problem in literature, but doing so assumes that the linear programming model consists of a linear objective and a single linear inequality constraint with nonnegative coefficients [Brown et al., 2004].

Brown et al. also list four assumptions for "simple" linear programs: additive objective values and additive costs, constant returns to scale, separable options, and deterministic data. They define a knapsack problem that does not meet these assumptions as an embellished knapsack problem. The following characteristics categorize our linear integer program as an embellished knapsack model:

- The value received in the objective function is additive in nature, as are the costs, i.e., the physical weight of the equipment.
- The returns to scale are not all constant, as the measures for the attributes are not all linear. Those that are not linear, however, are monotonic piecewise linear functions.
- The options are separable, though some are mutually exclusive. For example, the Small Arms Protective Inserts (SAPI) can only be issued to the positions that have also been issued flak vests.
- The data is deterministic, as it does not change based on the results of the model.
- We consider multiple competing objectives as defined in the MODA model.
- We employ set packing constraints in the model, i.e., the MODA model results in several disjoint sets. For example, the squad may receive value if one position is issued a particular type of item, but receive no value if the same item is issued to another position.
- We use balance constraints for the passenger variables. This will be explained later in this chapter.

## B. INTEGRATING THE MULTIPLE ATTRIBUTE DECISION ANALYSIS MODEL AND THE LINEAR INTEGER PROGRAM

Chapter III discusses the use of a MODA model to create the coefficients used in the formulation of our linear integer program. The creation of the MODA model, and the associated objective function was the most arduous task in this research. Had we not used a precise analytical approach to determining those coefficients, the model would have been constructed using coefficients that do not represent stakeholder preference in the optimization. We use Microsoft Excel [Excel, 2003] to represent the measures for the attributes, construct the swing weight matrix, and generate the coefficients for the linear integer program implement the problem.

## C. MODEL FORMULATION

### 1. Indices

$p$ squad members by position ($p = 1, 2, ..., 13$)

$i$ the type of items issued to the squd ($i = 1, 2, ..., 51$)

$n$ the number of items of type $i$ issued to the squad

### 2. Sets

$P$ the set of all positions in the squad

$I$ the set of all items that can be issued to the squad

$I'$ the set of items to be issued in the same quantity to all positions ($I'' \subset I$)

$I''$ the set of items to be issued in quantities of 0 or 1 ($I' \subset I$)

### 3. Data/Parameters

#### *a) Weight Data*

$BW_p$ the base weight of position $p$

$W_i$ the physical weight of one unit of item $i$

$MW_p$ the maximum weight to be carried by position $p$

#### *b) Coefficient Data*

$c^m{}_{pni}$ the incremental value that is gained by issuing the $n^{th}$ item of type $i$ to position $p$

$c^s{}_{ni}$ the value that is gained by issuing $n$ items of type $i$

## 4. Binary Decision Variables

$m_{pni}$ 1 if position $p$ is issued the $n$th order of item $i$, 0 otherwise

$s_{ni}$ 1 if the squad gets a total of $n$ of item $i$, 0 otherwise

## 5. Formulation

### *a) Objective Function*

$$\max \sum_{ni} c^{s}{}_{ni} s_{ni} + \sum_{pni} c^{m}{}_{pni}\; m_{pni}$$

### *b) Constraints*

$$\sum_{np} m_{pni} \geq \sum_{n} n s_{ni} \qquad \forall i \qquad (1)$$

$$BW_p + \sum_{ni} nW_i m_{pni} \leq MW_p \qquad \forall p \qquad (2)$$

$$\sum_{n} s_{ni} \leq 1 \qquad \forall i \qquad (3)$$

$$\sum_{p} m_{pni} \leq 1 \qquad \forall n, i \qquad (4)$$

$$\sum_{n} m_{pni} = \sum_{n} \frac{n}{13} s_{ni} \qquad \forall p, i \in I' \qquad (5)$$

$$\sum_{n} m_{pni} \leq 1 \qquad \forall p, i \in I'' \qquad (6)$$

$$m_{pni} \in \{0,1\} \qquad \forall p, n, i \qquad (7)$$

$$s_{ni} \in \{0,1\} \qquad \forall n, i \qquad (8)$$

## D. EXPLANATION OF THE MODEL

### 1. Formulation Explanation

The objective function maximizes the value that the squad receives from the assignment of equipment to each position. It does so by adding equipment to each position's base equipment. A position's base equipment is composed of items such as a uniform, weapon and associated weapon sight, and various other items, i.e., a patrol pack, chap-stick, and shaving gear. A list of the base equipment for each position is provided in Appendix A. The weight of the base equipment for each position is called the base weight, and is represented in the formulation by $BW_p$.

Constraint 1- distributes the squad-based equipment to the members of the squad. If the squad is assigned *n* of a squad-based item, this constraint ensures that all n items are then assigned to the members of the squad through the use of the $m_{\text{pni}}$ binary variables.

Constraint 2- ensures that each position meets their associated weight constraint. Each position starts with a base weight, to which the weight from the equipment assigned by the model is added. The sum of the two is not permitted to exceed a level set during the analysis.

Constraint 3- requires that one order of *n* is chosen for the squad-based items. This is necessary because the returns to scale are not constant. Without this constraint, the model may choose an interval representing the highest incremental value more than once.

Constraint 4- ensures that the $n^{\text{th}}$ order of each marine-based item is issued only once. This prevents the same problem as Constraint 3, but for marine-based items.

Constraint 5- requires that selected items are issued in the same amount for all positions.

Constraint 6- limits selected squad-based items to one per position.

Constraints 7 and 8- require that the decision variables be binary.

### 2. Explanation of the *n* Index

The *n* index represents the $n^{th}$ *order* of an item. For example, $n$=8 represents the eighth item to be issued to the squad, thereby implying that seven items have already been issued. This index must be controlled carefully in our integer linear program because the returns to scale generated from the qualitative model are not constant for all items. This causes some of the measures to have incremental values that are not equal throughout the range of the measure. For example, recall that the incremental value that is gained from issuing any of the first four entrenching tools is greater than the value gained from issuing the fifth. The objective function seeks to maximize the value gained, therefore it would attempt to issue one of the first four entrenching tools again as the fifth issued if the *n* index were not controlled using constraints 3 and 4.

### 3. Variable Explanation

The objective function uses two types of variables to represent two different categories of equipment. Examination of the list of equipment available to the DO squad reveals a natural division of the equipment into two categories. The first category, which we refer to as squad-based equipment, contains all of the equipment that provides the same value to the squad regardless of who is carrying it, such as ponchos, water, and batteries. The second category, called marine-based equipment, contains all of the remaining equipment, which provides a different value to the squad depending on who is carrying it. We use the two categories of equipment to create two different decision variables, $s_{ni}$ and $m_{pni}$. The use of variables for squad-based equipment also decreased the size of the linear program, as it greatly reduced the number of decision variables that had to be generated to provide a solution.

The use of two different variables resulted in the creation of two different coefficients, $c^s$ and $c^m$. The two types of coefficients can be categorized as follows:

$c^{m}_{pni}$ coefficients:

- Represent the incremental value that is gained by the squad by issuing the $n^{th}$ item of type *i* to position *p*.
- Used these to model equipment whose value is a function of position.
- The model may select multiple *n*'s for each item of type *i*. For example, the binary variables for *n*=1 and *n*=2 will both be equal to one if the model selects two of an item to be carried.
- Note: If the marginal value gained by providing the equipment to one position (or group of positions) is different from another, a new value measure was created. This provides great flexibility in representing value within the squad.

$c^{s}_{ni}$ coefficients:

- Represent the value that is gained by the squad by issuing *n* items of type *i*.
- The model will only select one *n* for each item *i*.
- We use these to model the value gained from equipment that has the same value for the squad regardless of the position it is issued to.

The set of squad based items and marine based items are mutually exclusive, i.e., all equipment is categorized as either squad based or marine based. Therefore, the coefficients for all items may only be greater than zero for either $c^m$ or $c^s$, but not both.

## E. MODEL IMPLEMENTATION

### 1. Data

We construct the data containing the physical weight of the items from multiple sources, including data files sent to us from our sponsor, data sheets from item manufacturers, and military publications.

Each position starts with a base load, $BW_p$ that is composed of items such as basic clothing and weaponry that do not change based on the results of the model. The base loads are generated and their weight is calculated for each position prior to running the integer linear programming model.

See Appendix A for the base equipment list for each position.

See Appendix B for the list of available equipment that can be issued by the integer linear program.

### 2. Software

The coefficients representing the value achieved by issuing each item to the squad are determined using Microsoft Excel [Excel, 2003].

We implement this model using the Generalized Algebraic Modeling System (GAMS) Integrated Development Environment. GAMS [2004] is a tool for encoding mathematical programming formulations. GAMS provides the user with a means of formulating the mathematical program in a manner that allows it to interface with separate software packages that actually solve the problem. It then receives and displays the output reports generated by the solver software. We use the CPLEX 9.0 solver [GAMS-CPLEX, 2004].

# V. ANALYSIS

In this chapter we present our model results and provide an analysis of those results to help decision-makers better understand possible improvements to the doctrinal combat loads.

We first compare the assault loads that our model produces with the doctrinal assault loads to show that there is trade space available to create more efficient loads. We then conduct exploratory analysis to show how to lighten the combat load. We also examine the trade-offs between weight and value of the heavier squad equipment. Finally, we suggest changes that can be made to the doctrinal approach march load to reduce the weight each individual must bear.

We conduct this analysis to help decision-makers gain key insights into the creation of combat loads. Throughout the analysis we reference example equipment lists that we provide in the appendices. We do not present the example lists as the ideal load for use by the DO squad, but rather to show examples of combat loads that provide more value to the squad and are lighter than the doctrinal loads.

## A. OBJECTIVES

The following five questions guide our analysis:

- Is there trade space available to improve the doctrinal combat loads?
- Can the variation in the weight of the combat loads across different squad positions be reduced?
- Can the amount and combination of equipment the DO squad carries be modified to reduce combat load weights to the levels recommended by the DOD literature?
- How does adding or removing the heaviest equipment affect the overall value the squad receives?
- What insights can be gained from this analysis to assist policy-makers in their efforts to determine the doctrinal equipment lists for the DO squad?

## B. ASSUMPTIONS

To properly address the above questions, we make assumptions that ensure our research covers the range of current doctrinal missions that the DO squad could encounter. The assumptions that we implement have a very significant effect on the model results. For example, as with previously published doctrinal combat loads, this thesis examines Marines fighting in a moderate climate as opposed to operating in an extremely cold climate which requires the addition of a significant amount of cold weather gear.

Our assumptions for the general mission scenario include:

- The squad is operating using the planned employment of the DO squad. This requires the squad members to carry specialized weapons and a more robust command and control network than the typical infantry squad.
- The squad is dismounted and must carry enough supplies to sustain themselves for 12 hours with the assault load or 24 hours with the approach march load.
- The DO squad is not acting autonomously for long durations. It is provided logistical support from its parent unit while operating in a dispersed manner that supports its DO mission.
- Each member of the squad carries his doctrinal DO weapon(s); however, the ammunition load is determined by the model.
- The squad is equipped for both day and night operations.
- The climate is moderate during the day and cold enough at night to warrant the use of cold weather gear such as polypropylene clothing and sleeping bags for safety.
- The likelihood of precipitation warrants carrying wet weather protection such as a poncho and Gore-Tex wet weather clothing.
- A Nuclear, Biological, or Chemical (NBC) attack is possible.
- Unless otherwise specified in the analysis, it is possible that the squad will receive enemy small arms fire.

## C. INITIAL ANALYSIS

In this section, we determine that our model can generate more efficient assault loads, thereby revealing that there is trade space available to improve the doctrinal loads. To do so, we generate equipment lists that represented the composition of the doctrinal DO squad assault load. Published literature stating the equipment lists for the DO combat loads does not currently exist. By supplementing the assault loads recommended in the ILBE CDD with additional equipment that will be at the DO squad's disposal, we are able to approximate the equipment list for the doctrinal DO assault loads.

To create the doctrinal DO assault loads, we make the following assumptions:

- Each Marine starts with the rifleman assault load as defined in the ILBE CDD.
- Replacement of the M-16 rifle by the M-9 pistol, the M-240G machine gun, and the M249 Squad Automatic Weapon (SAW) is made for the three positions that carry those weapons, and the equipment that is associated with them, such as tripods, are issued to the appropriate positions. We eliminate the M-16 magazines from the three positions carrying the weapons, distribute 400 rounds of M-240G ammunition to the machine gun team, distribute 500 rounds of SAW ammunition to the SAW team, and provide the corpsman carrying the M-9 four M-9 magazines.
- Additional weapons that are available to the squad, such as the Javelin anti-tank missile launcher and the Shoulder-Launched Multipurpose Assault Weapon (SMAW) are provided to the appropriate members of the squad.
- Additional non-weaponry equipment that will be available to the DO squad, such as personal role radios (PRR's), thermal binoculars, and AN/PRC-148 MBITR radios are provided to the squad.

To determine if we could generate more efficient assault loads, we first run the model while increasing the maximum individual combat load weight in five pound increments, starting at the minimum feasible weight of 55 pounds. This creates a curve that represents the maximum equipment value the squad receives while limiting the weight each member can carry. From this point on, we refer to this curve as a value curve. We then evaluate the doctrinal DO assault load in our model. The results reveal an average weight of 95.2 pounds for the doctrinal load with significant variation of weight across the members of the squad. The doctrinal load is compared to our value curve in Figure 6. The doctrinal assault load falls below our value curve, indicating it is less efficient than the loads that can be generated by our model.

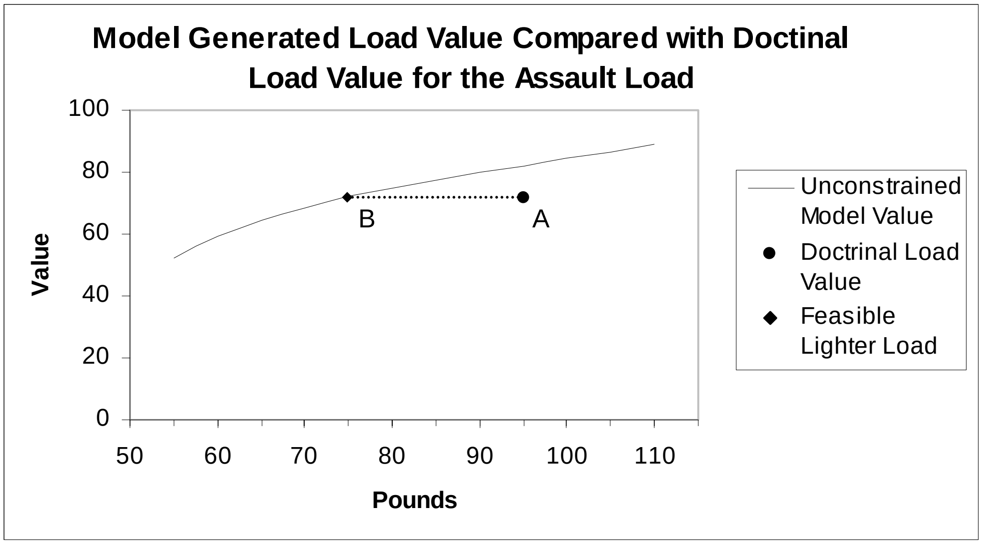


Figure 6. Assault load value curve and the doctrinal assault load

Point A represents the doctrinal DO assault load and reveals the inefficiency of the equipment composition of the doctrinal load, i.e., given the same weight, the doctrinal DO assault load provides less value to the squad. Figure 6 also shows that we can achieve a lower combat load weight while keeping the value the squad receives constant. Specifically, the squad can receive approximately the same value as it does from the doctrinal combat loads at a lower average load weight of 75.5 pounds, as depicted at Point B.

The model-generated loads provide an additional benefit not shown in Figure 5. The data point representing the doctrinal combat load, point A, is graphed using the average weight that the squad members carry, which is approximately 95 pounds. By cross-loading the equipment across the positions within the squad, the model reduces the variation of weight across the different squad positions. Table 2 shows that the doctrinal assault load weight varies by 34.7 pounds, but the model-generated assault load reduces the variation of weight to 1.7 pounds.

| | Average Weight (lbs) | Minimum Weight (lbs) | Maximum Weight (lbs) |
|---|---|---|---|
| Doctrinal Assault Loads | 95.2 | 76.5 | 111.2 |
| Model-generated Assault Loads | 75.5 | 74.3 | 76.0 |

Table 2. Comparison of weight variation across squad positions for the assault load

Our initial analysis reveals that we can generate loads that are lighter and provide more value to the squad. We also show that the amount of variation in pack weight across different squad positions can be reduced. Most importantly, we reveal that there is trade space available to improve the doctrinal assault load.

## D. CREATION OF THE MINIMUM COMBAT LOAD

In the previous section, we show how we can generate an assault load with an average weight of 75.5 pounds; exceeding the target weight set by DOD doctrine. To determine if the target weight of 51 pounds (as specified by doctrine) can be met, we create a load that we refer to from this point on as the minimum combat load for the DO squad. The minimum combat load is created by determining the combat load that meets several restrictions and has the lowest feasible weight.

To generate the minimum combat load, we constrain the model to ensure the following restrictions are met:

- Each squad member carries at least 2 quarts of water.
- Squad members with the M-16 carry at least two 30 round magazines.
- The Machine Gunner and the Automatic Rifleman each carry at least 200 rounds of ammunition.
- Lightweight kevlar helmets, flak vests, and SAPI plates are not worn.
- The SMAW and Javelin weapons are not carried.

Our analysis reveals that the weight of some weapons, i.e., the M-240G machine gun, prohibit the combat loads from meeting weight recommendations found in the DOD literature. The lightest feasible average weight that can be achieved while meeting the above restrictions is 54.6 pounds. The minimum combat load's weight characteristics are shown in Table 3.

| | Average Weight (lbs) | Minimum Weight (lbs) | Maximum Weight (lbs) |
|---|---|---|---|
| Model-generated Minimum Combat Load | 54.6 | 54.1 | 55.0 |

Table 3. Minimum combat load weight characteristics

The equipment list for the minimum combat load provides insight about the equipment that can be issued while keeping the weight that each position must carry to a minimum. See Appendix C, Tab 2 for the equipment list for the minimum combat load.

In addition to showing that the DOD doctrinal weight is not attainable given our equipment requirements, the minimum combat load also provides a starting point on which we build the rest of the analysis.

## E. EXPLORATORY ANALYSIS OF THE ASSAULT LOAD

To gain a better understanding of the assault load's trade space, we explore the results our model provides when constrained to carry and constrained to not carry certain equipment. First, we explore the trade space available when the squad carries the SMAW and Javelin and when it does not. The SMAW launch unit weighs 16.6 pounds, and its associated rockets each weigh 13 pounds. The Javelin launch unit weights 14.5 pounds and its associated missile weighs 35 pounds. The weight of these weapons should dictate that the DO squad only carries these weapons when required by the mission parameters.

The assessments impacted by these items are produced based on our general assumptions on page 34, therefore, they may not represent the value that the squad receives on specialized missions. For example, if the DO squad were assaulting a bunker position, they would receive more value from the SMAW than provided under the assumptions we used to generate our model. However, by using our general assumptions for this section of the analysis we gain an understanding of the effect these two weapons have on the combat load under most circumstances. This portion of the analysis also reveals the equipment the model will substitute in place of the SMAW and Javelin when they aren't carried.

We first examine the effect these weapons have on the combat load by determining how the addition of these weapons changes the value curve produced by the model. The results can be seen below in Figure 7.

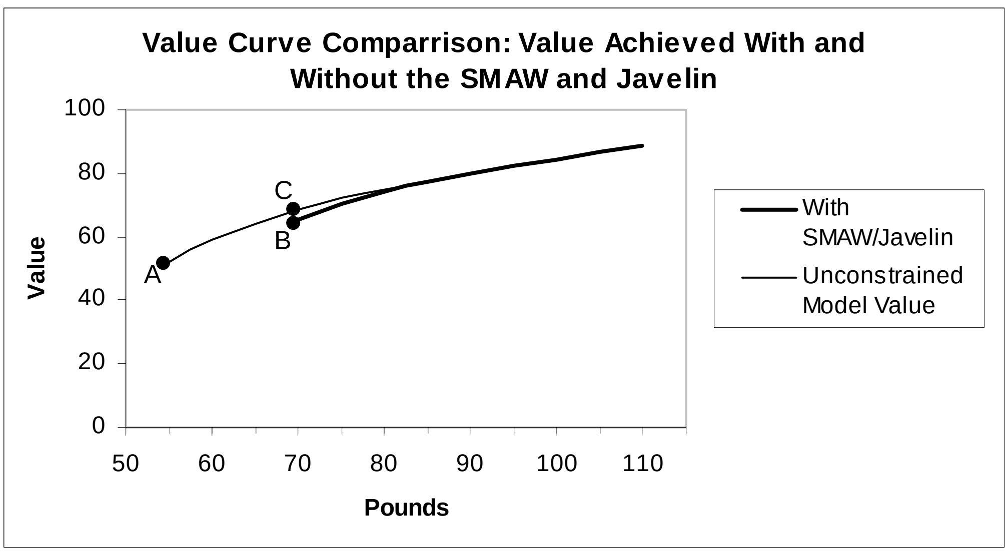


Figure 7. Assault load value curve with and without the SMAW and Javelin

Figure 7 shows the unconstrained model value curve and the value curve generated when the SMAW and Javelin are required to be carried by the DO squad. The unconstrained model value curve starts at the weight and value of the minimum combat load, represented by Point A, gaining value as more equipment (including the SMAW and Javelin) is added to the minimum combat load. Conversely, if the SMAW and Javelin are required, the weight of the 35 pound Javelin missile prevents the Marine in the Assistant Javelin Gunner position from dropping below a weight of 69 pounds (without body armor).

Also, Figure 7 shows that if the SMAW and Javelin are not carried the model is able to provide the squad with more value at some weights. More specifically, at Point B, the model requires that the squad carry the SMAW and Javelin launchers and munitions. Point C shows the increase in value the squad receives at the same weight by substituting items such as M-16 magazines, 40mm HE/DP rounds, and 5.56 belted ammunition in their place.

Next, we examine the use of body armor within the DO squad. The after action reports from Marine units participating in OIF and OEF provide great praise for the addition of the Small Arms Protective Inserts that slip inside the flak vest and provide increased protection from ballistic hits. A complete set of plates weights 8 pounds, and when combined with an 8.4 pound flak vest and a 3 pound helmet, the Marine wearing body armor is provided protection, but must carry nearly 20 extra pounds.

Though it is typically standard procedure for every Marine to wear body armor while engaged in direct action, DO literature suggests that the concept will place Marines in a number of missions where direct action is less likely. For example, statements such as, "Small units at the platoon level and below will require enhanced capabilities to collect, report, and exploit intelligence" [CMC, 2005, p. 8] suggest that reconnaissance is a role that the DO squad will conduct regularly. Further, the DO concept calls for additional "call for fire" training to enable the DO squad to focus indirect fire support on the battlefield as forward observers. Missions such as these, which extend beyond traditional force on force action, may reduce the need for body armor. We examine this issue by analyzing the trade space made available by adding or taking away body armor from the combat load. Figure 8 shows the resulting value curves.

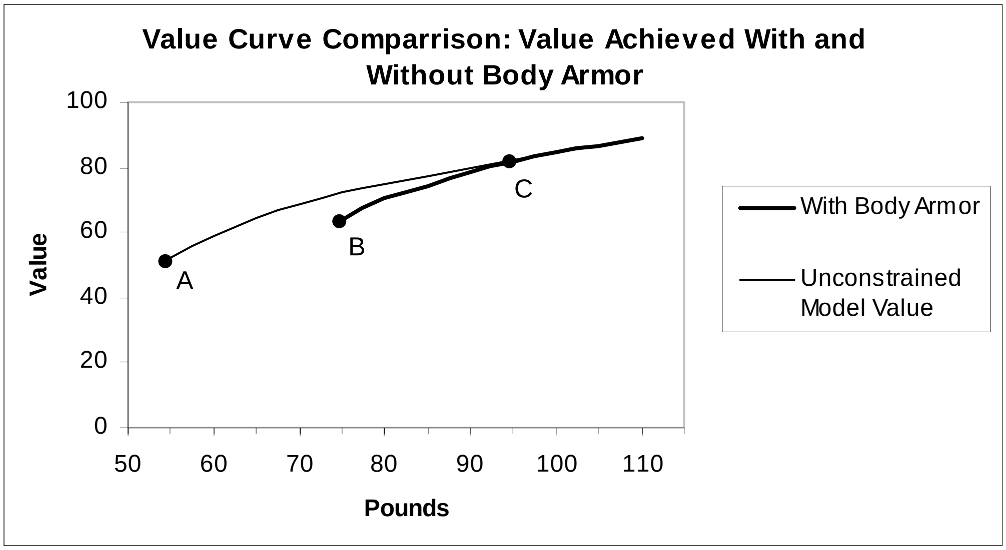


Figure 8. Assault load value curve with and without body armor

Figure 8 shows the unconstrained model value curve and the value curve generated when the DO squad is required to wear body armor. The unconstrained model curve starts at the weight and value of the minimum combat load, represented by Point A, and adds the three pieces of body armor (as well as other equipment) as they each become part of the model's optimal gear load. Our results show that if the squad is required to wear body armor the minimum weight that can be achieved is 75 pounds, depicted by Point B. See Appendix C, Tab 3 for an example assault load our model generates at Point B.

Figure 8 shows that for most weights, more value is provided by the model-generated loads when the squad is not required to carry body armor. It also reveals that the two curves meet at Point C when the maximum weight each individual carries is 95 pounds. This provides insight regarding the use of body armor by showing that no value is lost by mandating the use of body armor at assault load weights above 95 pounds.

To finish our analysis of the assault load, we examine the effect of requiring the squad to wear both body armor and carry the SMAW and Javelin. We determine that the minimum feasible combat load weight when the squad is required to do so is 91 pounds. The resulting equipment list for the assault load meeting these restrictions is shown in Appendix C, Tab 4. This example assault load provides more value to the squad than the doctrinal assault load, has a maximum combat load weight for all positions that is four pounds lighter than the average weight of the doctrinal assault load, and reduces the variation of combat load weight that is seen across the positions from 34.7 pounds to 1.3 pounds.

## F. ANALYSIS OF THE APPROACH MARCH LOAD

In this section we examine how carrying the approach march load, with sustainment sufficient for 24 hours of operation, affects the DO squad's combat load. DO forces that are foot mobile for an extended duration will need to carry sufficient consumable supplies to continue to be combat effective. Additional food, water, and ammunition is required when operating for longer periods away from supporting units. Further, the importance of protection from cold and wet weather will likely increase, thereby mandating that DO Marines carry additional equipment to protect themselves from the environment.

We first reevaluate the multiple attribute decision analysis model and modify the value functions to reflect the change from 12 hours of sustainment to 24 hours of sustainment. We also reassess the swing weight matrix to ensure that it accurately reflects the new trade-offs amongst attributes when the squad is operating for longer periods. The new coefficients resulting from these changes are incorporated into the integer linear program and a new value curve is generated. This curve starts at a higher minimum weight than that of the assault load, as our new assumptions ensure that sufficient sustainment is provided for 24 hours of operation. This new value curve can be seen below in Figure 9.

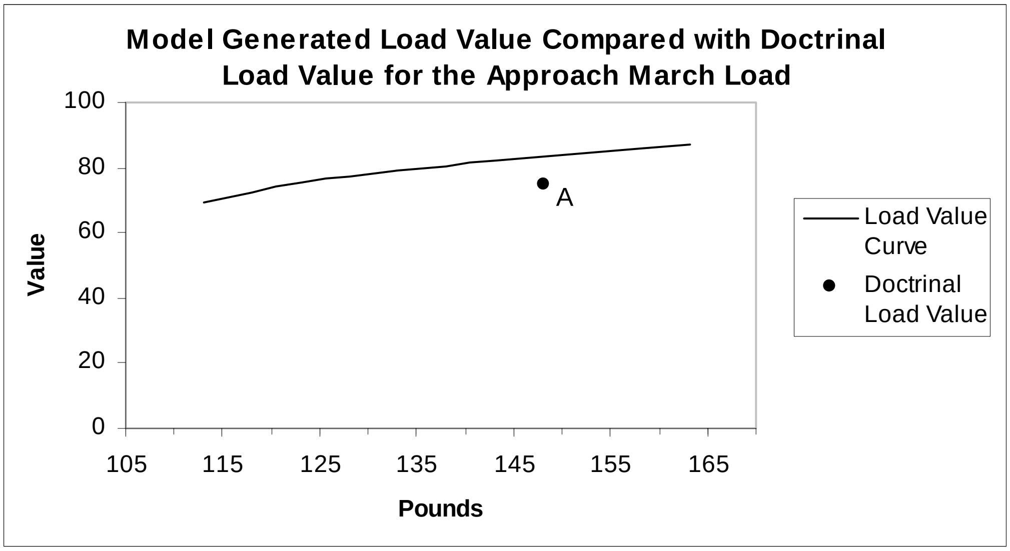

Figure 9. Approach march load value curve and the doctrinal approach march load

Point A in Figure 9 shows the value that is achieved when we evaluate the equipment provided by the doctrinal approach march load in our model. The average weight of the doctrinal approach march load, at 148.1 pounds, is nearly double the DOD literature's recommended load weight of 76 pounds. Similar to the assault load, the approach march load lies below the model-generated value curve, revealing that there is trade space available to create more efficient equipment combinations for the DO squad.

While the model is able to create approach march loads with weights for all members of the squad as low as 113 pounds, these loads provide less value to the squad than the doctrinal load and lack some items that would benefit the DO squad when they are carrying the approach march load. We use the model to create an example approach march load that provides more value to the squad while reducing the average weight that the squad members must carry by 21 pounds. We construct the example approach march load by adding additional items to the assault load, thus allowing the DO squad to remove the additional items to easily change from the approach march load to the assault load.

The example approach march load provides sufficient sustainment by ensuring that each member carries at least 5 quarts of water, two Meals, Ready to Eat (MRE's), more ammunition, and additional batteries. It prepares the squad for the various combat scenarios they may encounter while on the march by providing body armor, the M40 gas mask, and the SMAW and Javelin. Finally, the example approach march load provides several items, including the Modular Sleeping Bag System, Gore-Tex raingear, and ponchos, that protect the squad members from the environment. The resulting equipment list can be seen in Appendix D, Tab 5.

As before, the model distributes the equipment throughout the squad more effectively, resulting in less variation of the combat load weight across the positions. See Table 4, below, for the improvement seen when comparing the model-generated approach march load to the doctrinal load.

| | Average Weight (lbs) | Minimum Weight (lbs) | Maximum Weight (lbs) |
|---|---|---|---|
| Doctrinal Approach March Loads | 149.9 | 129.0 | 158.6 |
| Model-generated Approach March Load | 120.7 | 119.5 | 121.0 |

Table 4. Comparison of weight variation across squad positions for the approach march load

As we have in our analysis of the assault load, we show how careful creation of the approach march load can reduce the variation in the weight across different squad positions. We also present an example approach march load that is lighter and provides more value to the squad than the doctrinal load. Most importantly, we reveal here that more efficient doctrinal approach march loads can be created for the DO squad.

# VI. CONCLUSIONS

This analysis provides the Marine Corps with an analytical framework that can be used to evaluate and improve combat loads. To conduct the analysis, we develop an integer linear program incorporating Value-Focused Thinking principles and multiple objective decision analysis concepts.

Research regarding combat load weights conducted by the Marine Corps in the last five years was based on the infantry rifleman's doctrinal load. These previous studies tend to neglect the other members of the infantry squad who must carry heavier weapons and additional equipment, resulting in heavier combat loads. The amount and type of equipment that the Marine infantryman carries into battle exceeds the recommended assault load and approach march load weights found in the DOD literature. Based on our assumptions of the general mission scenarios developed from current DO literature, this problem is made worse by the implementation of the DO concept which has an average doctrinal load weight of 95.2 pounds for the assault load and 149.9 pounds for the approach march load. These weights are nearly double the DOD literature's recommended weights of 51 pounds for the assault load and 76 pounds for the approach march load. Examination of the doctrinal DO load weights reveals variation across the squad positions by as much as 38 percent of the average load weight. The Marine Corps cannot meet the recommended weights unless lighter equipment is developed or less equipment is carried.

Current doctrinal loads require the different positions in the Marine Corps infantry squad to carry varied weaponry. This ensures that each of the squad member's weapons contribute a vital portion of the total combat strength. Our results indicate that the Marine Corps can benefit from extending this concept to the rest of the equipment that composes the combat load. By building specialized loads for each position within the squad, we ensure that the equipment an individual carries is designed to serve as an integral part of the squad's overall capabilities, but at the same time allow enough redundancy to mitigate risk to mission accomplishment.

By allowing the model to cross-load equipment throughout the squad, we are able to build improved combat loads. The model-generated loads are lighter and more efficient than doctrinal loads. They also greatly reduce the variation of weight seen across the members of the squad ensuring that no individual carries more weight than another. See Table 5 below for a summary of the improved combat load weights.

| Load Name (Model-generated or Doctrinal) | Model Load Average Wt. (lbs) *Range (lbs)* | Doctrinal Load Average Wt. (lbs) *Range (lbs)* |
|---|---|---|
| Minimum combat load | 54.6 *54.1 to 55.0* | N/A |
| DO Assault load 1 (body armor required) | 74.7 *74.2 to 75.0* | 92.3 *76.5 to 111.2* |
| DO Assault load 2 (body armor, SMAW, and Javelin required) | 90.4 *89.6 to 90.9* | 95.2 *76.5 to 111.5* |
| DO Approach march load | 120.7 *119.5 to 121.0* | 149.9 *129.0 to 158.6* |

Table 5. Summary comparison of weights for model-generated example loads and doctrinal loads

Our research reveals that more efficient combat loads can be developed for the infantry squad, whether operating in a DO manner or not. Careful creation of specialized combat loads for each position within the Marine squad results in lighter loads that provide more value to the squad. We anticipate these findings will contribute to a shift in thinking among decision-makers, leading to doctrinal loads that promote mission success for the squad and lighten the weight of the doctrinal combat load Marines must carry into battle.

# APPENDIX A. BASE EQUIPMENT BY POSITION

The following equipment is provided to the squad before the model adds additional equipment, and is considered the base equipment for each position.

| | SQ LDR | FT LDR | SMAW GNR | AST SMAW GNR | JAV GNR | AST JAV GNR | MCH GNR | AST MCH GNR | MG TM LDR | AUTO RFL | AST AUTO RLF | RFL | CPS MN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CORPSMAN FIRST AID KIT | | | | | | | | | | | | | X |
| PATROL PACK | X | X | X | X | X | X | X | X | X | X | X | X | X |
| LBE - BASIC | X | X | X | X | X | X | X | X | X | X | X | X | X |
| M240 MACHINE GUN | | | | | | | X | | | | | | |
| GRENADE LAUNCHER, M203 | X | X | | | | | | | | | | | |
| JAVELIN COMMAND LAUNCH UNIT | | | | | X | | | | | | | | |
| M-240 TRIPOD | | | | | | | | | X | | | | |
| M-9 PISTOL | | | | | | | | | | | | | X |
| OTHER COMPONENTS M-249 | | | | | | | | | | | X | | |
| M16A4 with RCO | X | X | X | X | X | X | | X | X | | X | X | |
| SMAW LAUNCHER | | | X | | | | | | | | | | |
| SPARE BARREL M-249 | | | | | | | | | | | X | | |
| SQUAD AUTOMATIC WEAPON, M249 | | | | | | | | | | X | | | |
| PAS-13 THERMAL WEAPON SIGHT | | | | | | | | X | | X | | | |
| PVS-17B WEAPON SIGHT | X | X | X | X | X | X | | X | X | | X | X | |
| PVS-17C WEAPON SIGHT | | | | | | | X | | | X | | | |
| PEQ-2 AIMING LIGHT/SIGHT | X | | | | | | | | X | | | | |
| PSQ-18 (ENHANCED SIGHT M-203) | X | X | | | | | | | | | | | |
| 100oz WATER RESERVOIR | X | X | X | X | X | X | X | X | X | X | X | X | X |
| CAMOUFLAGE FACE PAINT | X | X | X | X | X | X | X | X | X | X | X | X | X |
| CHAPSTICK | X | X | X | X | X | X | X | X | X | X | X | X | X |
| EXTRA SOCKS | X | X | X | X | X | X | X | X | X | X | X | X | X |
| EAR PLUGS WITH CASE | X | X | X | X | X | X | X | X | X | X | X | X | X |
| TOOTH BRUSH WITH PASTE | X | X | X | X | X | X | X | X | X | X | X | X | X |
| SEWING KIT | X | X | X | X | X | X | X | X | X | X | X | X | X |
| REGULAR COMPLETE UNIFORM | X | X | X | X | X | X | X | X | X | X | X | X | X |
| SHAVING GEAR, TOWEL, FACE CLOTH | X | X | X | X | X | X | X | X | X | X | X | X | X |

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# APPENDIX B. LIST OF ATTRIBUTES AND ASSOCIATED EQUIPMENT

| Attribute Name | Associated Equipment |
|---|---|
| Hydration Maintenance | Quarts of water |
| Nutritional Sustainment | MREs |
| Individual Casualty Care | Individual First Aid Kits (IFAKs) |
| NBC Absorption Protection | JLIST NBC protective suits |
| NBC Inhalation Protection | M40 gas masks |
| Ballistic Head Protection | Lightweight kevlar helmets |
| Small Arms Protection | SAPI plates |
| Flak Protection | Flak vests |
| Cold Weather Sleeping/Stationary Comfort | Isopor mats<br>Modular Sleeping Bag Systems<br>Poncho liners |
| Cold Weather Awake/Mobile Comfort | Polypropylene bottoms/pants<br>Polypropylene tops/shirts |
| Wet Weather Sleeping/Stationary Comfort | Gore-Tex bivy sacks<br>2 man tents<br>Ponchos |
| Wet Weather Awake/Mobile Comfort | Gore-Tex bottoms/pants<br>Gore-Tex tops/parkas<br>Ponchos |
| Illumination Signals | 40mm illumination rounds |
| Smoke Signals | 40mm smoke rounds |
| Extended Inter Squad Communications | Personal Role Radio (PRR) batteries |
| Extended Intra Squad Communications | AN/PRC148 MBITR batteries |
| Inter Squad Communications | Personal Role Radios (PRR) |
| Intra Squad Communications | AN/PRC148 MBITR radios |
| Cutting Capability | Bayonets |
| Digging Capability | Entrenching tools |
| Thermal Night Vision | Thermal Binoculars |
| Ambient Light Night Vision | PVS-14 Night Vision Monoculars |
| Weapon Fired Battlefield Illumination | 40mm illumination rounds |
| Hand Thrown HE | M67 Fragmentation hand grenades |
| Sustainment of Pistol Fire | M9 pistol magazines w/ 15 rounds |
| Sustainment of Rifle Fire | M-16 rifle magazines w/ 30 rounds |
| Sustainment of Indirect HE Fire | 40mm HE/DP grenade for M203 |
| Sustainment of Anti-Tank Fires | Javelin missiles |
| Sustainment of Anti-Armor/Anti-Bunker Fires | SMAW rockets |
| Sustainment of Automatic Rifle Fires | 100 rounds 5.56 link ammunition |
| Sustainment of Light Machine Gun Fires | 100 rounds 7.62 link ammunition |

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# APPENDIX C. SELECTED EXAMPLE EQUIPMENT LISTS

## TAB 1. LIST OF ABBREVIATIONS USED IN THIS APPENDIX

The following abbreviations are used to describe equipment in this appendix:

| | |
|---|---|
| Batts | Batteries |
| Botts | Bottoms i.e. pants |
| E_tools | Entrenching Tools |
| G_Tex | Gore-Tex |
| Grenades | M67 fragmentation grenades |
| HE40mm | 40mm High Explosive Round |
| Illum | 40mm Illumination Round |
| Jav | Javelin man portable anti-tank weapon |
| JLIST_Suits | Joint Service Lightweight Integrated Suit Technology (NBC Suit) |
| Link | Linked ammunition |
| Ltwt | Lightweight |
| M40_Gas_Msk | M40 Chemical Gas Mask |
| Mag | Magazine |
| Pncho_Lnr | Poncho Liner |
| PRC148 | AN/PRC 148 MBITR Radio |
| PVS_14s | AN/PVS-14 Night Vision Monoculars |
| Smoke | 40mm Smoke Round |
| T_Bino | Thermal Binoculars |

The following abbreviations are used to describe squad positions in this appendix:

| | |
|---|---|
| AST AUTO RLF | Assistant Automatic Rifleman |
| AST JAV GNR | Assistant Javelin Gunner |
| AST MCH GNR | Assistant Machine Gunner |
| AST SMAW GNR | Assistant SMAW Gunner |
| AUTO RFL | Automatic Rifleman |
| CPS MN | Corpsman |
| FT LDR | Fire Team Leader |
| JAV GNR | Javelin Gunner |
| MCH GNR | Machine Gunner |
| MG TM LDR | Machine Gun Team Leader |
| RFL | Rifleman |
| SMAW GNR | SMAW Gunner |
| SQ LDR | Squad Leader |

**TAB 2. EQUIPMENT LIST, MINIMUM DO COMBAT LOAD: SMAW AND JAVELIN NOT REQUIRED, BODY ARMOR NOT REQUIRED**

This table lists the equipment that the model assigns to each position in the DO squad to create an efficient minimum combat load. It is generated by allowing all positions to carry up to 55 pounds and not requiring the DO squad to wear body armor or carry the SMAW or Javelin. Each position also carries the base equipment found in Appendix A.

| Item | AST AUTO RLF | AST JAV GNR | AST MCH GNR | AST SMAW GNR | AUTO RFL | CPS MN | FT LDR | JAV GNR | MCH GNR | MG TM LDR | RFL | SMAW GNR | SQ LDR | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bayonets | | 1 | 1 | 1 | 1 | | | 1 | | | 1 | 1 | 1 | 8 |
| E_tools | | 1 | 1 | | | | | 1 | | | | 1 | | 4 |
| Grenades | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | | | 1 | 1 | 1 | 10 |
| HE40mm | | | | 1 | | | 2 | 1 | | | 1 | 1 | 2 | 8 |
| IFAKs | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | 11 |
| Illum | | | | | | | | | | | | | 2 | 2 |
| Link_556 | 5 | 3 | | 1 | 2 | | | 2 | | | 2 | 1 | | 16 |
| Link_762 | | | 1 | | | | | | 1 | | | | | 2 |
| M16_Mag | 2 | 2 | 2 | 3 | | | 3 | 2 | | 2 | 2 | 2 | 2 | 22 |
| M9_Mag | | | | | | 4 | | | | | | | | 4 |
| PRC148 | | 1 | | 1 | | | 1 | | | | | 1 | 1 | 5 |
| PRC148_Batts | | | | 4 | | | | | | | | 1 | | 5 |
| PRR_Batts | | 3 | | 1 | | 1 | | 1 | 3 | 1 | 1 | 1 | | 12 |
| PRRs | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 12 |
| PVS_14s | | 1 | 1 | 1 | | 1 | | 1 | | | 1 | 1 | | 7 |
| Quarts_water | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 26 |
| Smoke | | | | | | | | 1 | | | | 1 | 1 | 3 |
| T_Bino | | | | | | | 1 | | | | 1 | | | 2 |

## TAB 3. EQUIPMENT LIST, EXAMPLE DO ASSAULT LOAD 1: SMAW AND JAVELIN NOT REQUIRED, BODY ARMOR REQUIRED

This table lists the equipment that the model assigns to each position in the DO squad to create an efficient assault load. It is generated by allowing all positions to carry up to 75 pounds, requiring the DO squad to wear body armor, and not requiring the squad to carry the SMAW or Javelin. Each position also carries the base equipment found in Appendix A.

| Item | AST AUTO RLF | AST JAV GNR | AST MCH GNR | AST SMAW GNR | AUTO RFL | CPS MN | FT LDR | JAV GNR | MCH GNR | MG TM LDR | RFL | SMAW GNR | SQ LDR | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bayonets | | 1 | 1 | 1 | 1 | | | 1 | | | 1 | 1 | | 7 |
| E_tools | | 1 | | | | | | 1 | | | 1 | 1 | | 4 |
| FLAK_Vests | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Grenades | 1 | 1 | 1 | 1 | | | | 1 | | | 1 | 1 | 1 | 8 |
| HE40mm | | 1 | | 2 | | | 2 | 1 | | | | | 2 | 8 |
| IFAKs | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | 11 |
| Illum | | | | | | | | | | | | | 4 | 4 |
| Link_556 | 5 | 2 | | 3 | 3 | | | 1 | | | | 3 | | 17 |
| Link_762 | | | 2 | | | | | | 1 | | 1 | | | 4 |
| Ltwt_Helmets | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| M16_Mag | 3 | 2 | 2 | 2 | | | 3 | 2 | | 2 | 3 | 2 | 4 | 25 |
| M9_Mag | | | | | | 4 | | | | | | | | 4 |
| PRC148 | | 1 | | | | | 1 | | | | 1 | 1 | 1 | 5 |
| PRC148_Batts | | 1 | | | | 1 | | | | | 2 | 1 | | 5 |
| PRR_Batts | | | 3 | 1 | | 1 | | 2 | | 4 | 2 | | | 13 |
| PRRs | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| PVS_14s | | 1 | | 1 | | 1 | | 1 | | | 1 | 1 | | 6 |
| Quarts_water | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 26 |
| SAPI_Plates | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Smoke | | | | | | | 1 | | | | | | | 1 |
| T_Bino | | | | | | | 1 | 1 | | | | | | 2 |

## TAB 4. EQUIPMENT LIST, EXAMPLE DO ASSAULT LOAD 2: SMAW AND JAVELIN REQUIRED, BODY ARMOR REQUIRED

This table lists the equipment that the model assigns to each position in the DO squad to create an efficient assault load. It is generated by allowing all positions to carry up to 91 pounds and requiring the DO squad to carry the SMAW and Javelin and wear body armor. Each position also carries the base equipment found in Appendix A.

| Item | AST AUTO RLF | AST JAV GNR | AST MCH GNR | AST SMAW GNR | AUTO RFL | CPS MN | FT LDR | JAV GNR | MCH GNR | MG TM LDR | RFL | SMAW GNR | SQ LDR | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bayonets | 1 | | 1 | | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 9 |
| E_tools | | | | | | 1 | 1 | 1 | | | 1 | | | 4 |
| FLAK_Vests | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Grenades | 1 | | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| HE40mm | 1 | | | | | | 2 | | | | 2 | | 3 | 8 |
| IFAKs | 1 | | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| Illum | | | | | | | | | | | | | 4 | 4 |
| Jav_Misl | | 1 | | | | | | | | | | | | 1 |
| Link_556 | 8 | | | | 5 | | 1 | 1 | | | 2 | | | 17 |
| Link_762 | | | 4 | | | | | | 2 | 1 | | | | 7 |
| Ltwt_Helmets | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| M16_Mag | 2 | 2 | 2 | 4 | 1 | | 3 | 2 | 2 | 3 | 14 | 12 | 6 | 53 |
| M9_Mag | | | | | | 4 | | | | | | | | 4 |
| PRC148 | | | | | 1 | | 1 | 1 | | | 1 | | 1 | 5 |
| PRC148_Batts | | | | | | 5 | | | | | | | | 5 |
| PRR_Batts | | | | | | 13 | | | | | | | | 13 |
| PRRs | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| PVS_14s | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 |
| Quarts_water | 3 | 3 | 3 | 3 | 3 | 6 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 42 |
| SAPI_Plates | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| SMAW_R | | | | 2 | | | | | | | | | | 2 |
| Smoke | | | | | | | 4 | | | | | | | 4 |
| T_Bino | | | | | | | | 1 | | | | | 1 | 2 |

## TAB 5. EQUIPMENT LIST, EXAMPLE DO APPROACH MARCH LOAD

This table lists the equipment that the model assigns to each position in the DO squad to create an efficient approach march load. It is generated by allowing all positions to carry up to 121 pounds. Each position also carries the base equipment found in Appendix A.

| Item | AST AUTO RLF | AST JAV GNR | AST MCH GNR | AST SMAW GNR | AUTO RFL | CPS MN | FT LDR | JAV GNR | MCH GNR | MG TM LDR | RFL | SMAW GNR | SQ LDR | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bayonets | 1 | | 1 | 1 | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 10 |
| Bivy_Sacks | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| E_tools | | | | 1 | | | | 1 | | | 1 | 1 | | 4 |
| FLAK_Vests | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| G_Tex_Bott | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| G_Tex_Tops | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Grenades | 1 | | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | | 9 |
| HE40mm | | | | | | | 3 | 2 | | | 6 | | 4 | 15 |
| IFAKs | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 |
| Illum | | | | | | | 13 | | | | | | 3 | 16 |
| ISO_Mats | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Jav_Misl | | 1 | | | | | | | | | | | | 1 |
| Link_556 | 8 | | | 3 | 7 | | | | | | | 2 | | 20 |
| Link_762 | | | 4 | | | | | | 3 | 1 | | | | 8 |
| Ltwt_Helmets | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| M16_Mag | 7 | 6 | 6 | 7 | | | 6 | 7 | | 7 | 6 | 7 | 6 | 65 |
| M40_Gas_Msk | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| M9_Mag | | | | | | 8 | | | | | | | | 8 |
| MOLLE | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| MREs | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 26 |
| MSBS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Polypro_Bott | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Polypro_Tops | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Ponchos | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| PRC148 | | | | 1 | | | 1 | 1 | | | 1 | | 1 | 5 |
| PRC148_Batts | 1 | | | | | 3 | | 2 | 1 | | 2 | 1 | | 10 |
| PRR_Batts | | 3 | | 4 | | 6 | | 3 | | | 5 | 3 | | 24 |
| PRRs | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 |
| PVS_14s | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 12 |
| Quarts_water | 5 | 5 | 5 | 5 | 5 | 11 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 71 |
| SAPI_Plates | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| SMAW_R | | | | 1 | | | | | | | | | | 1 |
| Smoke | | | | | 1 | | 1 | | | | | | 2 | 4 |
| T_Bino | | | | | | | | | | | 1 | | 1 | 2 |

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