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THESIS

IMPLEMENTATION OF THE QUANTIFIED JUDGMENT MODEL TO EXAMINE THE IMPACT OF HUMAN FACTORS ON MARINE CORPS DISTRIBUTED OPERATIONS

by

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September 2007

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The Distributed Operations (DO) concept is designed to answer the challenge of covert, highly adaptable, enemies operating with a dispersed command structure. The human variance that is part of military combat presents a critical challenge to the United States Marine Corps in the implementation of the DO concept. In addition to all current capabilities a DO Marine unit would have the additional capability of operating in smaller, more autonomous units, and would have greater authority to take actions in a given situation. The domains of Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities (DOTMLPF) and Human Systems Integration (HSI) are areas where augmentation of current Marine Corps policy could enable Distributed Operations as a capability. This thesis presents a modified form of Dupuy's Quantified Judgment Model (QJM) (1987) called the Predictive Force Ratio Model. It is programmed in Microsoft Excel and first develops a score for a given unit based on physical characteristics pertaining to fire power, then adjusts that score through the use of factor weightings. The model is intended for use by a subject matter expert in estimating the gains that can be achieved in combat power through improvement of a force's human capabilities.

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ABSTRACT

The Distributed Operations (DO) concept is designed to answer the challenge of covert, highly adaptable, enemies operating with a dispersed command structure. The human variance that is part of military combat presents a critical challenge to the United States Marine Corps in the implementation of the DO concept. In addition to all current capabilities a DO Marine unit would have the additional capability of operating in smaller, more autonomous units, and would have greater authority to take actions in a given situation. The domains of Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities (DOTMLPF) and Human Systems Integration (HSI) are areas where augmentation of current Marine Corps policy could enable Distributed Operations as a capability. This thesis presents a modified form of Dupuy's Quantified Judgment Model (QJM) (1987) called the Predictive Force Ratio Model. It is programmed in Microsoft Excel and first develops a score for a given unit based on physical characteristics pertaining to fire power, then adjusts that score through the use of factor weightings. The model is intended for use by a subject matter expert in estimating the gains that can be achieved in combat power through improvement of a force's human capabilities.

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LIST OF ABBREVIATIONS AND ACRONYMS

CEV	Combat Effectiveness Value
DO	Distributed Operations
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities
FS	Force Strength
HSI	Human Systems Integration
MCWL	Marine Corps Warfighting Lab
MOUT	Military Operations in Urban Terrain
OLI	Operational Lethality Index
PFRM	Predictive Force Ratio Model
QJM	Quantified Judgment Model
SME	Subject Matter Expert
TLI	Total Lethality Index
USMC	United States Marine Corps
VF	Variable Factors

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EXECUTIVE SUMMARY

Throughout history, various attempts have been made by military strategists to quantify the elements of combat. This task is difficult because of the inherent human dimensions involved in any combat engagement. Traditional techniques for estimating combat power have focused on those qualities of a military force that are easy to measure, such as number of soldiers or artillery. History has shown, however, that these type of concrete measurements often have a limited, sometimes even inconsequential, impact on the outcome of a battle or engagement.

The human variance that is part of military combat presents a critical challenge to the United States Marine Corps in the implementation of the Distributed Operations (DO) concept. The DO concept is designed to answer the challenges of warfare in the 21st century, where enemies are often covert, highly adaptable, and operate with a dispersed command structure. In response to these characteristics, a DO Marine unit would have the capability of operating in smaller, more autonomous units, and would have greater authority to take actions in a given situation. These capabilities must come without sacrificing any current day capabilities. The domains of Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities (DOTMLPF) and Human Systems Integration (HSI) are areas where augmentation of current Marine Corps capabilities could enable Distributed Operations as a capability.

One method for studying the effect of human behavior on combat is the Quantified Judgment Model (QJM) (Dupuy, 1987). This model is a tool for examining a historical conflict and measuring the impact of human factors on the outcome. The purpose of this thesis is to devise a strategy whereby decision makers can explore the potential effects of various DOTMLPF and HSI decisions. This thesis presents a modified version of the QJM model called the Predictive Force Ratio Model. This model is programmed in Microsoft Excel and first

develops a score for a given unit based on physical characteristics pertaining to fire power. This score is then adjusted through the use of factor weightings to estimate the actual combat power available in a given situation or type of operation. The model is intended for use by a subject matter expert in estimating the gains that can be achieved in combat power, through improvement of a force's human capabilities. This model represents a necessary step for the Marine Corps that will permit measurement of the gains that the Distributed Operations concept is expected to generate. This model will also enable a cost benefit analysis of various alternatives for achieving the Distributed Operations vision. The PFRM may be accessed at the following web address. http://www.nps.navy.mil/or/Desmond_PFRM_Model.htm

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I. INTRODUCTION

A. OVERVIEW

With the end of the cold war, the likelihood of the United States fighting a conventional war with a peer or near peer competitor decreased drastically. Instead, the military services began to look to a small regional conflict as the most probable form of a future confrontation, and altered their respective force planning approaches accordingly, while maintaining the capability to engage in a conventional battle. In the aftermath of the 2001 terrorist attacks, force planners had a new variable to consider in the force planning equation, an enemy who is a non-state actor, characterized by flexibility, decentralized command, and covert behavior. Future American military forces require flexibility to engage these non-state actor enemies, as well as engage in regional conflicts or conventional warfare. The United States Marine Corps is pursuing Distributed Operations (DO) as an approach to help meet the broad spectrum of challenges presented by this new global security environment. The Distributed Operations concept seeks to employ smaller, more heavily trained forces that can leverage a robust command, control, and communications system to achieve an advantage over an adversary. One of the challenges in developing a conceptual future force is the difficulty in estimating the capabilities that will be required and in measuring the force's ability to achieve those capabilities. The problem of predicting the performance of a military force in a future engagement is not new. However, in today's military, it is of particular concern due to the vast amounts of money involved in the Department of Defense budget, including new acquisitions, each year.

B. OBJECTIVE

The Marine Corps Warfighting Laboratory (MCWL) is responsible for developing the Distributed Operations concept. This is an enormous project that includes live force experimentation, and modeling and simulation, in order to determine existing capability gaps that must be filled in order to implement Distributed Operations successfully. In accordance with the Department of Defense Joint Capabilities Integration Development System, the Warfighting Lab is exploring Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities (DOTMLPF) solutions that can be used to fill these capability gaps in a cost effective way. The changes required to implement Distributed Operations will involve tradeoffs in the DOTMLPF domains. Two primary areas of focus for the Distributed Operations concept are the domains of training, and the domain of leadership and education.

Force planners have historically had a difficult task in measuring military capabilities in these domains, since characteristics involving human behavior such as training and leadership are not easy to quantify. In fact, throughout history this has been a challenge to anyone attempting to study combat from a scientific point of view. Dupuy (1987) developed the Quantified Judgment Model (QJM) as a mathematical model. It was designed to measure all the factors that he believed would affect the outcome of a battle, including these intangible qualities of combat. His contention was that the model fits the theory of combat developed by Carl Von Clausewitz as described in *On War* (Von Clausewitz, 1984). The QJM was specifically designed as an analysis tool for historical engagements in which causes of a known outcome were sought. This study applies an adaptation of the Quantified Judgment Model programmed Microsoft Excel (Dupuy, 1987).

The goal of the adapted model is to analyze capabilities gaps that exist between echelons of current Marine forces. This comparison is a first approximation of the difference between the current force and the future Distributed Operations capable force. The use of this comparison gives a concrete starting point in attempting to identify the capabilities and characteristics that will be required by a DO force in the future, but are lacking in the modern day force.

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

This study seeks to develop a method to compare the combat potential of two Marine units of different echelon or composition, across domains that are traditionally difficult to quantify, such as training or leadership. This process will enable the identification of capability gaps between current force and future force, as well as providing a measurement system that can be used for cost benefit analysis. The method developed using the Quantified Judgment Model is only one technique for analyzing this problem and is heavily dependent on expert opinion to determine the influences of different combat regimes on the result. The model resulting from this study is unclassified and contains artificial data. This methodology is based heavily on Dupuy's Quantified Judgment Model (1987) and assumes his calculations of historical combat factors are accurate, and that human warfare in the future will share certain timeless characteristics with the battles of the past.

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II. LITERATURE REVIEW

A. OVERVIEW

The challenge in attempting to measure the combat capability of a military unit arises from the fact that war is a human activity. Throughout history, human behavior is the factor that has created examples of an army defeating a numerically superior foe. It is the factor that produces most of the variance in any engagement. The necessity for measuring the combat potential of a military force has existed for thousands of years. The military treatise *The Art of War* written by Sun Tzu in ancient China over two thousand years ago, mentions this process as a key to victory, “As for military methods: the first is termed measurement; the second, estimation [of forces]; the third, calculation [of numbers of men]; the fourth, weighing [relative strength]; and the fifth, victory.” (2001, p. 184). There have been many other attempts throughout history to quantify the requirements for a military force to achieve success. Lanchester developed one of the better-known methods during the First World War, to describe the principle of concentration as it related to aerial combat (Dupuy, 1987). The method developed later by Dupuy was in some ways similar to Lanchester’s approach, but was inspired by Von Clausewitz, author of *On War* (Von Clausewitz, 1984).

B. LANCHESTER EQUATIONS

The Lanchester equations are sometimes referred to as the Linear Law and the Square Law. These equations are differential equations that represent the rates of loss of forces over time. For the Square Law, the loss rates for the attacker depend upon the number of defenders and the rate at which those defenders can cause casualties. The loss rates for the defender are calculated in the same manner. The Linear Law is similar, in that the loss rates for the attacker depend again upon the number of defenders and the defender's ability to cause casualties, but the number of attackers is an additional factor.

The assumptions in Lanchester's Laws are that both forces have the same type of weapons and perfect coordination. Additionally, the choice of attrition rates within the model plays an enormous role in determining the outcome. As shown in Figure 1, the loss rate for the attacker under the square law is the rate at which each defender can kill attackers, multiplied by the number of defenders. This represents a situation where each defender makes a single attempt to attack during one period of time and each attempt is directed against a single enemy. The same situation holds true for the attackers (also termed aimed fire). Under the Linear Law, the situation represented is that each defender takes a shot at the entire attacking group. The more attackers there are, the more will become casualties of each attempted shot. The Lanchester Laws do not take into account any of the situational or contextual factors of a battle such as terrain or human fatigue. There is also no way to compare forces made up of multiple weapon systems that might produce differing attrition rates.

$$dA/dt = -K_d D \qquad dD/dt = -K_a A \qquad \text{square law} \tag{A.2}$$

$$dA/dt = -\tilde{K}_d AD \qquad dD/dt = -\tilde{K}_a AD \qquad \text{linear law} \tag{A.3}$$

It is usually said that the square law applies to "aimed fire" (e.g., tank versus tank) and the linear law to "unaimed fire" (e.g., artillery barraging an area without precise knowledge of target locations). Alternatively, it is sometimes said that the key feature of the square law is that it describes concentration of fire.

Figure 1. Example of Lanchester Laws From Aggregation, Disaggregation, and the 3:1 Rule in Ground Combat (From Davis, 1995).

C. QUANTIFIED JUDGMENT MODEL

In *Understanding War*, Dupuy (1987) offers a mathematical model of combat called the Quantified Judgment Model. This model was developed through an analysis of historical battles and is an attempt to describe the mathematical relationship between combat factors that combine to determine the outcome of a military engagement. In chapter nine of the text, the author describes a study of the Flanders campaign of 1940. The fascinating feature of this study is the author's technique of converting aircraft and tanks into an infantry equivalent. The score for an Allied aircraft is 100 while an Allied tank gets a score of 50. This means that each aircraft is worth 100 infantry soldiers. The QJM was used to develop these scores which allow an even scale comparison between the forces. This technique of providing an even scale is one of the missing pieces of the Lanchester Equations is an advantage offered by the Quantified Judgment Model (Dupuy, 1987).

The foundation of Dupuy's model (1987) is derived from his own interpretation of the following passage by Von Clausewitz.

> If we thus strip the engagement of all the variables arising from its purpose and circumstances, and disregard the fighting value of the troops (which is a given quantity), we are left with the bare concept of the engagement, a shapeless battle in which the only distinguishing factor is the number of troops on either side.
>
> These numbers, therefore, will determine victory. It is, of course, evident from the mass of abstractions I have made to reach this point that superiority of numbers in a given engagement is only one of the factors that determines victory. Superior numbers, far from contributing everything, or even a substantial part, to victory, may actually be contributing very little, depending on the circumstances.
>
> But superiority varies in degree. It can be two to one, or three or four to one, and so on; it can obviously reach the point where it is overwhelming. (Von Clausewitz, 1984, p. 194).

Dupuy interpreted this passage as a mathematical theory of combat. He derived a differential equation representing the outcome of a battle between forces labeled blue and red. This equation as seen in Figure 2 is the ratio of each combatant's numbers adjusted for situational factors and the quality of the forces.

$$\text{Outcome} = \frac{N_r \times V_r \times Q_r}{N_b \times V_b \times Q_b}$$

Where: N = number of troops
V = variable circumstances affecting a force in battle
Q = quality of force
r = red identifier
b = blue identifier

Figure 2. Dupuy's (1987) formula describing a mathematical theory of combat.

The author then rewrites his equation as the combat power available to each side. This equation, which is shown in Figure 3, is the basis for the Quantified Judgment Model.

$$P = N \times V \times Q$$

Where: P = combat power of the force
N = number of troops
V = variable circumstances affecting a force in battle
Q = quality of force

Figure 3. Dupuy's equation for combat power (From Dupuy, 1987).

Dupuy ends his chapter on Clausewitz's theory of combat with a rather bold statement: "Just as Newton's physics can be summarized by the simple formula, F = MA, so too can Clausewitz's theory of combat be summarized in an equally simple formula: P = NVQ" (1987, p. 30).

D. DISTRIBUTED OPERATIONS CONCEPT

On the April 25, 2005, the Commandant of the Marine Corps General Hagee signed *A Concept for Distributed Operations* (United States Marine Corps, 2005). The document defines Distributed Operations as "an operating approach that will create an advantage over an adversary through the deliberate use of separation and coordinated, interdependent, tactical actions enabled by increased access to functional support, as well as by enhanced combat capabilities at the small-unit level." (United States Marine Corps, 2005, p. 1). The Marine Corps developed Distributed Operations to answer the challenge of future force planning in the emerging global security environment. Future foes will engage in unconventional operations, categorized by flexibility, decentralized command, and covert behavior. In theory, Distributed Operations will give commanders the capability to aggregate and disaggregate their forces to meet this threat.

One of the principle tenets of the DO doctrine is the focus on the individual Marine. In DO, education and training initiatives will target small unit leaders enabling them to operate autonomously and to apply tactical decision making at lower echelons of command. These junior Marines must be trained and educated to understand the command and control system, fire support coordination, and logistics disciplines traditionally mastered by leaders that are more senior. In addition, training will be provided in directing supporting arms, terminal guidance for aircraft, and cultural awareness.

The training and education initiatives that will be required will have a profound impact on the current Marine Corps system for education and training. In addition, personnel implications caused by the more challenging and lengthy training will result. An additional challenge is that the development of a Distributed Operations capability must not cause any degradation in the current capability of a unit. The fact that many of the initiatives in the DO concept involve the human element of combat (and that the requisite capabilities are gained through education and training) makes the ability to accurately assess these gains crucial to the development effort.

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III. PREDICTIVE FORCE RATIO MODEL

A. OVERVIEW

The challenge of implementing the Marine Corps Distributed Operations concept is to develop of cost effective methods to build a future force with the required capabilities. Before these methods can be developed however, the key capabilities required to ensure efficient achievement of full DO capacity must be identified. A comparison between echelons of the current Marine force allows a first approximation of the gap in capabilities between conventional forces and DO capable forces. This gap is difficult to identify accurately given the variability of human behavior in combat. One method of predicting the effects of human behavior on combat is the use of expert opinion, but a framework for this method is desirable.

The Predictive Force Ratio Model (PFRM) is a modification of Dupuy's Quantified Judgment Model (1987). Its purpose is to enable comparisons between military forces, across the domains of combat that are difficult to measure or quantify such as leadership and training. Whereas the QJM was specifically designed to analyze historical data, the PFRM is designed as a predictive tool. A cost benefit analysis to determine the best methods of implementing the Distributed Operations concept will rely on assumptions about the gains in combat power achieved through better leadership, education, and training. The Predictive Force Ratio Model performs a sensitivity analysis of the assumptions using expert opinion. For this reason, there are certain areas where the PFRM departs from the QJM, although the differences are small. The Predictive Force Ratio Model is divided into two general steps. The first step is the calculation of a value for weapons' effectiveness; the second is the application of weights (representing force employment variables) to the weapons effectiveness. The calculations for weapons effectiveness are based on factual data, although they do not necessarily represent perfect accuracy. The results of the PFRM are dependent on how the weightings are assigned so they are only valid if the Subject Matter Expert's (SME) judgments are valid.

The PFRM may be accessed at the following web address http://www.nps.navy.mil/or/Desmond_PFRM_Model.htm.

B. FORCE STRENGTH

Force Strength (FS) is the basic measurement of weapons effectiveness for a given military unit. This value represents the rate at which a unit can cause attrition on an enemy force calculated solely from the physical makeup of the unit itself, and without regard to situation or enemy. The unit of measurement for Force Strength is casualties per hour. The result of the Force Strength calculation is multiplied by the various weightings for Variable Factors and Combat Effectiveness Value to achieve the result. In calculating the Force Strength, a lethality index is calculated for each class of weapon. These indices, divided by class, have a weighting factor applied to them. The Force Strength is the sum of these weighted indices for each weapon class.

1. Total Lethality Index

The Total Lethality Index (TLI) is calculated for each weapon class by multiplying a rate of fire by several factors. It is defined by Dupuy as "the relative lethality of weapons against a theoretical target array of unarmored soldiers, standing in formation on an infinite plane surface, each occupying one square meter of space" (1987, p. 83). The Total Lethality Index is the starting point from which adjustments are made to account for the many variables affecting the outcome of combat. The TLI is the result of multiplying the base rate of fire by the four factors to achieve a rate of hits per hour as seen in Figure 4.

$$\text{TLI} = \text{Rate} \times \text{Reliability} \times \text{Accuracy} \times \text{Lethality} \times \text{Range}$$

Figure 4. Total Lethality Equation.

The unit of measurement for rate of fire is rounds per hour, the maximum rate at which the weapon system can attempt to fire. Five examples are shown in Table 1 demonstrating the effect of each of the factors on the TLI. In Example 1, the base case, the reliability and accuracy are set at a level of one hundred percent and the lethality and range factors are both set at one. In this case, the TLI value is identical to the raw rate of fire since every attempt to fire the weapon system would result in a single success.

	Rate	Reliability	Accuracy	Lethality	Range	TLI Value
Example 1	100	100%	100%	1	1	100
Example 2	100	50%	100%	1	1	50
Example 3	100	50%	50%	1	1	25
Example 4	100	50%	50%	6	1	150
Example 5	100	50%	50%	6	2	300

Table 1. Examples of Total Lethality Index calculations.

A weapon's reliability is the probability that the weapon functions as designed for any given attempt to fire. In Example 2, reliability is set at fifty percent while accuracy is set at one hundred percent, and lethality and range are set at one. This means the reliability percentage adjusts the rate of fire for any malfunctions that might occur in the weapon system in this case resulting in a TLI value representing one success for every two attempts, or half the raw rate of fire.

Accuracy is the probability that the target will be hit assuming that the weapon functions properly. An accuracy level of fifty percent (as shown in

Example 3) where reliability is set to fifty percent and lethality and range are set to one results in a TLI value representing one success for every four attempts, or one fourth the raw rate of fire. This shows that for every attempt where the weapon functions reliably, the accuracy determines whether the target will be successfully hit.

The lethality factor is used to adjust for area weapons such as an artillery shell. The lethality factor represents the number of targets that can become casualties as the result of a success. A rifle has a lethality factor of one, since it is assumed it can only damage one target for any successful attempt. The corresponding factor for a high explosive shell or general purpose bomb might result in numerous hits for one successful attempt. In Example 4, the lethality is set to six indicating that every successful attempt results in six casualties for the enemy. With reliability and accuracy set at fifty percent each and range set at one the result is a TLI value representing one and a half times the raw rate of fire.

The factor of range is the degree to which a weapon's effective range increases its chances of achieving a hit. In the Quantified Judgment Model, this is calculated using muzzle velocity to allow for historical comparisons between dissimilar weapons. For the PFRM the range factor is defined as the ratio of the weapon's effective range to the range of the basic infantry weapon the M-16. Thus, a weapon with twice the effective range of an M-16 would have a range value of two. In Example 5, the range setting of two with reliability and accuracy set at fifty percent and lethality set at six produces a TLI value representing three times the raw rate of fire.

The choice of factor weightings in the computation of the Total Lethality Index will have a profound effect on the result. As demonstrated in Table 1 these weightings allow the adjustment of the raw rates of fire to add realistic constraints. These weightings may also be set to use only the original rate of fire in the TLI calculation.

2. Operational Lethality Index

The Operational Lethality Index (OLI) is simply the TLI adjusted for dispersion. In ancient armies, the combat formations were extremely dense, approximately 10 square meters per man; however, the increasing capability of ranged weapons throughout history has led to more widely dispersed formations. The estimates used in this model are those corresponding to Dupuy's prediction for the 1990s of about 50,000 square meters per man. The Dispersion Factors used in *Understanding War* are normalized to the dispersion estimate for ancient armies and are presented in Table 2 (Dupuy, 1987).

Dispersion Factor	
Ancient Armies	1
Napoleonic Era	20
American Civil War	25
World War I	250
World War II	3,000
1970s	4,000
1980s	5,000

Table 2. Dispersion Factors From *Understanding War* (Dupuy, 1987, p. 84).

3. Weapon Classes

The weapon classes implemented in the PFRM are the same as those used by Dupuy (1987). These classes are infantry weapons, artillery weapons, armor weapons, air support weapons, air defense weapons, and anti-armor weapons. The aggregate TLI and OLI values for each class are calculated by summing the lethality indices for each individual weapon system. As an example the overall TLI for infantry weapons is calculated by adding the individual TLI values for each M-16, M-249, M-203, and M-67 grenade in the units physical makeup. This technique allows the user to obtain higher resolution by using specific weapon systems, or to use an overall general value for the entire class.

4. Force Strength Summary

The final calculation to determine the overall Force Strength is to multiply the aggregate OLI for each class of weapon system by a weighting representing effectiveness in the desired scenario. As shown in Figure 5, these values corresponding to each class of weapon system are added to achieve the Overall Force Strength.

$$\text{Force Strength} = (OLI_{Inf} \times V_{Inf}) + (OLI_{Art} \times V_{Art}) + (OLI_{Arm} \times V_{Arm}) + (OLI_{Airsupp} \times V_{Airsupp}) + (OLI_{Antiarm} \times V_{Antiarm}) + (OLI_{Airdef} \times V_{Airdef})$$

The symbols represent:

OLI	=	Operational Lethality Index
V	=	Weapon effect factors
Inf	=	Infantry weapons identifier
Art	=	Artillery weapons identifier
Arm	=	Armor weapons identifier
Airsupp	=	Air support weapons identifier
Antiarm	=	Anti-armor weapons identifier
Airdef	=	Air defense weapons identifier

Figure 5. Force Strength Equation.

Since Force Strength is the result of adding the product of each OLI and weapon effect factor, it is possible to use a factor of zero to disregard a specific weapon class. This is of note only because the later operations involving Variable Factors must not have a weight factor of zero or the end result will be zero.

C. VARIABLE FACTORS

The Overall Force Strength represents a score for the combat potential of a military unit but it is based only on the unit's intrinsic abilities with no consideration given to the situation in which combat takes place. However, since the situation in which an engagement takes place has a great impact on the outcome, Variable Factors (VF) are used as weights to adjust the value of Force Strength. As an example, a force that is expected to retain an advantage in combat due to defensive posture might have its Force Strength doubled by application of a vulnerability weight. The result is that by occupying a defensive role, the force has effectively doubled its combat potential. The Variable Factors are subdivided into two categories, environmental and operational.

1. Environmental Variable Factors

Environmental Variable Factors represent the state of nature in which an engagement takes place. These include terrain, weather, and season. The combatants generally cannot influence these factors. Since these weights represent the effect of the environmental conditions upon the Force Strength of a given unit, the weights might be different for each side. Although the physical characteristics of the environment are similar for both sides, one force might be better able to deal with them than the other might. Figure 6 illustrates the calculation used for Environmental Factors.

$$\text{Environmental Factors} = V_{ter} \times V_{wea} \times V_{sea}$$

The symbols represent:

V	=	Variable effect factors
ter	=	terrain
wea	=	weather
sea	=	season

Figure 6. Environmental Factors Equation.

2. Operational Variable Factors

Operational Variable Factors consist of the factors that can be influenced by the actions of forces themselves. These factors include vulnerability, posture, mobility, logistic capability, surprise, and air superiority. The QJM has specific values for vulnerability and posture, based on the historic performance of forces in these particular roles. The values calculated by Dupuy (1987) are shown in Table 3.

Vulnerability	
Default offensive	0.9
Default defensive	2.8
Posture	
Offense	1.0
Hasty defense	1.3
Prepared defense	1.5
Fortified defense	1.6

Table 3. Vulnerability and Posture Factors From *Understanding War* (Dupuy, 1987).

In a departure from Dupuy's model, logistics capability is included in the PFRM as an Operational Variable Factor rather than a Behavioral Factor under Combat Effectiveness Value. Similarly, fatigue has been removed from the list of Operational Variable Factors and included as a Behavioral Factor. Figure 7 shows the equation for Operational Factors.

$$\text{Operational Factors} = V_{vul} \times V_{pos} \times V_{mob} \times V_{log} \times V_{su} \times V_{airsup}$$

The symbols represent:

V	=	Variable effect factors
vul	=	vulnerability
pos	=	posture
mob	=	mobility
log	=	logistic capability
su	=	surprise
airsupp	=	air superiority

Figure 7. Operational Factors Equation.

3. Variable Factors Summary

The Variable Factors are a series of weights or adjustments to the Force Strength. They are multiplied together to calculate the overall value for Variable Factors. This overall value represents the total effect of the environmental and operational situation on combat power. The Variable Factors equation is shown in Figure 8.

$$\text{Variable Factors} = \text{Environmental Factors} \times \text{Operational Factors}$$

Figure 8. Variable Factors Equation.

D. COMBAT EFFECTIVENESS VALUE

In the historical analysis of a battle using Dupuy's model the Force Strength, based on physical characteristics, and adjusted for environmental and operational effects, predicts the outcome. Historical battles do not always result in the outcome that is predicted by these calculations. The element that is missing is the behavioral element due to differences in human behavior. This element is identified by Dupuy as the Combat Effectiveness Value (CEV), the effect of human behavior on the outcome of an engagement (1987). In using this model to predict an outcome, the effect of the CEV factors must be estimated to set the appropriate weights. The weights for Combat Effectiveness Value are leadership, training, morale, and fatigue, as shown in Figure 9.

$$\text{Combat Effectiveness Value} = V_{lea} \times V_{tra} \times V_{mor} \times V_{fat}$$

The symbols represent:

V	=	Variable effect factors
lea	=	leadership
tra	=	training
mor	=	morale
fat	=	fatigue

Figure 9. Combat Effectiveness Variable Equation.

E. SUMMARY

The PFRM closely follows the Quantified Judgment Model. The major departure is the ability to use the model for prediction rather than for analysis after the fact. In the final form, the overall Combat Potential for a force is the result of the Force Strength multiplied by the Variable Factors and the Combat Effectiveness Value. Figure 10 shows the basic equation for the Predictive Force Ratio Model.

$$\text{Combat Potential} = \text{Force Strength} \times \text{Variable Factors} \times \text{Combat Effectiveness Value}$$

Figure 10. PFRM Summary Equation.

The PFRM is a mathematical formula but a software implementation is desirable to enable its efficient use. The software implementation presented in this study allows a user the capability to use the PFRM quickly and easily. Additionally it provides an straightforward method of varying the inputs and examining a large number of scenarios in a short amount of time.

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IV. PREDICTIVE FORCE RATIO MODEL IMPLEMENTATION

A. OVERVIEW

This PFRM has been implemented in Microsoft Excel and requires Macros be enabled in order to function correctly. The Excel file consists of seven worksheets that progressively execute the required calculations as seen in Figure 11.

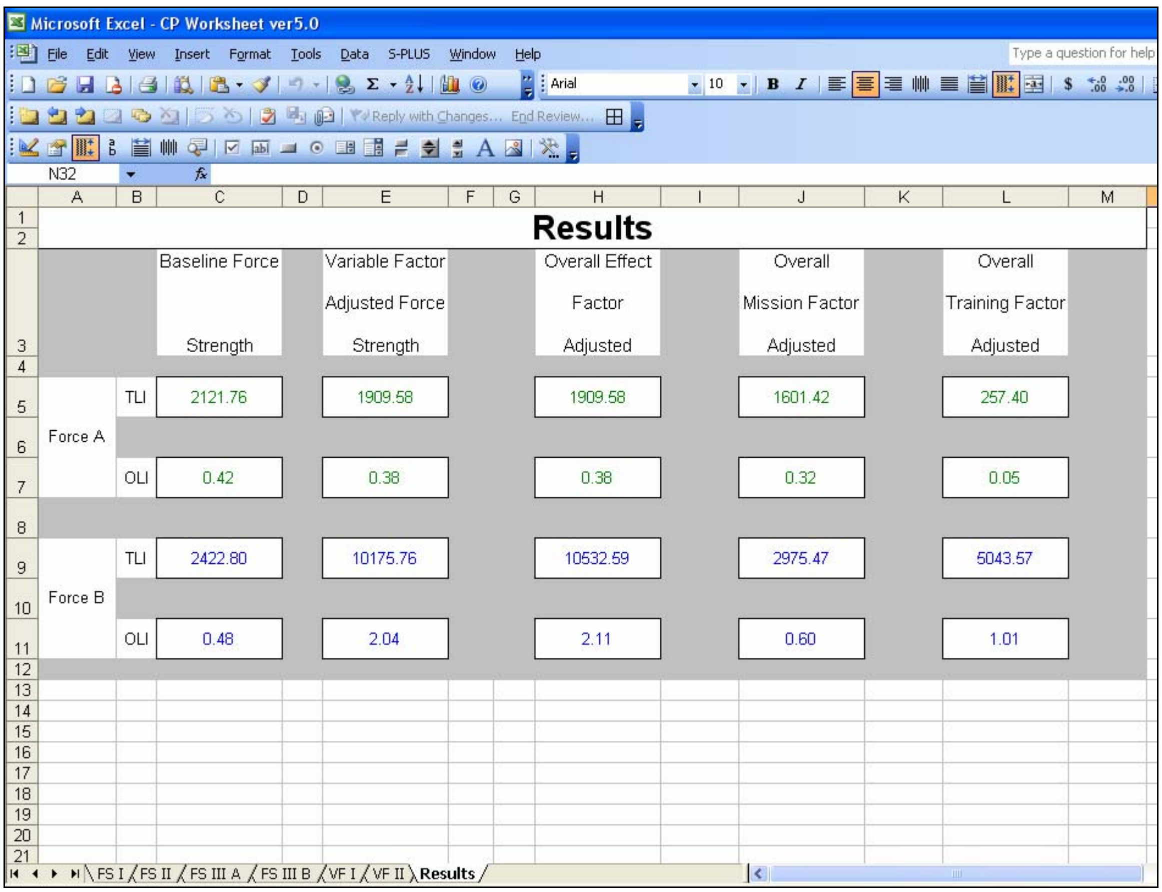


Figure 11. Example showing the seven worksheet tabs used for calculations in the PFRM Excel implementation.

Comparisons may be made between two forces using different physical characteristics and factor weightings. The two forces, called A and B, are represented as blue and green, and their respective values use font color to help indicate which force calculations are being made in a given cell.

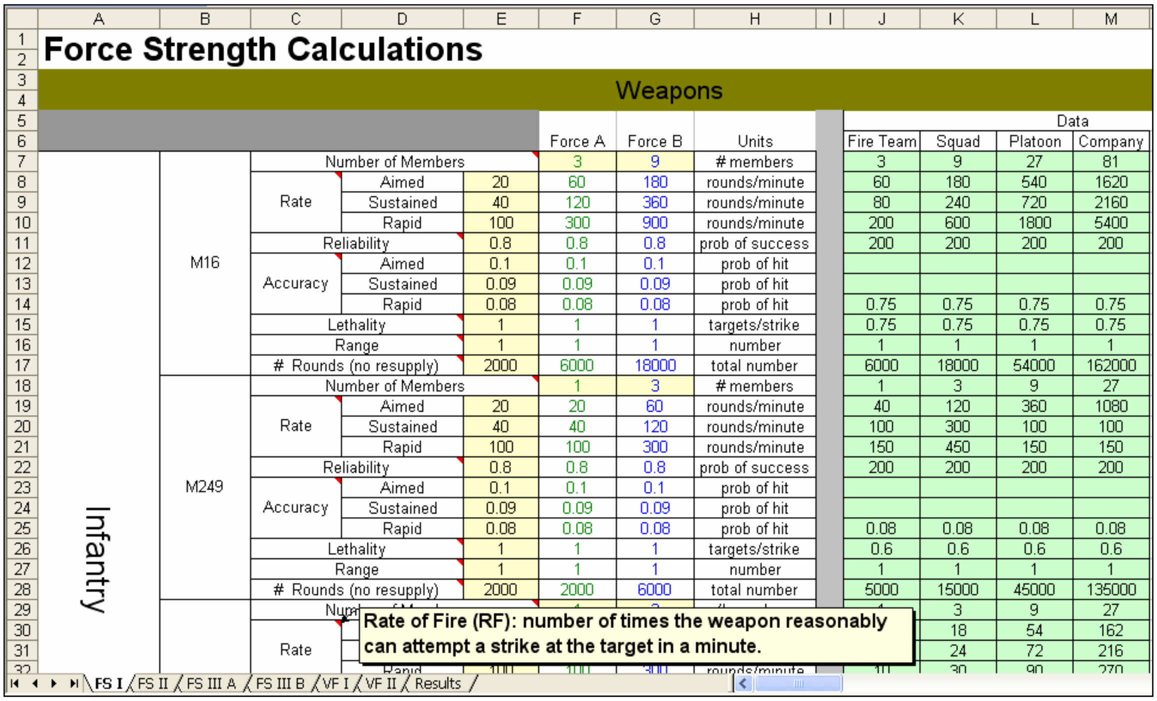
There are three methods for the user to enter data into the model. Data may be entered by typing it into a particular cell, indicated by a yellow background. Drop down menus are indicated by the word “Select” followed by a right facing arrow, all on a yellow background. There are also a series of slider bars that may be used to manipulate the various weighting factors in the model. Buttons labeled “Reset” on a gray background accompany the slider bars. These buttons will set all related sliders to a default value of one. Throughout the model, Total Lethality Indices and Operational Lethality Indices are displayed both for intermediate results and on the final results worksheet. This is a departure from the Quantified Judgment Model, and is meant to facilitate comparisons of smaller forces or larger forces. A small force may result in fractional OLI levels that are difficult to interpret, and a large force may result in TLI levels in the tens or hundreds of thousands, so both TLI and OLI measurements are included. In all figures displaying screenshots of the Excel model, the data being used are notional and bear no relationship to any real world or classified data.

B. FORCE STRENGTH

The calculations for Force Strength are performed on the first four worksheets in the file. The labeling convention for these worksheets is FS indicating Force Strength calculations, and a Roman numeral designator. Additionally the FS III sheet has been split into an individual worksheet for each force due to the number of calculations required for each force.

1. Force Strength One Worksheet (FS I)

The purpose of the FS I worksheet is to allow entry of the physical characteristics of a force related to Force Strength. The six weapons classes are listed vertically in the leftmost column, and divided into categories for data entry as shown in Figure 12. The data concerning weapons parameters is entered in the yellow shaded boxes to the left. Additionally there is a cell corresponding to the number of each weapon system included in the unit. The data for number of weapons is multiplied by rate of fire to determine the overall rate for the unit. Under the column labeled Units, are listed the units of measure used for each category, in order to aid data entry. The region with a green background is designed to save default data if desired.


Force Strength Calculations

Weapons

					Force A	Force B	Units	Fire Team	Squad	Platoon	Company
Infantry	M16	Number of Members			3	9	# members	3	9	27	81
		Rate	Aimed	20	60	180	rounds/minute	60	180	540	1620
			Sustained	40	120	360	rounds/minute	80	240	720	2160
			Rapid	100	300	900	rounds/minute	200	600	1800	5400
		Reliability		0.8	0.8	0.8	prob of success	200	200	200	200
		Accuracy	Aimed	0.1	0.1	0.1	prob of hit				
			Sustained	0.09	0.09	0.09	prob of hit				
			Rapid	0.08	0.08	0.08	prob of hit	0.75	0.75	0.75	0.75
		Lethality		1	1	1	targets/strike	0.75	0.75	0.75	0.75
		Range		1	1	1	number	1	1	1	1
		# Rounds (no resupply)		2000	6000	18000	total number	6000	18000	54000	162000
	M249	Number of Members			1	3	# members	1	3	9	27
		Rate	Aimed	20	20	60	rounds/minute	40	120	360	1080
			Sustained	40	40	120	rounds/minute	100	300	100	100
			Rapid	100	100	300	rounds/minute	150	450	150	150
		Reliability		0.8	0.8	0.8	prob of success	200	200	200	200
		Accuracy	Aimed	0.1	0.1	0.1	prob of hit				
			Sustained	0.09	0.09	0.09	prob of hit				
			Rapid	0.08	0.08	0.08	prob of hit	0.08	0.08	0.08	0.08
		Lethality		1	1	1	targets/strike	0.6	0.6	0.6	0.6
		Range		1	1	1	number	1	1	1	1
		# Rounds (no resupply)		2000	2000	6000	total number	5000	15000	45000	135000
		Num…							3	9	27
		Rate							18	54	162
									24	72	216

Figure 12. FS I worksheet example (unclassified data).

Figure 12 shows the upper portion of the worksheet including infantry weapons. The other classes of weapons are implemented below infantry weapons in the portion of the worksheet not shown in the diagram. For convenience the rates for infantry weapons are entered in rounds per minute since that is the unit normally used by the Marine Corps. The worksheet will perform the necessary conversion to rounds per hour which is the measurement unit for the model. Weapon classes other than Infantry Weapons are entered in rounds per hour as well. The different data types such as accuracy have comments describing them to aid in data entry, as seen in Figure 12.

2. Force Strength Two Worksheet (FS II)

The Force Strength Two worksheet performs the calculations necessary to generate a Total Lethality Index and Operational Lethality Index for each of the six weapon classes. The infantry portion of the worksheet is shown in Figure 13 illustrating the combination of multiple weapons into a composite infantry score. Also shown are the drop down menus allowing the user to choose the rate of fire desired for the calculations.

Force Strength Calculations

Infantry Weapons

	A	B	D	F	H	J	L	M	O	P
4	Total Lethality Index (TLI) Force A						Overall Lethality Indices			
5		Rate of Fire	Reliability	Accuracy	Targets/strike	Range	TLI	OLI		
6	Select ▶	Rapid		Rapid					Overall TLI	2006.40
7	M-16	300	0.8	0.08	1	1	1152.00	0.23		
8	M-249	100	0.8	0.08	1	1	384.00	0.08		
9	M-203	100	0.8	0.08	1	1	384.00	0.08	Overall OLI	0.40
10	M-67	4	0.8	0.5	1.2	0.75	86.40	0.02		
11	Total Lethality Index (TLI) Force B						Overall Lethality Indices			
12		Rate of Fire	Reliability	Accuracy	Targets/strike	Range	TLI	OLI		
13	Select ▶	Aimed		Aimed					Overall TLI	1699.2
14	M-16	Aimed	0.8	0.1	1	1	864.00	0.17		
15	M-249	Sustained	0.8	0.1	1	1	288.00	0.06		
16	M-203	Rapid 60	0.8	0.1	1	1	288.00	0.06	Overall OLI	0.34
17	M-67	12	0.8	0.5	1.2	0.75	259.20	0.05		

Figure 13. Infantry portion of worksheet FS II.

The TLI and OLI for each weapon is calculated and displayed for each force. There is also an overall TLI and OLI for the infantry weapon class displayed on the far right. The individual weapon TLI is calculated according to the model formula, by multiplying rate times 60 to convert to rounds per minute, and then multiplying by reliability, accuracy, lethality (targets per strike), and range. The individual weapon OLI is calculated by dividing the TLI by the dispersion factor of 5,000. The Overall TLI and OLI values are obtained by summing the individual TLI and OLI values. For the other classes of weapons, which are not subdivided, the process is similar. Figure 14 shows the artillery portion of the worksheet which shares its format with the remaining weapon classes.

Artillery Weapons								
Total Lethality Index (TLI) Force A					Overall Lethality Indices			
Rate of Fire	Reliability	Accuracy	Targets/strike	Range	Overall TLI	75.60	Overall OLI	0.02
36	0.7	0.5	2	3				
Total Lethality Index (TLI) Force B					Overall Lethality Indices			
Rate of Fire	Reliability	Accuracy	Targets/strike	Range	Overall TLI	151.20	Overall OLI	0.03
72	0.7	0.5	2	3				

Figure 14. Artillery portion of worksheet FS II.

3. Force Strength Three Worksheet (FS III A+B)

The third and fourth worksheets in the Excel implementation are identical except that the third worksheet performs the calculations for force A, and the fourth worksheet performs the calculations for force B. The purpose of these worksheets is to apply the weapon effect factors to achieve the Force Strength TLI and OLI. These worksheets offer three separate perspectives whose different intermediate results will be carried through to the final results worksheet. These three approaches are custom weighting, mission weighting, and training weighting. The custom weighting portion of the worksheet as shown in Figure 15 allows the user to enter individual weightings for each class of weapons to adjust the final Force Strength result. This is implemented by slider bars, which allow weights between the values of 0 and 100 by intervals of .01, and the use of a reset button, which returns each weight to the default value of one. The value for Force Strength is the sum of each weapon class value multiplied by the assigned weight factor. The OLI is simply the TLI divided by 5,000 to account for dispersion.

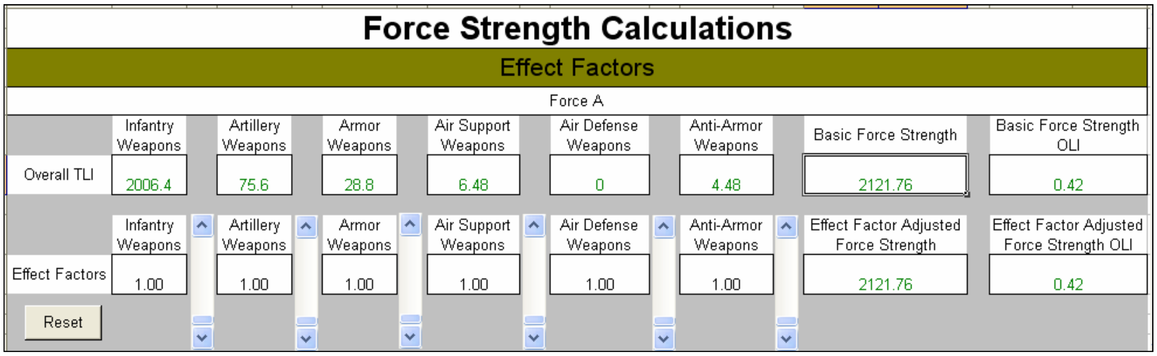


Figure 15. Custom weighting portion of worksheet FS IIIA.

The mission and training implementations are located below the custom weighting on the worksheet and can be seen in Figure 16. These implementations are identical, each allowing the user to select a default set of weights corresponding to a particular desired situation. In Figure 16, the user has chosen to explore mission weightings related to a peacekeeping mission from the mission type weighting drop down box. This selection results in the weight values for each weapon class being filled in from a table. Similarly, the choice of Military Operations in Urban Terrain (MOUT) generates the appropriate weightings from a separate table. The TLI and OLI for Force Strength generated in each of these three implementations will be carried through to the results worksheet.

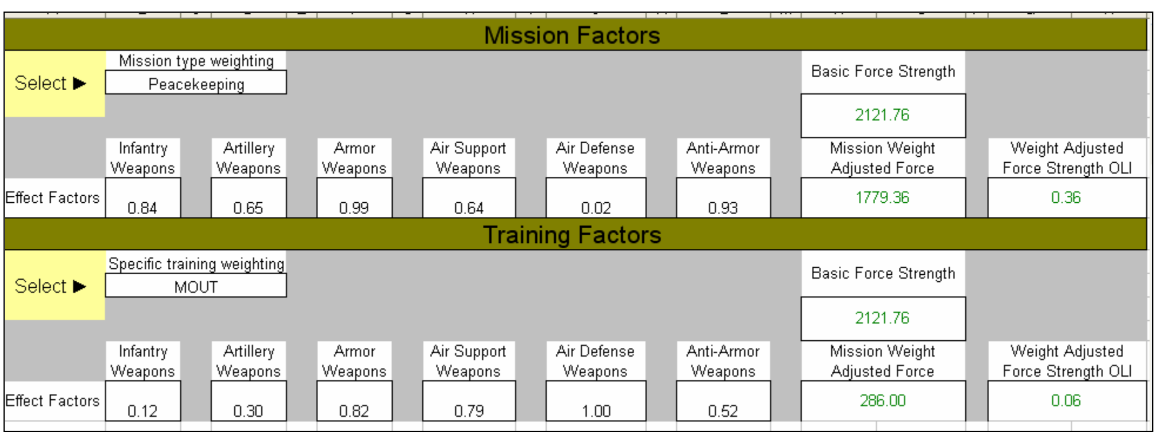


Figure 16. Mission and Training weighting portion of worksheet FS IIIA.

C. VARIABLE FACTORS AND COMBAT EFFECTIVENESS VALUE

The fifth and sixth worksheets allow the input of all the Variable Factor weights and the Combat Effectiveness Value weights. Each of the worksheets has a summary value for each force calculated. This summary is the product of all the weights on the worksheet and is calculated to facilitate the final result calculations.

1. Variable Factors One Worksheet (VF I)

The fifth worksheet provides for the input of the Operational Variable Factor weights, which include vulnerability, posture, mobility, logistic capability, surprise, and air superiority. The vulnerability weights are selected through a drop down menu containing default offensive and default defensive as choices. Similarly, the posture is selected from a separate drop down menu. The choices for posture are offense, hasty defense, prepared defense, and fortified defense. The remaining factor weights are implemented as slider bars similar to those used on the previous worksheet and can be seen in Figure 17.

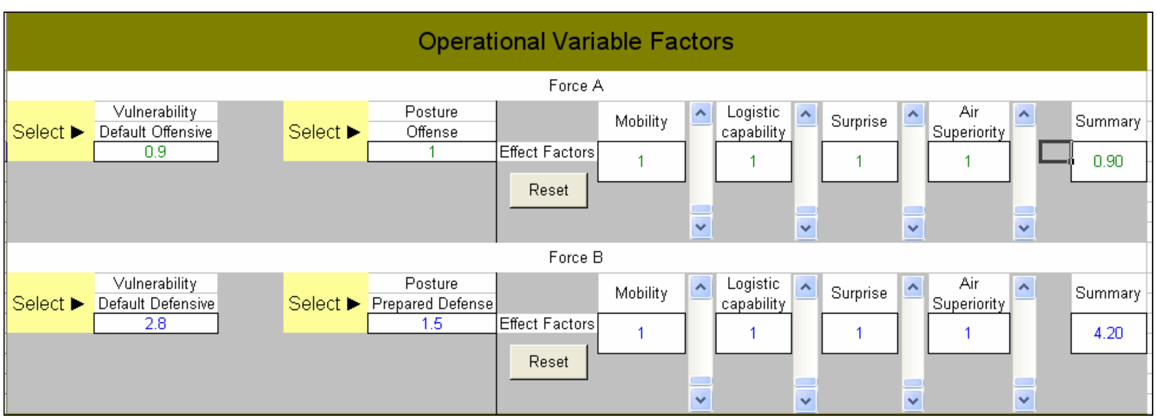


Figure 17. Worksheet VF I.

2. Variable Factors Two Worksheet (VF II)

The second Variable Factors worksheet is divided between the environmental factors and the human factors or CEV. Both follow the same slider bar format found on preceding sheets. Figure 18 displays the Variable Factors Two Worksheet.

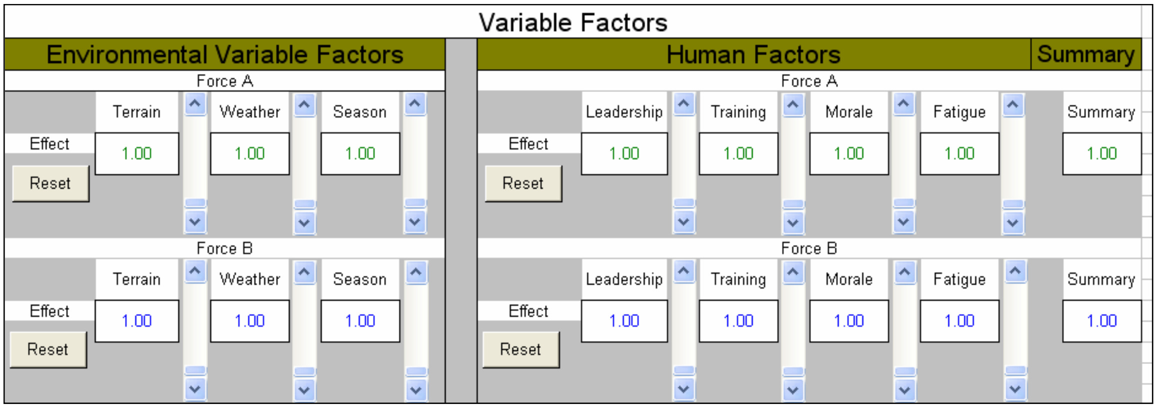


Figure 18. Worksheet VF II.

D. RESULTS

The results worksheet has a very simple format. It displays TLI and OLI values for each force over several situations. The first set of values is the baseline force strength calculated from the aggregate physical values, with no weight factors applied. This value is the sum of each of the weapon class overall TLI values and is taken from worksheet FS III. The next set of values is variable factor adjusted force strength, which is calculated by multiplying the baseline force strength by the total product of all variable factor weights found as the summaries on FS I and FS II. The variable factor adjusted force strength does not take into account any of the weapon effect factors input on the FS III worksheets. The next three sets of values are based on the weapon effect factors from FS III, and do not take into account the variable factors from worksheets VF I and VF II. The intent of this results format is to enable comparisons between different sets of weight factors, with the baseline to show the effect of the user introduced weightings. Using this system a user can generate results for a custom set of weapon effect weights, a specific set of mission weights or training weights, and a set of variable factors and compare them all. The results worksheet is shown in Figure 19.

Results						
		Baseline Force Strength	Variable Factor Adjusted Force Strength	Overall Effect Factor Adjusted	Overall Mission Factor Adjusted	Overall Training Factor Adjusted
Force A	TLI	2121.76	1909.58	1909.58	1601.42	257.40
	OLI	0.42	0.38	0.38	0.32	0.05
Force B	TLI	2422.80	10175.76	10532.59	2975.47	5043.57
	OLI	0.48	2.04	2.11	0.60	1.01

Figure 19. Results worksheet.

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V. DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

The model developed in this study is not intended as a stand-alone analysis tool, but rather as an aid to expert opinion in predicting the effects of human behavior on combat. The intent of the model is to be one tool among many used to analyze the effect of various factors such as training and education upon combat effectiveness. The different stages in the model have varying degrees of accuracy. The physical data entered to describe weapon systems represents a high degree of accuracy, but may not be accurate with respect to description of the desired effects. As the effect factors are applied to these data, the user can add an individual (or Subject Matter Expert) perspective on weapons effectiveness in the given situation. This added perspective increases the practical usefulness but decreases the strict accuracy of the baseline force strength TLI. The reason this distinction is important is that the weightings established in the model have a potentially huge effect on the outcome. For example, a single soldier with high settings across many of the weights may score better than a regiment with conservative settings. The use of the factor weightings are key however in examining the human factors in the analysis. Thus, the model represents a tradeoff between strict accuracy and expert opinion in calculating the proper weights for all the factors. For this reason, the use of the weighting system represents both a strength and a weakness of this model.

B. RECOMMENDATIONS

There are many analysis methods being used to examine the development of the Distributed Operations concept including live exercises, wargaming efforts and modeling and simulation. This model should be complementary to those efforts and subject to improvement and refinement as they generate results.

1. Model Use

The key to successfully utilizing this model is to set the factors and their weightings properly. The best way to accomplish this will be to have an expert such as an infantry officer set the weightings. Another technique that might be helpful is the use of a panel of experts to determine a reasonable weighting system. This technique is often used to estimate costs for Department of Defense projects when accurate data are unavailable. The use of actual data is preferable to the use of expert opinion. However, in the process of analyzing the DO domains involving the inherent variability of human behavior, expert opinion may be the best technique available. To ensure that results achieved using the PFRM are accurate, they should be compared to results achieved through modeling and simulation efforts and live exercises. The user must realize that the PFRM will not provide a strict factual result but instead can provide a framework for exploration of the solution space by an expert and offer insight into the sensitivity of results as factor weightings change.

2. Modifications

The PFRM may be easily modified. If the user wants to modify the current PFRM, additional factors may be added to the Excel implementation. These added factors should be multiplied into the formulas on the results page. This is only necessary if all other factor weightings are being used at a value other than one. If a factor does not apply in the user's scenario, another factor can be substituted. For example, the user might decide to add a factor representing the effect of increased protection from body armor. If that user was unconcerned about the effect of weather in the scenario, the weather factor might be used to represent the body armor protection factor. The PFRM could be easily implemented in a variety of computer programming languages or equipped with a graphical user interface as well.

3. Future Work

Some of the weights, which make use of the data from Dupuy's (1987) research, seem very reasonable. One potential area for further research would be to attempt to identify more factor weightings based on historic research. In addition, the DO modeling and simulation initiative will most likely have data sets that may be used to verify or produce a weighting system. The development of more standardized settings for the Factor Variables will increase the usefulness of the PFRM.

A follow on effort using this model is to examine the possible advantages obtained through different implementations of the Distributed Operations concept. For example, determining how much combat capability may be gained through a specific type of training such as aircraft terminal control training will benefit the DO enterprise. The ability to measure increases in combat capability will enable users to quantify their cost and allow the user to perform a cost benefit analysis. This should give decision makers an additional input to the choices of which programs produce the best end result in the implementation of Distributed Operations.

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