A FRAMEWORK FOR THE REPRESENTATION OF COHESION IN SMALL COMBAT UNITS

by

William Eugene Warner

B.S. June 1989, Old Dominion University
M.S. December 2000, Old Dominion University

A Dissertation Submitted to the Faculty of
Old Dominion in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

ENGINEERING WITH A CONCENTRATION IN
MODELING AND SIMULATION

OLD DOMINION UNIVESITY
May 2006

Approved by:

____
Andreas Tolk (Director)

____
James Bliss (Member)

____
Bowen Loftin (Member)

____
Russell J. Rockefeller (Member)

Abstract

A FRAMEWORK FOR THE REPRESENTATION OF
COHESION IN A SMALL COMBAT UNIT

William Eugene Warner
Old Dominion University, 2006
Director: Andreas Tolk

Current combat simulations deal well with large unit formations, weapon systems, and physical effects such as attrition. Human factors such as morale, cohesion, and effects of stress are modeled much less adequately. Of the human factors affecting the psychology of a combat unit, military psychologists have identified cohesion as one of the most important. The concept of cohesion, referring to both the interpersonal relationships between soldiers in a military unit and to the morale solidarity of a military force, has been central to military analysis for many years.

A model framework has been developed that can operationalize the concept of cohesion by measuring the relationship between members of a small combat unit to the individual soldier's reaction to battlefield stress. This framework is such that it will be able to be implemented in any modeled environment that has a need to represent cohesion within the context of a training or analysis experiment. To evaluate the assumption of constant human factors, a model was created to represent a classical Greek phalanx unit. Three historically based scenarios were run to validate the model. The results show that a model with the properties defined in the framework can represent a reasonable facsimile of infantry combat showing the effect of stress and cohesion. These results imply

possible uses for the framework in the future of military training, analysis and experimentation using computer simulations.

This Dissertation is dedicated to all those soldiers that have faced the point of a spear so that I would not have to.

Acknowledgments

The language of combat and most combat narratives lend themselves to male examples and male gender. The author, especially when quoting established sources, will use the male gender. This is not meant as a detraction of any soldier of any gender that has decided to give their service to their particular cause. I would like to acknowledge all those soldiers of every gender, whose experiences provided the context for this research.

I would like to acknowledge Dr. Russell Rockefeller, Dr. James Bliss and Dr. Bowen Loftin for their support and guidance in designing and executing this research effort. I would also like to thank my Advisor, Dr. Andreas Tolk, who has guided me through this effort and has proven to be a great inspiration and friend.

I would also like to acknowledge my wife Eva who put up with the multi-year effort of library searches, discussion and writing and my editor Kay Fleetwood who was instrumental in getting all the words right and all the right words into this document.

Table of Contents

Page

List of Tables

List of Figures

1.0 Introduction

1.1 Overview

"If the war doesn't go according to the game, you just keep trying to make it fit."
James Der Derian, principal investigator of the Information Technology War and Peace Project, April 3, 2003

"We have simulators for generals and colonels and captains and majors, but never anything specifically for the squad leader.
Mike Macedonia, chief scientist in the Army's simulation and training department STRICOM, June 10, 2004

Computer simulations are used in military application to train combat personnel so that performance can be improved in specific military situations, for analysis of military situations to investigate why certain events occurred, and to design experiments to examine what can be learned from existing and newly designed military situations. The use of historical battles for these purposes is well known[1]. Students at all the military academies re-fight past battles to learn strategy and methods of command. However, whether it is re-fighting Gettysburg or conducting an experiment about some future military operation, the need to accurately represent computer generated forces has become a priority in many of today's armed forces.

To provide adequate tools for training, analysis and experimentation using computer simulations, the representation of computer-generated forces must be as realistic as possible. This provides representations of either opponents or

[1] Citation format for this manuscript is taken from the Shipley Associates Style Guide Revised edition.

friendly organizations to make the computer simulations more effective. Many current computer simulations work well at tracking the motions of large-scale forces, the interactions of weapon systems and abstract strategies and tactics. However, they are less effective when it comes to representing human behavior (Kipps & Stack 30).

The Defense Modeling and Simulation Office (DMSO), in their 1995 Modeling and simulation master plan describe the need to accurately represent human behaviors; of particular concern are the psychological aspects, such as individual and group performances, organizational and environmental performances, and command and control.

The DMSO report for its 2000 Behavior Representation Workshop identified the need to model psychology, particularly the effects of stress on human behavior. The workshop concluded that the development of models of group behavior that take into account traditional "soft" factors such as leadership, cohesion, morale and culture were of great importance in the accomplishment of the goal (Defense Modeling and Simulation Office 2000, 4). In April of 2001, the DMSO concluded that the top items that needed attention for the experimentation segment of the simulation community were those dealing with psychological behaviors of small groups and individuals, and how to integrate them into combat models (Defense Modeling and Simulation Office 2001, 13).

There are many psychological factors that influence the behavior of an individual in combat. These psychological factors determine why a soldier will fight, do what is expected, or run away. Military sociologists identify, from among these many motivating factors, small unit cohesion as one of the most important influences on a unit in combat (Steckel, 300).

The relationship of an individual soldier to the other members of a small unit is one of the cornerstones of that unit's effectiveness. This relationship, commonly referred to as cohesion, is developed though training, leadership and the "espirit de corps" that is forged by a common purpose.

Cohesion provides combat units the ability to overcome effects such as fear or fatigue and is a result of the psychological effects of the camaraderie within the unit. The strongest motivation for combat units is the bond formed among the members of a primary group, such as a squad or platoon. This cohesion, according to some researchers, is the most important force sustaining and motivating combat soldiers. Cohesion of armies is a result of the cohesion of the small units. Simply put, soldiers fight because of the other members in their small unit.

This dissertation assumes that cohesion has been a variable present in military units throughout history. Although weaponry and strategies have changed over time, the human factors that influence cohesion on the field of battle have remained the same. Assuming the psychological human factors that hold small units together on the battlefield would be the same for a classical Greek phalanx or a modern Military Operation in Urban Terrain (MOUT) combat team, a model framework should be able to be developed that can represent cohesion. This framework representing cohesion could be implemented in current computer simulations to improve the human behavior representation.

This may provide a tool to study the effect of cohesion on combat unit performance and be used to meet the military simulation community requirements for more realistic simulations. This model framework should be applicable to any historical or hypothetical small combat unit and provide improvements in all aspects of modern military simulation.

1.2 Purpose

The purpose of this dissertation is to create and test a conceptual model of the factors that influence military unit cohesion. A model framework will be presented, defined and discussed in reference to how it may impact the discipline of modeling and simulations. The framework will be used to investigate the physical and psychological human factors that may be important in battlefield combat performance.

The models to be presented in this work are exploratory in nature and will be developed using relevant models for experimental evaluation. A brief set of system specifications will be created to provide a rudimentary starting point. After validation tests based on specific domain knowledge produce “satisfactory” results, the framework will be dubbed as "finished" and implemented. The results of testing implementation will be evaluated to see what the framework does, what can be learned from it, and how it may be improved.

The framework will consist of a collection of models based on the description of various environmental, physical and psychological factors that influence an individual soldier’s behavior and performance during a combat situation. Those influencing factors such as how an individual reacts to stress and the mediating effects of unit cohesion and leadership will be defined and explained. Based on these high-resolution models of an individual soldier, the aggregate of the stress and mediating factors of all the members of a unit will influence its performance.

The conceptual model of the framework is based on the idea that stressful experiences are construed as person-environment transactions. These transactions depend on the impact of the sum of external stressors. The external stressors are mediated by firstly, the person's appraisal of the stressors, and secondly, on the social resources available (Lasarus & Cohen, 234; Antonovsky & Katz, 15). This "transactional" approach will be based on the following sequence (Glanz, 215):

- **Event** - A physical threatening event occurs on the battlefield.
- **Primary Appraisal** - An individual soldier observes the event battlefield and evaluates the significance of the event.
- **Secondary appraisal** - The soldier perceives the event and evaluates the controllability and the coping resources.
- **Coping efforts** - The soldier reacts to the event and evaluates strategies to mediate the primary and secondary appraisal.
- **Outcome of coping** - The reaction causes the soldier to have a behavior that sustain his emotional well being and functional status.
- **Primary Group Appraisal** - The other members of the combat unit observe the individual soldiers behavior.
- **Secondary Groups appraisal** - The others in the combat unit appraise the individual soldier's behavior.
- **Group Reaction** - The group then reacts to the individual soldier's behavior.
- **Group Effects** -The group reaction either provides mediation or becomes new stressors.

Before presenting and explaining the framework in detail, the factors will be defined. Among the most important factors in modeling the behavior of a computer-generated soldier are stress, cohesion, and leadership. Stress is the internal process of preparing to deal with an event or situation, which requires a non-routine change in adaptation or behavior (Department of the Army, 25). Cohesion (particularly, in this case, military cohesion) is the bonding together of members of an organization/unit in such a way as to sustain their will and commitment to each other, the unit and the mission (Henderson, 4). The leadership factor is a representation of a command or emergent individual's ability to reduce stressors, take corrective action, and directly or indirectly influence and create the conditions to accomplish missions effectively (Department of the Army, 25).

Measures of performance must be identified and defined to model these factors in order to provide variables for validation during the implementations of the framework. The simulation of the *heart rate variability* of an individual soldier, which reflects the psychophysiological state during a given stressful event, will indicate stress. Cohesion will be measured by the two factors of *group connectivity*, which measures how well groups bond together, and *conditional density*, which defines how difficult groups are to break apart.

The framework will be constrained to specify the parameters for the human factors and performance only during a combat incident and not over an extended time. A combat incident is defined as an event or circumstance outside the normal experience that disrupts a soldier's sense of control and involves the perception of their life being threatened. The effects of long-term combat such as those incurred during long campaigns will be implicitly included in the framework by personal variables that will define the individual soldier's history and experience. These personal variables will be defined by the specific contextual situation in a given experiment.

To create a conceptual model of cohesion one needs to gain some understanding of the ideas and concepts described above. The next section of this work will describe and discuss the psychological concepts that define cohesion, stress and leadership, along with some methods of measuring or implementing them into models.

1.3 Outline of the presented work

The first chapter is written to present the context and address the problem of cohesion representation. It provides a short discussion of the conceptual models that will frame the dissertation's context and scope. This chapter also describes the method that is used to build and explain the model framework.

The second chapter of this dissertation reviews the literature that shows the principles on which the model framework was developed. The conceptual definitions of cohesion and stress are described. The psychological and physiological underpinnings of the presented concepts that make up the representation of cohesion in small combat units is addressed.

In the third chapter the proposed framework and what is necessary to operationalize the cohesion concepts is presented. The individual soldier models as well as a unit model are described along with the methods of measuring the effects of these on the dependent and independent variables associated with the measuring of stress and cohesion. This chapter also describes a specific implementation of the framework.

Chapter four describes the experimental plan for the implementation of the framework. The chapter also includes background information on why the specific experimental methodology was chosen.

Chapter five presents and describes the results of the experimentation as well as a discussion about the inferences derived form these results. The ramifications and future utilities of the results of the dissertation research are also discussed.

The unifying concepts throughout this work are that cohesion is the result of the psychological relationships and interactions of a combat unit during a combat incident. Cohesion also strengthens the unit. Cohesion can be described as the binding effect that holds combat units together despite the stresses of combat.

2.0 Literature review

2.1 Cohesion

"Tribesmen or clansmen do not feel any great concern for their kinsfolk in time of danger, but a band which is united with ties of love is truly indissoluble and unbreakable, because one is ashamed to be disgraced in the presence of another, and each stands his ground at a moment of danger to protect the other."

Plutarch, Pelopidas 18

"It has been seen, that a troop never be stronger than when it is formed of fellow-combatants that are friends."

Xenophon, Cyropaedia 7.1.30

The psychological concepts that make up cohesion have been debated since the 1950’s. The study of what makes groups perform tasks and succeed in endeavors has become increasingly important in the fields of social and military psychology. The emphasis of this work is on military cohesion and the psychological components that comprise it. The concept of cohesion and the forces that influence it, such as stress and leadership, will be discussed. Each concept will also be examined in an effort to find methods of measuring which can be used to describe them conceptually and to implement them operationally.

Soldiers do not engage in combat for ideological concepts such as motherhood, the flag or apple pie. They do not fight for patriotism. They may have volunteered for these reasons, but when their lives are at risk, and the incredible stress of close personal violence is immediately at hand, the key truth emerges: soldiers fight for their friends. The “primary group” is the major factor in explaining a soldier’s behavior in combat (McBreen 4).

Leon Festinger proposed the classical definition of cohesion in 1950. His definition was that cohesion is the sum of the forces that cause members of a group to remain in that group (Festinger, Schachter and Back 164). Festinger attempted to examine individual forces that influenced the member of a group to stay in the group. However, because it often was unclear which forces were more important or how many forces should be measured, he later proposed that cohesion be re-conceptualized as the result of all forces that influence the members of a group. The original definition focused on the cause of cohesion; the later one focused on the effects of cohesion (Hagstrom, Selvin 31).

Cohesion is the absence of latent conflict, whether caused by racial, economic or political reasons, among others, and the presence of strong social bonds, as noted by the existence of trust, reciprocity, and associations cutting social divisions and the presence of institutions of conflict management (Brekman & Kawachi 200). It is the elements of these notions that contribute to the building of communities and strengthening of social bonds, especially during conditions of war and hardship.

Military analysts have defined the cohesion of military units as the bonding together of members of an organization/unit in such a way as to sustain their will and commitment to each other, the unit and the mission. Some prefer to use the term “military cohesion” to describe the above definition.

Military cohesion has been the soul of combat units throughout history. The Greek military leader Xenophon wrote: You know I am sure that not numbers or strength bring victory in war; but whichever army goes into battle stronger in soul, their enemies generally cannot withstand them (Warner 146). All noted military leaders agree that soldiers united in a cause, trusting each other, and confident in their leaders will be an effective army (Stewart 12). These attributes that result in the aforementioned “effective army” are the factors that influence cohesion and will be investigated in the body of this work.

Cohesion moderates the way a person handles stress. An individual’s response to the stressors of a combat incident is improved if the trust and confidence in the support of the other members of the combat unit are present during combat. Cohesion is the bond of trust between the members of a group, such as a combat unit. A combat unit in which cohesion is present improves team coordination, because individuals will risk harm for the preservation of the unit (Department of the Army, 25).

There are four types of cohesion. These are horizontal cohesion, vertical cohesion, organizational cohesion, and societal cohesion. Horizontal cohesion involves building a sense of trust among soldiers, which takes into account elements such as sense of mission, technical proficiency, teamwork, trust, respect and friendship. Vertical cohesion involves the relationship between the subordinate and the superior soldier. This relationship depends on the leader’s concern for the men, leader example, trust and respect for the leaders, sharing discomfort and danger, and shared training. Organizational cohesion is the relationship of a soldier to the military as an organization, which includes characteristics such as loyalty to the nation, patriotism, military tradition, strong religious belief and a well-defined concept of valor (Stewart 27-29). Societal cohesion is the relationship of the military and the individual to the society or culture at large. The important societal factors contributing to cohesion are things such as culture, values and organization of the military, doctrine and strategy, training and tactics, command control and communication structure and medical care facilities (29).

All four types of cohesion affect individual and unit effectiveness. A unit that exhibits the cohesive trust and support of the group, leadership, military and society, exhibits the following behaviors (McBreen 5):

- *Fight better*. Warriors who trust their comrades overcome fear, fight courageously, and execute more effective tactics. An example can be seen in Reuven Gal's study of soldiers who received the Israeli medal of honor during the 1973 Yom Kippur war, which indicated that men who are cohesively bonded to their fellow soldiers performed heroically in combat (Gal 88).
- *Communicate better.* Implicit communication permits less detailed orders, and makes understanding of the commander's intent, mission orders, and tactics easier.
- *Suffer fewer battle casualties*. Units that fight well suffer fewer casualties. In the Vietnam conflict, battalions that had been together for longer than six months and that been able to form cohesive bonds, suffered battle deaths at a rate only two-thirds that of less experienced combat units (Krepinevich 156).
- *Do not fracture under stress*. Shared privation is easier to bear. Cohesive units remain capable after losses and are easier to reconstitute. This can be seen when comparing combat units in the American army and the German army during the Second World War. German units, which

> maintained the members of a unit together as long as possible remained viable and fought skillfully until the very end of the war despite tremendous pressure (Shils and Janowitz, 281). In contrast, Units such as the 275th fusilier battalion which was made up of recently assembled soldiers from elements of fifteen different army units, fell apart when encountering the allied advance in late 1944 (Shils and Janowitz, 288). In the American army units such as the 106th Division completely collapsed in combat. Sixty percent of the members of the division had been used as replacements for other combat units and the men that were added to fill in the ranks were a collection of air cadets, men from other division, cooks and drivers. They did not fight well and disintegrated under the stress of combat, despite a high quality of supplies and equipment (Watson 108-109).

It has been suggested that the importance of cohesion in explaining combat performance has been overstated or that cohesion can be replaced by alternative sources of motivation and control (from patriotism to drugs). However, motivation is directly linked to the satisfaction of needs and values, which in turn can often be determined from a soldier's attitude. Three approaches to motivation are generally recognized--coercive, utilitarian, and normative (Henderson 22).

Coercive motivation is based on the need of the individual to avoid severe physiological deprivation, hardship, or pain for himself or for someone whom he values. Such an approach is often termed negative motivation, and the individual is alienated from the organization. The limitations of this type of motivation for an army are obvious (22).

Utilitarian motivation is the motivation of the marketplace; individual decisions are made primarily for tangible benefit on the basis of a calculative attitude, with the decision to opt out of the army always a real choice if the going gets too tough. In an army where significant incentives are utilitarian, the commitment of a soldier to his unit is not very strong--no job is worth getting killed for (Henderson 22).

The normative power of the group causes the strong personal commitment on the part of the soldier that he ought to conform to group expectations, that doing so is the responsible thing to do, and that conformity is expected in spite of the fact that he might personally prefer to be doing something else. Such commitment is often referred to as a calling or, at the small-unit level, as "not letting your buddies down." This is the strongest possible type of motivation for soldiers to endure the danger and hardship of war (23).

The normative motivation of the primary group is the essence of cohesion. Soldiers that feel that they are members of the primary group and bound by the expectations and demands of its members are more likely to perform well in a combat incident (Shils and Janowitz 284).

However, a cohesive unit may act in a manner that can be defined as inappropriate. Behavior such as the abuse of prisoners or failing to advance can be perceived to be failures of soldier performance. These behaviors are usually a result of protecting one’s own against the military hierarchy who may be perceived as not having the best interest of the unit in mind. This is usually a failure of trust between the military hierarchy and the primary group or tacit acceptance of such behaviors by the military hierarchy. In other words, what is not explicitly spoken against is viewed as permitted. These types of situations are deeply rooted in the way armies are organized and perceived within the society. These implicit factors will be discussed later in the work (Kaurin 2006).

If normative motivation promotes cohesion, how is it built and what effect does it have? Frederick Wong of the U.S. Army War College characterizes cohesion as a summation of stability, stress and a perception of success. Stability among peers is an important requirement for cohesion. Soldiers should serve in their initial unit with the same peers for as long as possible, ideally for their entire first enlistment. Soldiers should be re-assigned during reconstitution periods only. The longer a person is a member of a group, the more they learn who to trust. Lack of anonymity and an expectation of future service together reinforce positive team-building behavior. Men do not cooperate well if they know they will never see each other again (Wong 20).

The level of stress that is exhibited by a soldier can affect cohesion. Whether a soldier's stress level rises to an optimum performance level or causes a catastrophic failure of morale it will influence the cohesion of a combat unit. The ability of a soldier to maintain the optimum level of stress to perform the duties on the battlefield will be improved by the trust and comradeship developed by the cohesive group (28).

Teams that win build cohesion. A frequent successful exertion to the utmost limits of their strength shows soldiers their capabilities, and shows the men that they can depend on each other. These ‘cohesion events’ are shared success. The success of overcoming realistic training challenges leads to shared celebration, shared confidence, and shared experiences. Success raises the status of the unit. Members are more likely to feel loyalty to a high status group. A leader should continuously provide timely feedback and recognition to his unit concerning success on military tasks, especially success that exceeds well-defined standards (21).

Successful units throughout history have exhibited these traits. The first studies concerning unit cohesion, conducted by Stouffer, Shils and Janowitz demonstrated that the small group ties promoted stability and moderated the stress of combat situations. Also, when a unit had some sense of being successful at a particular mission it increased the cohesion and thus increased its performance (32).

Stouffer’s landmark survey of American World War II veterans showed that high performing units, which were defined as those with low rates of non-battle casualties, were those which developed bonds of loyalty to the group and had pride in their unit’s accomplishments. These traits helped significantly in the reduction of fear in the unit during combat (Stewart 13).

Shils and Janowitz studied German prisoners at the end of World War II to determine why some German units fought against insurmountable odds and others surrendered right away. They found that those units that had primary-group ties broken, (i.e. no stability) or soldiers whose families' towns had already been overrun by the Allies (i.e. no chance of successfully defending them) surrendered quickly (14).

In the 1982 Falkland Island war, a direct correlation can be seen in the relation of stability, stress and success. During this conflict the Argentine army deployed newly formed conscript units with less than a month's training. These units, in which the soldiers barely knew each other, had never been in combat. Their performance was poor and they quickly surrendered to the more experienced British units they encountered in combat. In contrast units that had long regimental histories, whose members had at least a year's training and had been veterans of years of internal anti-insurgency conflicts, such as the 3rd Corrientes Artillery Battalion and the Commando units put up stiff resistance. These units were responsible for causing the British the highest rate of casualties during the war (Stewart, 59).

The experience of historical wars such as World War II and the Falkland conflict suggests that the creation of cohesion in a combat unit is an issue that needs to be considered in the strategic and training policies of a country's military. A German army officer initially serves six years in the same battalion. This builds unit loyalty and fosters both horizontal and vertical cohesion. After serving in supporting billets, career soldiers return to their original regiment. This also enhances cohesion, quality of life, family support and retention. Command tours are stabilized for up to thirty months (Phipps, 2-3).

In the British army, officers and soldiers usually serve in the same regiment for their entire career. The British army regiment is historically viewed as an unrivaled builder of cohesion. In both peacetime morale and wartime doggedness, the British infantry regiment was a tightly knit family. This family bonding maximizes a shared spirit of sacrifice and teamwork (McBreen 15).

The U.S. Army in the last quarter century has tried numerous cohesion programs in an attempt to counteract the effects of their individual replacement system. The most notable program was the Cohesion, Operational Readiness Training (COHORT)[2]. COHORT soldiers were found to be more competitive, trained to higher levels, and had more feelings for their unit and stronger unit bonds experienced lower attrition. COHORT, and all the other Army cohesion programs, failed because they were not supported or valued by the senior leaders of the Army and could not overcome the individualist nature of the personnel system (Wong 12-15).

In the early 1960s, United States Marines Corps infantry battalions on the West Coast rotated back and forth to Japan using the transplacement system. This system was a unit reconstitution system. All Marines, including officers and non-commissioned officers served 30 months, two 15 month cycles, with a 50 percent personnel turnover at the end of each cycle (Canby, Gudmundsson and Shay). This system was discontinued during the first year of the Vietnam War,

---

[2] The Army's experimental cohesion, operational readiness training (COHORT) program creates new combat arms companies which keep the same soldiers together through basic training and links them with their leaders in advanced individual training. The COHORT program then keeps the personnel in the company or platoons together (as much as possible) through the first enlistment. This maximizes the horizontal bonding and first level of vertical bonding.

when the Secretary of Defense pressured the Marine Corps to conform to the Army's individual personnel system.

Although the militaries of various nations, as noted above, have implemented various schemes of cohesion building, the question arises of how to implement the best cohesion program in the ever-changing domain of fighting wars. With the apparent shift from traditional massed battles between identifiable opponents to the small brush wars, how can militaries create the best cohesion plans to meet their needs?

Current military studies on cohesion often take the shape of questionnaires. These questionnaires, in which soldiers are asked how they think members of their unit felt about subjects such as trust, leader confidence and organizational aspects, have been used to develop a measure of cohesion (Siebold and Kelly, 4, 37). These measures have been effective in creating the cohesion pictures of existing units; however, in the case of looking into historical or yet to be developed units, where a questionnaire cannot be administered, a modeling and simulation approach needs to be taken. A method to conceptualize and operationalize the factors that make up cohesion needs to be developed. This creates the question of how to conceptualize, measure and implement cohesion into models that can be used to study any military organizational innovations in this field.

To determine how to conceptualize, measure and implement cohesion into models, a survey of the work in the nature of social cohesion needs to be done. Because the principles that hold a combat unit together are those that hold any social group together one should be able to derive the concepts of military cohesion by the study of social group interactions.

George C. Homans suggests that because it is difficult for the total forces acting on members of a group to be calculated, the group characteristics can be taken as indicators of cohesiveness. These include the degree to which members of a group choose friends from within the group, verbal expressions of satisfaction with the group, participating in group activities, willingness to remain in the group when alternatives exist, and consensus on values relevant to the group's activities.

Using this approach Hagstrom and Selvin introduce the concept that cohesion exhibits two dimensions, s*ocial satisfaction and sociometric cohesion*. *Social satisfaction* involves satisfaction with the group, as well with the aspect of the social life of the group. *Sociometric cohesion* indicates the proportion of friendships and the proportion of those who seek advice from other group members. These dimensions reflect the distinction between the instrumental and the intrinsic attractiveness of small groups. They surveyed 20 living women's groups at the University of California. The survey examines 19 factors that refer to cohesiveness. The result supported the concept of the two dimensions of cohesion in small groups; however they indicated that further study is necessary because the findings would be difficult to replicate in certain situations. In groups that are strongly task-oriented or groups that are not under pressure from their environment, analytic studies may not yield distinct dimensions of cohesiveness.

Linton Freeman introduces two models of cohesion that look at the strong and weak forces that hold small groups in place. Freeman contends that previous models that tried to specify the structure of groups in exact terms fail because group interactions overlap and blur the structures of a group. These models also fail to take into account the internal structure of the groups that makes it difficult to get a useful picture of their behavior (Freeman 152).

Freeman introduces the Winship model, which uses network analysis to specify the conditions that partition individuals into non-overlapping groups while permitting the display of internal structures. This model begins with a set of individuals, P = {x, y, z . . .}. These individuals are partitioned into a hierarchical structure by forming a nested sequence of *k* distinct levels of equivalent classes, E'_i, E''_i. . .,i = 0 to *k*. At any given level, any pair of objects x and y are either equivalent or not (154).

At the lowest level, E_o, each object is equivalent to itself, or in other words, each person stands alone as an individual, and at the highest level, E_k, all members belong to a single equivalent class or overarching group. To construct the hierarchy, a quantitative measure of the members' social affiliation is created to tally the frequency of interaction between the members of a group, such as how many minutes individuals are observed in conversation. This quantitative measure is referred to as a *social proximity function* (154).

The *social proximity function* depends on three conditions. First, each person must be closer to himself than to anyone else. Second, the proximity of one person to another must be the same as the proximity of that other to the original person. Third, there should be no intransitive triples (i.e. any triple of persons or pair may be less proximate than the minimum of the other two pairs) (154).

Freeman presents another model that captures the essential features of groups. The Granovetter model defines properties that investigate the relationship of what he called “strong” and “weak” ties that link people in groups together. This model uses the same frequency of interaction used in the Winship model, but allows intransitive triples. The Granovetter model proposes that intransitive triples empirically occur with high frequency and that if an individual is strongly tied to two others, the two others should be at least weakly tied to each other. This allows the Granovetter model to exhibit not only the ties between individuals in an organization, but also the ties between groups in an organization (155).

Freeman applied the two models to seven data sets and discovered that with the Winship model the intransitive triples appeared in such numbers that groups could not be identified. In the Granovetter model, groups could be identified in some cases but not all. The conclusion was made that interaction frequencies are not adequate to measure social affiliations, because they reflect the effect of external concerns. The Granovetter model shows some interesting implications that indicate the possible use for the investigation of groups. The key is to develop an accurate and quantitative measure that can reflect the interaction of individuals within the group.

Moody and White expand on the concept of social cohesion based on network connectivity. They introduce a methodology of cohesive blocking that allows researchers to identify cohesive substructures in a network and simultaneously identify the relative position of such structures within a population.

Moody and White refer to the relational component of social solidarity of cohesiveness. They first define cohesion in terms of the importance of multilateral connectivity (9, 13):

> *A group is cohesive to the extent that multiple independent social relations among multiple members of the group hold it together.*

This definition is reinterpreted in the following definition:

> *A group's cohesion is equal to the minimum number of members who, if removed from the group, would disconnect the group.*

In other words, in a group, represented by a network of nodes, each member is reachable from every other member. The path that links two non-adjacent nodes must pass through a given sub-set of other nodes. These nodes if removed would disconnect the two actors and break the network into pieces.

Moody and White describe previous models of cohesion, such as the Winship and Granovetter, as inadequate due to vague and contradictory definitions. These models are difficult to operationalize and do not provide a good measure of cohesion. The network approach does not depend on size because the model works on the measure of cohesion directly and can scale it to any size group.

Moody and White expand on Durkheim's concept of social solidarity, which is defined as the factor that keeps the "social collective" (i.e. group) together. Emil Durkheim, in 1897, divided social solidarity in two components, one that refers to the psychological identification of members within a group and another that refers to the observed connections among the members in a group. Cohesion models need to distinguish between the individual components and the connective components of a group to adequately operationalize the concepts of cohesion.

White and Harary define two types of connective components to a group: the cohesive group, which is united through multiple distributed connections and the adhesive group, which is united though strong ties to a central leader. Adhesive groups are dependent upon the unilateral action of a single person while cohesive groups will maintain a group status regardless of the unilateral action of any one member in the group. These relational patterns are used to understand how groups of individuals are linked together and how those links change.

Using the relationships seen in adhesive and cohesive groups they demonstrate that the more connections between the members of a group the greater the cohesion. They operationalize this conception of social cohesion though the graph theoretic property of connectivity, which shows that cohesion, increases with each additional independent path in a network. This differs from previous conceptualization of cohesion in that they identify cohesive groups by the properties of the network that do not necessarily correspond to network patterns that are not a result of unilateral action on an individual in the group. The previous models, such as Winship's and Granovetter's, which are based on relational distance, number of interactions, or relative group density cannot distinguish between adhesive and cohesive social structures.

Moody and White theorize that increasing the connections between the members in a group enhances a group's cohesion. They indicate that the higher the connections the more members must be removed to break the group. This can be used to empirically measure the cohesion of a group. Therefore, an adhesive group will be easier to disrupt because the removal of the key individual will break the network. On the other hand, a cohesive network will be maintained longer because many individuals will have to be removed to disrupt the group.

White and Harary continue the network connectivity ideas of Moody and White. They describe a pair of related measures that combine into an aggregate measure of cohesion. They define the concept of *connectivity* as the minimum number *k* of its actors whose removal would not allow the group to remain connected or would reduce the group to a single member. This measures the cohesion of a group at a general level. They introduce the concept of *conditional density* to measure the proportions of ties beyond that required by a graph's connectivity *k* over the number of ties that would force it to *k+1*.

A graph is defined as G = (n, m) which consists of n nodes or vertices and m edges each joining a pair of nodes. The graph is described as G has an order n and size m. The *connectivity* of the graph is denoted by κ (G) and is defined as the smallest number of nodes that when removed from graph G leave a

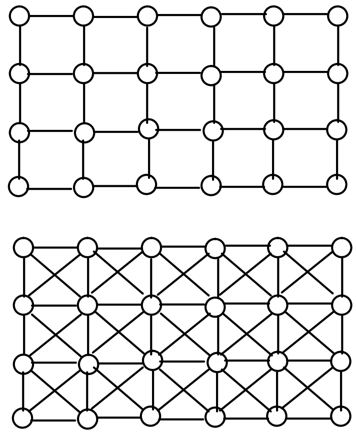


Figure 1. Example of graphs G and F and their definition based on White and Harary. *It can be observed that the interactions increase makes the connectivity and density increase therefore increasing the cohesion of the graph. The graph with the most connection is the one most difficult to break apart, thus "more cohesive."*

discontinuity or a set of smaller graphs. The density of the graph is denoted by ρ (G) and is defined as the ratio of the difference between m and the maximum number of m1 of edges of a graph G of order n. As m1 = n (n-1)/2 gives ρ (G) to be equal to 2m/n (n-1) (See Figure 1).

White and Harary demonstrate that connectivity and density are two aspects of cohesion which are tightly bound together. They take advantage of this interdependence to combine and unify them into a single measure of cohesion, which is denoted as κ+ρ (G: κ).

The White and Harary's concept of cohesion measurement through the strength of social networks holds the most promise for the conceptual model developed for this dissertation. The strength of the combat unit derived from the connectivity implies that the breaking point of a unit can be indexed to this value and the conditional density can be used to index the relationships that strengthen the unit during a combat incident.

Before continuing to discuss vertical, organizational and societal cohesion and how they affect the performance of a small combat unit, there is another aspect of cohesion that needs to be addressed. This is the difference between what is indicated as task versus social cohesion.

In recent years a debate has emerged between some in the academic community and the military community about a difference between social and task cohesion. The argument of whether social cohesion is important in the performance of combat or whether task cohesion is the sole indicator of performance is raging between the communities. These terms are defined as:

- ***Social cohesion*** refers to the nature and quality of the emotional bonds of friendship, liking, caring, and closeness among group members. A group displays high social cohesion to the extent that its members like each other, prefer to spend their social time together, enjoy each other's company, and feel emotionally close to one another (MacCoun, R.J., 1996)

- ***Task cohesion*** refers to the shared commitment among members to achieving a goal that requires the collective efforts of the group. A group with high task cohesion is composed of members who share a common goal and who are motivated to coordinate their efforts as a team to achieve that goal (MacCoun, R.J., 1996)

MacCoun argued that task cohesion not social cohesion is correlated with unit performance. Social cohesion, according to MacCoun, has little relationship to performance, and can even interfere with unit performance by causing undesirable behavior such as “groupthink” and the “fragging” of officers. MacCoun’s arguments are echoed by Segal and Kestnbaum, who stated that, “There is no clear causal link that can be demonstrated using rigorous methods between social cohesion and high levels of military performance (MacCoun 157-176, Segal & Kestnbaum 453).

Leonard Wong states that despite the academic debate concerning social cohesion and its effects on performance, social cohesion remains a key component of combat motivation in U.S. soldiers. Social cohesion is what motivates soldiers not only to perform their job, but also to accept responsibility for the interests of other soldiers. At the same time, social cohesion relieves each soldier of the constant concern for personal safety as other members of the unit take on that responsibility (Wong 14).

Wong also states that social cohesion appears to serve two roles in combat motivation. First, because of the close ties to other soldiers, it places a burden of responsibility on each soldier to achieve group success and protect the unit from harm. The second role of cohesion is to provide the confidence and assurance that someone soldiers could trust was "watching their back." This is not simply trusting in the competence, training, or commitment to the mission of another soldier, but trusting in someone they regarded as closer than a friend who was motivated to look out for their welfare (10).

Although there is considerable controversy among members of academic circles on the importance of task cohesion versus social cohesion, for this work the primary focus is on task cohesion because the performance during a combat incident is primarily a function of the members of a unit to coordinate their efforts to achieve an objective or goal. However, the role of social cohesion cannot be ignored, because the quality of the bonds among the members of the unit are going to have a profound impact on whether soldiers, as Henderson states, show a willingness to risk death for the welfare of "their buddies" in their unit. Although the primary factor in a combat unit staying effective during a combat incident, another secondary factor is extremely important to a unit attaining an objective. That is the factor involving leadership of the unit. The various theories and models for representing the leadership aspect of cohesion will be discussed next.

2.2 Leadership (Vertical Cohesion)

"Our Squad Leader kept an eye on us, he was always talking to us, calling us by name. His voice helped as we advanced on the Comandancia . . . It was the hardest thing I ever did."

Member of a combat squad describing the attack on the Comandancia during the 1989 Panama invasion

The relationship between subordinates and superiors, as described by Nora Stewart, is one of the major elements of cohesion. Known as vertical cohesion or bonding, it involves the trust and respect a leader and the members of a combat unit have for each other (28).

To investigate this trust between the leader and the members of a combat unit one has to investigate the aspects of leadership that create it. There are many views and theories about leadership and how it manifests itself in an organization. The purpose of this section is to examine the aspects of leadership in combat: how they affect cohesion, investigate how they can be modeled and incorporated into the cohesion framework presented in this dissertation.

Leadership is basically how a person with authority gets individuals under their charge to perform a required mission. Getting soldiers to march into combat is where leadership is of utmost importance. However, leadership that influences cohesion needs to be at the small intimate level, not at the large managerial level. The source of a soldier's values are at the small unit level, and because the only force strong enough to make a soldier willing to advance under fire is the loyalty to the small unit and that group's expectation that they will advance, it becomes important to an army to control that primary group though its leaders (Henderson 108).

The paramount importance of leadership in combat has been recognized because antiquity. The history of battle has always been a history of leaders building their subordinates' confidence to achieve victory. Confidence in the leader is an essential component of a soldier's performance in combat, whether he is part of a small band of spear-armed warriors or a vast army of laser-armed riflemen. Despite the configuration and technologies on the battlefield, confidence of the troops in their commanders is a critical ingredient in the soldier's process of coping with stress (Gal 139).

Leaders are the key factor in the cohesion of a combat unit. During combat the leader influences cohesion through personal example and by enabling and ensuring communication and flow of information. This communication reduces the soldier's isolation on the battlefield and allows the soldier to manage fear and remain with the unit, and thus provide reliability and reassurance to other members of the unit (Spiszer 4).

A leader must bring out the internalized values and discipline within soldiers to enable them to overcome battlefield stressors and enter a combat situation (Henderson 111). Soldiers in danger become aware of the qualities of their leaders. They wish for their anxieties to be controlled and desire their leaders to provide reassurance in stressful situations (109). The leader is the crucial factor in protecting the soldier from overwhelming battle stress. A leader can provide a positive impact on the self-esteem of a soldier; however, the leader can also provide a negative impact on the unit's situation.

A leader can be characterized as a lens either magnifying or minimizing the effects of the stressors of a combat incident (Gal 135). A leader's position of power and prestige puts the interactions among the members of a combat unit as through a lens that amplifies the results the combat incident. This can result in improved performance or complete collapse of the cohesion on the battlefield (Shay E45).

The ability to produce positive effects in soldiers from battlefield stress is based on the decision quality of the leader and the decision acceptance of the soldiers. Soldiers supporting or endangering the cohesion of the group as well as the stated mission will perceive the decision quality. The decision acceptance will be based on how much the soldiers trust the leader's decision (Yukl 1985). Studies produced by the Israeli army during the 1982 Lebanon war identified three elements that made soldiers trust a leader's decision. These were:

- Belief in the leader's professional competence
- Belief in the leader's credibility
- Perception that the leader cares about the troops

Of these three elements, trust in the leader's professional ability was identified as the primary component in building the trust in a leader (Gal 139).

Social scientists have researched leadership and produced many theories and models to try to explain how the relationship between leadership and groups works. Early research focused famous leaders and tried to find certain personality traits that these leaders had in common.

It was believed that a specific set of leadership traits could be identified that could be linked to leader and group performance. However, researchers failed to discover any traits that would guarantee success (Northouse, 29). It was realized that it is nearly impossible to develop an inclusive list of leadership traits and that no conclusions can be made regarding the connection between a particular trait and leader effectiveness (Wu).

Researchers later developed behaviorally based models that focus on the leader’s observable actions instead of the leader's traits. These models examine the behavior of a leader based on two dimensions:

- **Concern for Production** -A manager who has high concern for production is task-oriented and focuses on getting results or accomplishing the mission.

- **Concern for People** -A manager who has a high concern for people avoids conflicts and strives for friendly relations with subordinates.

The behavioral leadership approach has its advantages and disadvantages. It focuses on observable actions of the leader to determine if the leader's main concern is for production or for people. This provides a more reliable method for studying leadership than the trait approach. The behavioral model aims at identifying the most effective leadership style for all situations, which is not supported by evidence in real organizations. These models, however, introduced the important dimension used to examine leadership behavior and characteristics (Wu).

Fred Fiedler began to research leaders in 1953 to better describe the observed relationships in organizations. His studies included artillery crew commanders, tank commanders and ROTC cadet officers. Fiedler developed theories postulating that the effects of a leader on their subordinates are contingent on both the leader's motivation and the situation. This contingency theory uses a measure of effectiveness known as an LPC or least preferred coworker score to determine the leader's motivation. The LPC score is obtained from responses to a semantic differential scale on a questionnaire. A leader with a high LPC will be motivated to have a close interpersonal relationship with subordinates and is people oriented. A leader with low LPC will be concerned with task objectives and is production oriented (Yukl 133).

The relationship between a leader's LPC scores and the leader's effectiveness depends on a complex situational variable with multiple components. The situational variable is called “Situational Favorability.” It is defined as the extent to which the situation gives the leader influence over a subordinate’s performance (139). Situational control is measured it terms of the following three factors:

- **Leader member relations** -which refers to the degree of mutual trust, respect and confidence between the leader and the subordinates
- **Task structure** -which refers to the degree to which the task at hand is low in multiplicity and high in verifiability, specificity, and clarity
- **Leader power position** -which refers to the power inherent in the leader's position itself

When there is a good leader-member relation, a highly structured task, and high leader position power, the situation is considered a "favorable situation"(Wu).

Fielder’s model has been criticized because the LPC variable is arbitrary and doesn’t correlate with the application of the model to test organizations. Critics have also suggested that the factors of the Situational Favorability variable are not entirely independent and could confound results when the model is applied. Debate is continues on the applicability of the Fiedler model but he did introduce the perspective that the combination of leader traits and the situation on hand determine the effectiveness of the leader (Yukl 139).

In 1971 Robert House developed the “Path-Goal Theory” of leadership, which explained how leadership can influence the satisfaction and performance of individual followers (Yukl 266). The theory proposes that a leader’s behavior is motivating to a follower if the behavior increases the attractiveness of a goal while simultaneously increasing the follower’s confidence in achieving it. The leader in the “Path-Goal Theory” must exhibit one or more of the following behaviors:

- **Supportive**, in which the leader goes out of his way to make the task enjoyable and treats the followers with respect
- **Directive**, where the leader sets clear standards of performance and makes rules and regulation for followers
- **Participative**, where leadership involves consulting with followers and taking their contributions into account during decision making
- **Achievement-oriented**, in which a leader challenges followers to perform their best and demonstrates confidence in their ability to accomplish their task.

The leader will pick the best type of leadership for a given situation and the individual follower. The leader is actively guiding, motivating and rewarding the followers in their tasks (Howell 42-43). The deficiency in the “Path-Goal Theory” is that the leader’s behavior is defined in terms of broad behavior categories and the way that different situational variables interact is not clearly defined. The theory does not take into account other ways in which a leader can affect performance and motivation, such as training subordinates to increase skill level and thus raising their motivation. The theory does provide a conceptual framework to guide researchers in identifying potentially important situational moderator values (Yukl 262).

V.H. Vroom and P.W. Yetton developed in 1973 a leadership model that stipulates the overall effectiveness of a leader on their decision quality and the decision acceptance by the followers (Yukl 127). Known as the “Normative Decision Model”, it identifies the decision quality as the objective aspect of the decision that affects group performance. It also states that for the decision to be implemented effectively, the degree that the subordinates accept must be determined (128).

Both decision quality and decision acceptance are affected by the follower’s participation during decision making. The behavior used by the leader when making decisions affects the follower’s acceptance as well as the specific situation in which the leader makes the decision. The “Normative Decision Model” emphasizes the leader’s behavior and shows how leaders can perform effectively when faced with situations causing decisions to be substituted or neutralized (127).

In more recent times researchers have presented more radical theories about leadership. The “Leader Substitute Theory,” created by Kerr and Jermier in 1978, describes situational aspects that reduce or even eliminate the importance of the leader. Certain characteristics of the subordinates, task or organization become substitutes or neutralizers for the leader's influence upon the organization (272).

Neutralizers are constraints that prevent a leader from making improvements to battlefield situations or, in other words, block a leader's effectiveness. This can occur if the leader is incapacitated or loses "face" with the members of the combat unit. Substitutes are aspects such as follower effort, follower ability, role clarity and cohesion, which when they are at a high enough level can be substituted for leader behavior (273).

Not many studies have been done on this leadership model, so there is still much discussion about its validity and utility. However, the ideas presented by Kerr and Jermier have added the interesting possibility that leaders are sometimes redundant, which is seen as a new way to look at leadership (Wu, Yukl, 276).

To incorporate leadership in the cohesion framework it is important to choose a model that best represents the effect of the leader on a combat unit during the specific instance of combat. The stressful nature of the combat incident requires, as Henderson stated, control of the individual's behavior at the intimate level to assure that the combat task is conducted effectively.

The theory that seems to concur with the military leadership literature is the "Normative Decision Model." The quality of the decision in the "Normative Decision Model" and the acceptance by the subordinates can be seen as similar to the trust soldiers had with their commanders in the 1982 Lebanon war example that Gal describes. This can also model the lens aspect that Gal describes as amplifying the situational conditions. If a combat unit does not trust the leader's decision, the stress effect will be magnified and the cohesion of the unit will suffer.

The other aspect that needs to be incorporated in the cohesion framework is the concept of leadership substitution, especially in a small unit combat incident. In situations such as ancient man-to-man combat or modern urban warfare, the view the soldier can see is the immediate area around the fighting. A leader may not be visible or may be killed. At this point the leadership trust is not the primary thing on the soldier's mind. So the only factors that can mitigate the stress of the situation are the soldier's task or organizational characteristics.

A historical example of this can be seen at the Spartan (480 BC) stand at Thermopylae. During the battle the Spartan King Leonidas was killed. The Spartan soldiers did not act as a leaderless mob; instead, the group behavior of the highly trained and cohesive king's bodyguard and admiration for Leonidas resulted in the surrounding and protection of Leonidas' body and the continuation of the fight (Selincourt 494, Cartledge, 262). The death of the leader, King Leonidas, was a neutralizer but the bodyguard's cohesion and training substituted for the leadership behaviors and the unit continued in their task of fighting the enemy.

The normative and substitution concepts of leadership will be incorporated into the vertical cohesion components of the framework that is presented in this work; these can be seen in the implementation section. These trust relationships will be set at the time that a combat unit enters a battle. As soon as the first bullet begins to fly or first spear is thrust, the established trust between a leader and the followers will begin to affect the cohesion and performance of the unit. The unit characteristics and history will also in effect substitute or neutralize the actions of the leader. These ideas will be used to operationalize the effect of leadership in this work's proposed cohesion framework.

Two more aspects need to be examined to get the full picture of the phenomenon of cohesion. Although more implicit in the makeup of cohesion, factors such as ideology and military traditions play a part in the cohesion of small units. These concepts will be discussed in the next section.

2.3 Organizational and Societal Cohesion

"*The secret of all victory lies in the organization of the non-obvious."*

Marcus Aurelius

Organizational characteristics are important to the maintenance of cohesion in a combat unit. The organization influences the unit cohesion by providing the goal and objectives that allow the unit to perform its function. The overall aim of the army to which a combat unit belongs will promote or detract from the cohesion. If a unit is forced to fight in an endeavor that it is not suited for, the cohesion will suffer. The organization provides the personnel and logistical support that sustains the unit during a combat incident. Finally, it provides the organizational structure characteristics that will promote cohesion (Henderson, 10).

Organization goals and objectives effects on cohesion can be seen in the the invasion of Grenada in 1982. In the initial hours of the invasion, although the joint task force accomplished its mission, things went wrong. Troops had to use tourist maps, Army and Marine operations were poorly coordinated, and lack of radio interoperability led to a break down in cohesion (Cole, 58).

The replacement policies of the American army versus that of the German army in World War II exemplify the organizational policies that affect cohesion. The American army replacement policy was to feed new replacements into existing units. This creates a situation where the new recruits did not know anyone in the existing unit and the trust bonds necessary to create cohesion did not exist. However, this did provide a core around which the incoming replacements could crystallize into an effective combat unit. This lack of trust bonds would make the American units very fragile, but able to maintain the integrity of the unit much longer. This integrity would make the unit that would survive a long time more cohesive and able to contribute to the strategic level operations. The German army on the other hand would maintain the composition of unit until it took enough losses to become ineffective. Then it would be made a depot unit where the organization would be rebuilt. This made the cohesion and efficiency high in the unit during combat. This would make the German unit extremely efficient tactically, but as they took loses they would become ineffective strategically (Rush, 137).

Certain organizational characteristics are thus important. The size of the group, for example, takes on added significance because cohesion is inversely proportional to the numbers in the group. Several armies, in fact, have determined that the ideal size is up to nine men, with some armies choosing a three-man unit or Military cell, which becomes the basic personnel building block of the army (Henderson, 10).

Common attitudes, values and beliefs are the attributes from societal cohesion. A group's sense of a common and unique history and shared values will be a force that draws a population together, especially if it includes a significant period of trial such as fighting and winning a revolutionary war or a war in defense of its boundaries. If such similarity does not exist, conflict will often result, especially if the group is held together primarily by outside authority (Henderson, 75-76).

Most analysts agree, however, that compared to the influence of the small group, broad political and cultural values are not nearly as significant in explaining why soldiers fight. Leadership, especially great confidence in the commander at the company level, far outweighs any feelings that question the legitimacy of the war in affecting troop performance in combat (Gal, 13).

Because organizational cohesion is a function of the way an army is organized and functions, its implementation needs to be implicit in any framework that models cohesion. When a scenario is set up, the organization of the forces involved will provide the organizational aspect of the units to be studied. Societal cohesion needs to be modeled by having a factor that moderates any effects implemented in the definition of the relationships between the soldiers in a combat unit.

To begin to define the nature of the relationships that determine the connections between the members or nodes in a combat unit the concept of stress needs to be investigated. The stress reaction of the individuals at the nodes will have an effect on the other individuals of a group and influence the connectivity and conditional density of the group. The next section will define and examine the concepts of stress for the purpose of this dissertation.

2.4 Stress

"Bugs, Mr. Rico, Zillions of them"

Robert Heinlein, Starship Troopers

"He has not learned the lesson of life who does not every day surmount a fear"

Gaius Julius Caesar (100-44 B.C.)

The department of defense defines combat stress as the expected and predictable emotional, intellectual, physical, and/or behavioral reactions of soldiers who have been exposed to stressful events of combat. Combat stress reactions vary in quality and severity as a function of operational conditions, such as intensity, duration, rules of engagement, leadership, effective communication, unit morale, unit cohesion, and perceived importance of the mission (Department of the Army, 25). However, to understand combat stress one needs to investigate the concept of stress in general and how it can influence the performance of soldiers, as well as the unit they serve.

Hans Selye, regarded by many as the father of stress research, described stress as "a state, manifested by a specific syndrome of biological events." He argued that it was *not* "nervous tension," nor the "discharge of hormones from the adrenal glands," nor "simply the influence of some negative occurrence." What stress *is*, according to Selye, is the common response of the body to any demand on it for readjustment or adaptation. "Any kind of normal activity ... can produce considerable stress without causing any harmful effects" (Selye, 56).

The United States army has devoted much time to the study of how stress caused by combat will ultimately determine a soldier's behavior in a combat incident. The army breaks down the common response of the body into three parts. These parts consist of the stressors, the stress appraisal and the stress behaviors that result from dealing with stress during combat (Department of the Army 26).

Stressors are the stimuli that trigger the stress reaction and are also referred to as stress triggers. Stressors can also be defined as the things in the environment that one can determine as threatening or signaling danger. These things may be real threats; however, thinking one is in danger, even if it isn't real, will trigger stress responses (Selye, 62).

The stress response is the full range of behaviors that result from the reaction to the stressors in combat. These range from positive performance improvement, such as heightened alertness and tolerance, to discomfort, to negative behaviors, such as violations of military conduct or irrational behaviors.

Appraisal is an important assessment of an individual's environment, which determines whether and to what extent the stress response is expressed. This assessment of stressors determines whether or not a person engages a threat or not. Many factors are incorporated in the appraisal, including one's baseline view of the world as safe or dangerous, and personality factors such as self-confidence or one's ability to successfully cope with life in addition to the specific stressor. An individual's perceptual stance is a major factor in the interpretation of the experience. For example, the emotional reaction to an injection of adrenaline can be experienced as anger or euphoria depending on the experimentally manipulated context. Much of managing stress, therefore, is incorporated within the variables of appraisal (Schachter, 247).

Stress, according to Selye, is not entirely negative. It helps the individual to function better, stay alive and cope successfully with stressors. However, if there is too little stress, the job is done haphazardly or not at all because the individual is easily distracted, makes errors of omission, or falls asleep. If stress becomes too intense, the individual may be too distractible, too focused on one aspect of the task, have difficulty with fine motor coordination and with discriminating when and how to act. With extreme stress, the individual may freeze (become immobile or petrified by fear) or he may become agitated and flee in disoriented panic. If stress persists too long, it can cause physical and mental illnesses (Department of the Army, 33). Extreme stress with hopelessness can even result in rapid death, either due to sympathetic nervous system over-stimulation (such as stroke or heart attack) or to sympathetic nervous system shutdown (not simply exhaustion). An individual giving up can stop the heart from beating (Department of the Army, 35).

As mentioned before, the original purpose of stress is to keep the person alive. The military requirement for the stress process is different. It is to keep the soldier in that range of physiological, emotional, and cognitive mobilization that best enables him to accomplish the military mission, whether that contributes to individual survival or not. Tasks which require heavy muscular exertions are performed best at high levels of arousal. Tasks that require fine muscle coordination and clear thinking (such as walking point on a booby-trapped jungle trail, or distinguishing subtle differences between friendly and enemy targets in a night-vision gun sight) or that require inhibiting action (such as waiting alertly in ambush) will be disrupted, unless the stress process is kept finely tuned. If the stress process allows too much or too little arousal or if arousal does not lessen when it is no longer needed, stress has become harmful (Department of the Army, 35).

The notion of attaining the optimal stress range where stress becomes useful for performance has been conceptualized in two theories that form the basis of much contemporary stress theory. These two theories are Sale's General Adaptation Syndrome and the "Inverted-U Hypothesis", otherwise known as the Yorkers-Dodson Law (Karasek and Theorell, 90-91).

The first theory, known as the General Adaptation Syndrome (GAS), states that, in response to a stressor, an initial 'alarm reaction' is followed by a "stage of resistance" and finally a "stage of exhaustion" is reached, which ends in catastrophic inability to cope with *any* form of stress. In the alarm phase, also commonly called the "fight or flight" syndrome, the body produces the initial stress hormones. The result is raised heart rate, blood being diverted from digestion and faster reaction times (Selye 31).

If the stressors are not removed, the body will move into a "resistance" phase where *corticosteroids* are triggered. The "alarm phase" effects are maintained and the body uses less energy. However, unless the situation is resolved it will eventually lead to exhaustion and collapse times (31).

The third and final phase is "exhaustion," which can be seen in people that suffer physical and mental breakdown. If the situation remains unresolved death can result as a body continues to break down its own tissues to maintain an aroused state at all times (31).

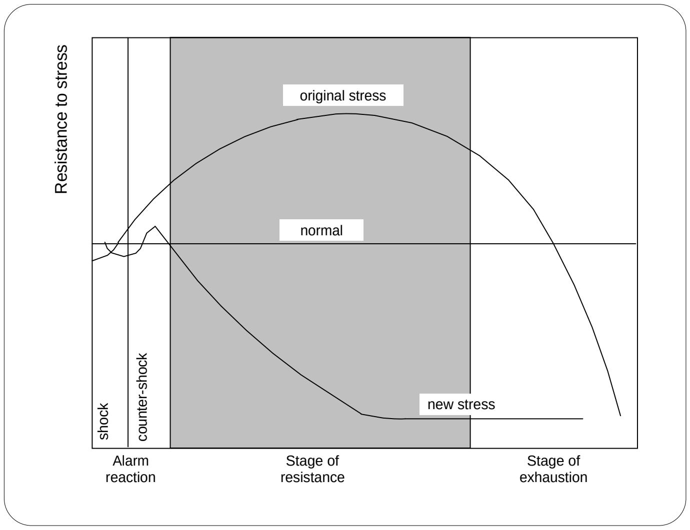


Figure 2. Selyes' General Adaptation Syndrome. The initial alarm reaction is followed by a stage of resistance. This means that resistance to the original stressor builds, while the ability to resist a new stressor is lowered. Eventually a stage of exhaustion sets in which ends in a catastrophic inability to cope with any form of stress (Gray, 61).

The second of the two theories is the Inverted-U hypothesis, or Yerkes-Dodson law. This states that there is an optimum level of arousal for any task, which will be lower as the difficulty of the task increases (Hockey and Hamilton, 1983). This is consistent with Selye's GAS in that the need to perform a task, which may here be considered to be a stressor, causes an arousal which builds up towards a maximum and then declines. This is accompanied by an increasing ability to deal with the task, again up to a maximum level, after which performance declines. Hockey and Hamilton (1983) offer an explanation of this:

> The general form of the Inverted-U function is said to result from an increasing reduction in the processing of environmental information as arousal level increases, starting with peripheral or secondary sources, then restricting the use of even primary task information (Hockey and Hamilton, 1983).

The Selye and the Yerkes-Dodson models are static models. They assume that the stressors acting upon an individual must be endured; they fail to take into account an individual's ability to interpret a threat as a source of pressure and act to change the situation. The two models are considered by many in today's stress research field to be a rather simple representation of stress. It is apparent that stressors affect performance in way that cannot be fit into simple arousal generalization, such as The Selye and the Yerkes-Dodson models.

Dynamic behaviors of constantly changing situations are difficult to account for with the previously described models. If such models can be incorporated with dynamic features they would better account for the variability in real situations.

Taking into account the dynamic nature of stress, Tom Cox presented a five-stage model that would represent the ideas that would need to incorporate dynamic behaviors into models of stress performance. The stages Cox proposed are as follows (Cox, 18-20):

- **Stage 1**- sources of demand (part of the environment) faced by the individual.
- **Stage 2**- the individual's perceptions of those demands in relation to the ability to cope.
- **Stage 3**- the psychological and physiological changes associated with recognition of stress arising from stage 2, including perceived ability to cope.
- **Stage 4**- the consequences of coping.

- **Stage 5**- the general feedback (and feed forward) that occurs in relation to all other stages of the model.

Based on Cox's five stages model of stress, Williams proposed the following model to represent the stress dynamic process.

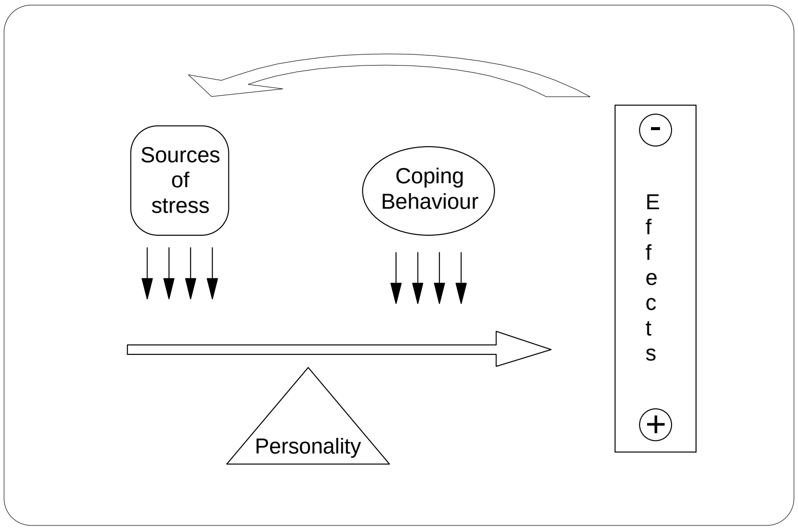


Figure 3. Stress Processes. The importance of the model comes in the feature of the feedback loop. If individuals realize that they are failing to cope with the demand of a task, then this is the stress scenario and the indicator moves towards the negative. The effects of the stress might then cause further deterioration of an individual's performance as the effects are fed back into the source of stress (Williams, 158).

Williams defined an indicator that rests on the fulcrum, which represents personality. Pressure from stress sources and coping behaviors both exert downward pressure on the indicator on either side of the fulcrum. The indicator's position is affected by the contest between the stress and the coping methods. Positive or negative effects are created based on the direction of the indicator. The effects are feedback to add weight either to the sources of stress or to the coping mechanisms. Clearly the position of the fulcrum, the individual's personality attributes, has a very significant influence on the potentiality both of the sources of stress and of the coping behaviors.

A similar dynamic stress model that provides some operational measures of stress in relation to performance was developed by Reuven Gal, former chief psychologist for the Israeli defense force, to study the complexities of human behavior of groups under stress. The model Gal proposed (see Figure 4) is interaction which posits a number of antecedent variables acting through mediating variables to affect the individual's appraisal of the combat situation and subsequently result in a soldier's modes of response and coping with combat.

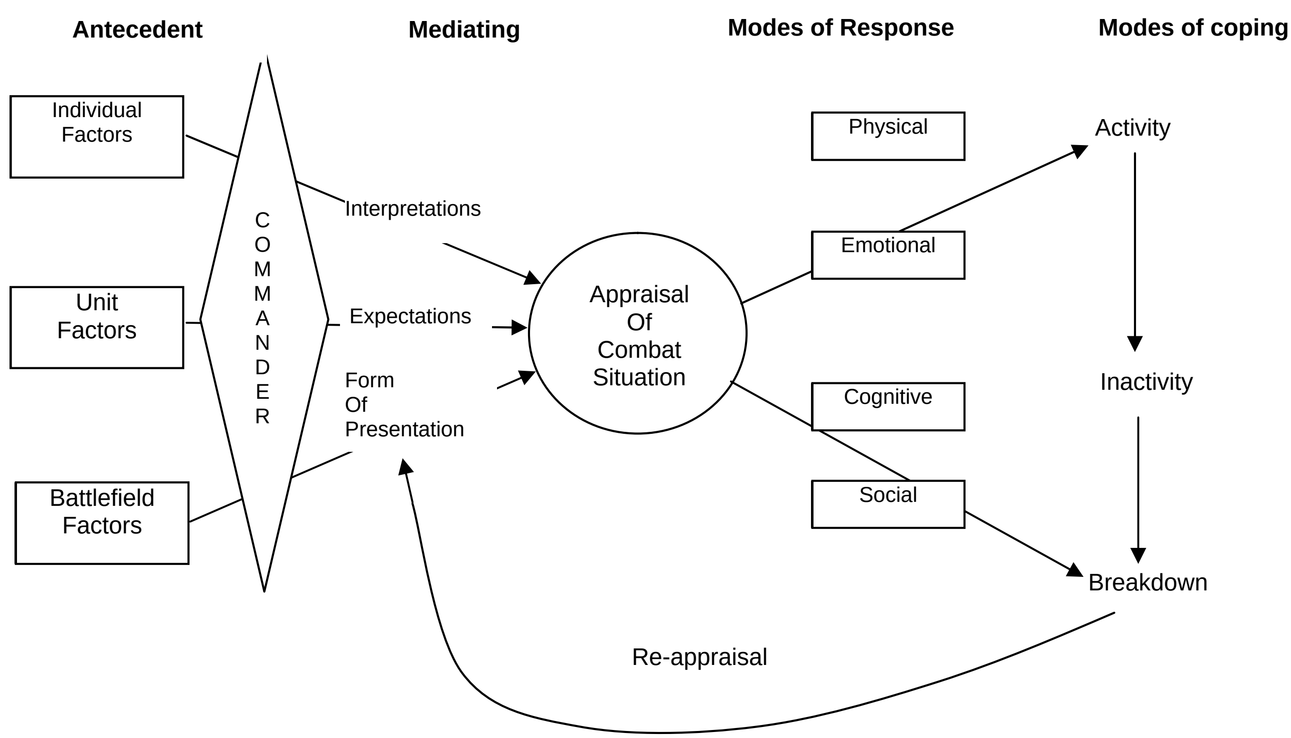


Figure 4. Gal's model of a soldier's behavior in combat stress conditions. *The model illustrates the feedback loop for reappraisal similar to the William's model. Gal's model introduces the effect of leadership and understanding for the military aspects of stress (Gal, 136).*

The model is dynamic because the coping behavior affects the reappraisal of the situation and then may further affect the combat responses.

Gal defines the antecedent variables as:

- Individual factors – Personality, nonmilitary stress (family, etc.), prior combat exposure, role in combat.
- Unit factors – cohesion and morale, training, leadership, and commitment.
- Battlefield factors – Type of battle, surprise environmental factors (weather, terrain, etc.).

These factors are mediated by the mediating variables, which are the soldier's expectations and interpretation of the immediate situation. The way in which the information of any impending military operation is processed will strongly color the evaluation of stress and the ability to handle it. The soldier's commander mediates the antecedent variables by either magnifying or minimizing their impact on the soldier's cognitive appraisal.

The appraisal process is the central notion of the model. It is the bridge between the external conditions and the soldier's response. It is the combination of the soldier's perception and evaluation of the situation and the ability to cope with it. The individual's reaction to battlefield conditions can be determined by the mediating variables, which are primarily controlled by the commander. From the different appraisals will result different modes of response or coping. The modes of coping in Gal's model are as follows:

- Physical: includes autonomic changes, musculoskeletal changes, and glandular changes.
- Emotional: includes a variety of affective reactions varying from enthusiastic excitement to apprehensive fear, anxiety, or depression.

- Cognitive: includes distortion of perception with narrowing of attention span, hyper-alertness to certain stimuli, and increased utilization of automatic or over-learned responses.
- Social: includes increased dependency on leadership and need affiliation, sometimes expressed by seeking reassurance and physical clustering.

While the modes of response are relatively involuntary or autonomic, and brief, the individual's modes of coping are more flexible, voluntary and may be delayed and prolonged.

The individual's appraisal of the situation and the variety of mode of response are incorporated into an integrated mode of coping, ranging from various levels of activity from passivity to actual breakdown. During combat the active coping mode is seen in controlled aggression by the combat soldier. Decreased movements, relative apathy and lack of initiative manifest relative inactivity or even passivity in combat situations. The ultimate result of a passive mode of coping may be a complete breakdown. This breakdown occurs when the soldier's preoccupation with his own anxieties leads to removal from battle, shutdowns, immobility and erratic behavior.

Whatever the mode of coping, it is not only an outcome of the combat appraisal but also serves as an input into an ongoing reappraisal of the situation. This in turn will generate new modes of response and coping that further modify the appraisal.

The Israeli Defense Force and Command School, where combat veterans were presented with the model and asked to compare it to their personal experiences, tested this model. The officers at the command school gave positive evaluations of the validity of the model for combat.

For Gal's model to be operationalized there needs to be a way to determine at what point the different coping behaviors are triggered. Janis and Mann associate coping with stress as driven by time, pressure and risk. They map the performance effectiveness to a stress level based on those three factors. They define the coping patterns into five levels that encompass Gal's range from inactivity to breakdown. They can also be correlated to Selye's three level of the adaptation theory. Janis and Mann define the following five coping strategies (Silverman, 13):

- *Unconflicted adherence* – the risk information is ignored and the individual continues to do whatever they were doing.
- *Unconflicted change* – The individual adopts whichever new course of action is most obvious and strongly recommended.
- *Vigilance* – the individual searches painstakingly for relevant information, assimilates in an unbiased manner and appraises alternatives carefully before making a choice.
- *Defensive avoidance* – the individual evades conflict by shifting responsibility to someone else, or constructing wishful rationalizations and remaining selectively inattentive to corrective information.

- *Hypervigilance* – the individual searches frantically for a way out of the situation and impulsively seizes upon a hasty solution that seems to promise a speedy relief. In the most extreme form hypervigilance is referred to as panic.

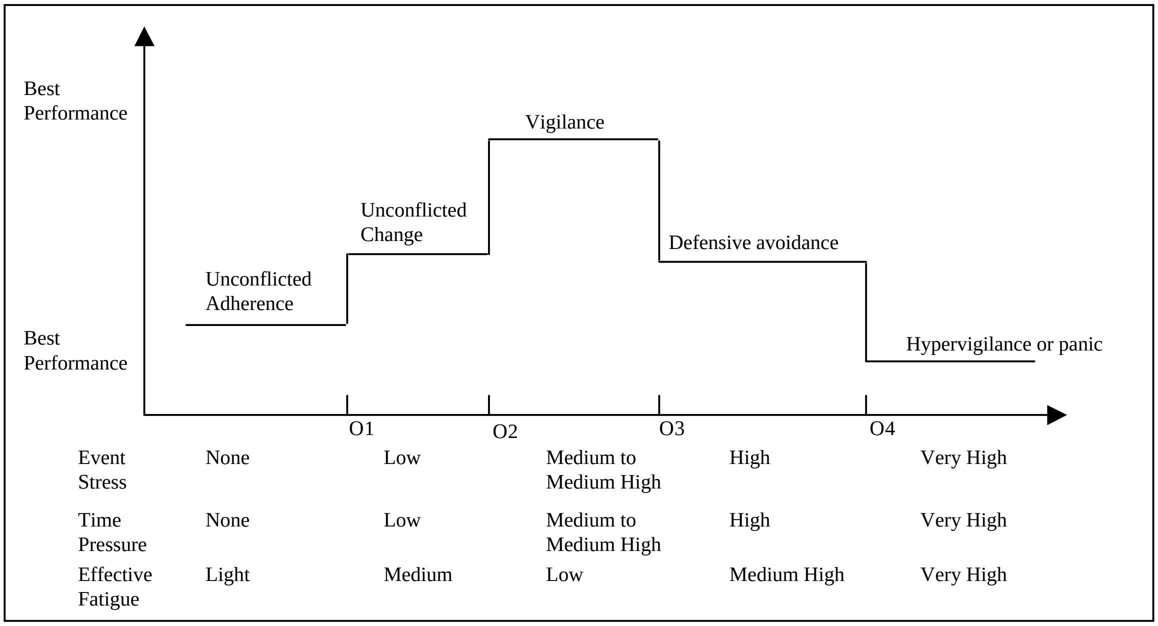


Figure 5. Janis and Mann stress model. *This model shows trigger points at the appropiate stress caused by event, pressure and fatigue stress. The value for* O_I *needs to be defined for model to reflect the stress levels (Silverman, 12).*

These coping strategies are indexes to four thresholds at which the coping strategies are triggered denoted $O_{i.}$ It is evident from Figure 5 that the idea of an increase in stress will raise an individual to an optimal performance level and then eventually drive that same individual into a detrimental condition. This is described in the army literature as well as in Selye's model and the Yerkes-Dodson inverted U model.

Unfortunately Janis and Mann do not provide either precise threshold values that indicate when individuals trigger a change in coping styles, or any insight into how to integrate the many diverse stimuli and factors that determine the time, pressure and risk. The framework presented in this work will conceptualize the factors of stress, cohesion and leadership to arrive at a determination of those trigger points for the purpose of adapting these principles to human behavior modeling. The next part of this work will examine cohesion and its influence on stress to soldiers in a combat situation.

2.5 Heart Rate Variability

"O God of battles! Steel my soldiers' hearts"

William Shakespeare, Henry V,
Act 4, Scene 1".

"And the officers shall speak further unto the people, and they shall say, what man [is there that is] fearful and fainthearted? Let him go and return unto his house, lest his brethren's heart faint as well as his heart."

Deuteronomy 20:8

Heart rate variability will be the measure of performance for the framework to determine the individual soldier's stress state. The soldier's stress state will be used to drive a stress reaction that will be interpreted by the rest of the unit to drive a unit reaction.

According to various psychological and physiological studies heart rate measure is a reliable correlate of fear and heart rate variability can be used to measure the levels of stress an individual is experiencing during a combat incident (Hodgson & Rachman, 320, Gauthier & Marshall, 407, Hugdahl 80). Studies conducted by the law enforcement community and fire fighting companies have reiterated the use of heart rate as a measure of perceived fear (Putman 3, Scanlon 1 & 4, DeLois & Knight). This is based on physiological changes that occur when stressors are introduced into an individual's environment. Recent research at the Institute of HeartMath[3] has demonstrated that the emotional state of an individual and positive and negative emotion can be distinguished by changes in heart rhythm patterns. In 2000 the HeartMath Institute conducted a study including sixty-five law-enforcement personnel

---

[3] The Institute of HeartMath was founded in 1991 to further the research on the role of the heart in learning, cognitive performance, health, and organizational effectiveness and stress reduction.

between the ages of 24 and 55 to determine the cardiovascular impact of acute stressful situations during a simulated domestic violence training exercise. One of the performance measures was for the officer to not fire his/her weapon. The results showed that at high rates of heartbeats (at the range of 180-200) the officers tended to fire their weapons (See Figure 4). This reaction showed that the stressful state of the officer could be determined by the heart rate. The reason that an individual's stress state can be measured using the heart rate is due to the physiological changes in the human body during stress.

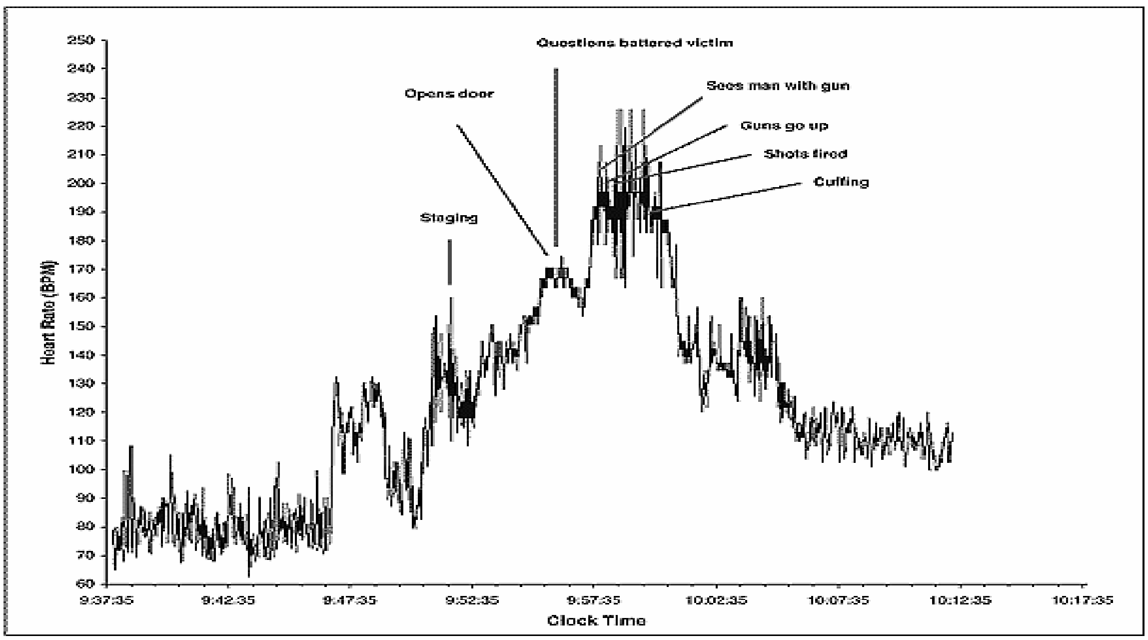


Figure 6. Heartrate reactions of a police officer under stressfull conditions. *The object of the test was to resolve the dispute with out firing. Upon seeing the suspect the officer's heart rate rose to a level above 200 and he reacted by firing his weapon (*McCraty et al, Results)*.*

Dr. Joseph LeDoux of New York University studies showed that responding to stimuli that warn of danger involves neural pathways that send

---

Since its inception HeartMath Institute has demonstrated the critical link between emotions, the rhythms of the heart and brain functions.

information about the outside world to the *amygdala*. The *amygdala* in turn determines the significance of the stimulus and triggers emotional responses like running, fighting, or freezing, as well as changes in the inner workings of the body's organs and glands such as increased heart rate (LeDoux, 51).

A stressful situation such as combat causes the *hypothalamus* to increase arousal in the sympathetic nervous system (SNS). Once activated, the SNS causes immediate physiological changes, of which the most noticeable and easily monitored is increased heart rate. SNS activation will drive the heart rate from an average of 70 beats per minute (BPM) to more than 200 BPM in less than a second. As combat stress increases, heart rate and respiration will increase until catastrophic failure or until the parasympathetic nervous system is triggered (Grossman, Physiological, 145).

The correlation of heart rate to the physical state of an individual has been established in studies of heart rate variability. The higher the heart rate, the more stress will affect a person's perception of the threat. Also, the higher the heart rate, the more negative effect it will have on motor skill performance (Siddle, 48-49).

Bruce Siddle's research brought to light the physiological effects of the emotion of fear, such as increased heart rate and motor skill deterioration. Siddle's research drew a direct correlation between stress response and heart rate increases (46).

The problem with drawing a direct correlation between stress and heart rate is that for people such as runners who can have very high heart rates, stress response does not take effect. A runner's high heart rate is caused by physical exertion, and not the emotion of fear caused by a spontaneous or immediate threat to body or life. This explains why trainers, who have attempted to mirror Siddle's research through hooking students up to heart monitors like those worn by runners, and then subjecting them to physical exertion exercises such as pushups and wind sprints, have failed to see any fine complex motor skill deterioration. It should also be noted that even Siddle acknowledges the fact that heart rate increase is nothing more than a "thermostat" or "indicator" of a perceived stress level, and is not the driving force of performance deterioration (Luar).

When an increased heart rate is caused by a stressful situation, such as experienced by law enforcement or combat personnel, certain physical reactions occur. Siddle has been able to correlate a heart rate level with certain physical effects that have a pronounced effect on the performance of an individual. These effects are as follows (Grossman, psychological, 145):

- Effects to Motor Skills
    - *At 115 beats per minute (bpm)* - Most people will lose fine complex motor skills such as finger dexterity, eye hand coordination; multi-tasking becomes difficult.
    - *At 145 bpm* - Most people will lose complex motor skills (3 or more motor skills designed to work in unison).

Effects to Visual System

- *At approximately 175 bpm* - A person will experience an eyelid lift; their pupils will dilate and flatten. As this reaction takes place, a person will experience visual narrowing (commonly known as tunnel vision). This is why it is very common for a person to back away from a threat to see, through this tunnel.

- *Above 175 bpm* - Visual tracking becomes difficult. This is very important when it comes to multiple threats. During multiple threats, the brain will want the visual system to stay with what it sees to be the primary threat. Once this threat has been neutralized, the brain and visual system will then find its next threat. This is commonly known as the “lighthouse” effect. Studies have found that a person experiencing survival stress reaction will experience on average about a 70% decrease in their visual field. At this heart rate a person will also find it difficult to focus on close objects. A person in a combat situation will become far sighted rather than near sighted. This is why it is very common for people experiencing survival stress reaction to say that the threat was either closer or farther away from where they actually were.

Effects to the auditory system

- *At approximately 145 bpm* - The part of the brain that deals with hearing shuts down during survival stress reaction. This is one reason why it is not uncommon for people in combat situation to say, “ I didn’t hear that”, “ I heard voices but I couldn’t understand what they were saying” or “ I didn’t hear a gun shot.”

Effects to the brain

- *At approximately 175 bpm* - It is not uncommon for a person to have difficulty remembering what took place or what they did during a confrontation. This recall problem is known as “ Critical Stress Amnesia”. After a critical incident, it is not uncommon for a person to only recall approximately 30% of what happened in the first 24hours, 50% in 48 hours and 75-95 % in 72-100 hours.

- *At 185-220 bpm* - Most people will go into a state of “hypervigilance”; this is also commonly known as the “deer in the headlights” mode. It is not uncommon for a person to continue doing things that are not effective (known as a feedback loop) or to show irrational behavior such as leaving cover. This is also the state in which people find themselves when they describe that they can not move, yell, scream. Once a person is caught in a state of hypervigilance it is a downward spiral that is very difficult to recover from. Once caught in a state of hypervigilance, information of the threat is reduced to the brain, which leads to increased reaction time. This increased reaction time then leads to a heightened state of stress, which further plunges one into a deeper state of hypervigilance.

Effects to motor skill performance

- *At approximately 115 bpm* – Fine complex motor skills are decreased (pulling a trigger, handling a knife), but gross motor skills turn on and become optimized.

Now that a scale for triggering stress reaction has been determined, a mapping can be made to Jannis and Mann's model of performance to stress level, as seen in Figure 7.

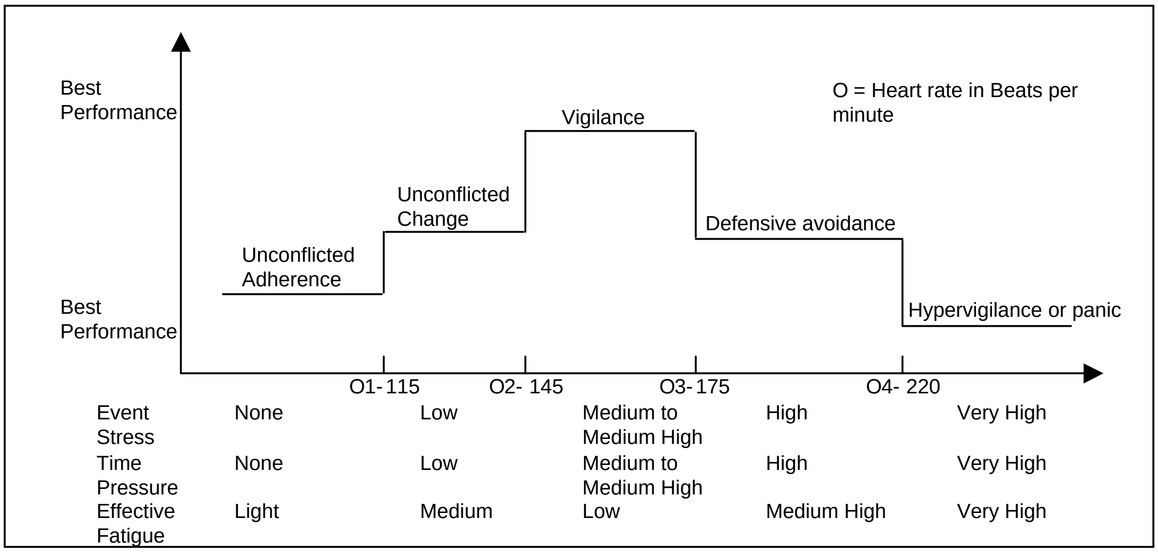


Figure 7. Association of the Janis & Mann Model with Siddle's stress levels. *The levels for the O_I trigger point have been matched with Siddel's reaction levels.*

The concept of heart rate can now be operationalized into the framework. The heart rate will be used as an indicator of the soldiers stress level and drive the model for the unit cohesion. The next section will present the framework, describe the component parts and provide a methodology for an example implementation of the conceptual model.

3.0 Methodology

3.1 The Framework

Cyrus thought the common life would lead to the happiest results in the discipline of the regiments. ... And finally, he felt, there was the fact that those who live together are the less likely to desert one another; even the wild animals, Cyrus knew, who are reared together suffer terribly from loneliness when they are severed from each other.

Xenophon in the Cyropaedia

The framework described in this dissertation will be used for building models of unit cohesion based on the stress level of the individual soldier. Much of the research in these areas is based on guess-work, estimation, and hypothesis. In these cases, an assumption is made as to how the system might work and then rapid iterations are used to quickly incorporate suggested changes and build a usable system. Therefore, the framework will be developed in the absence of precise specifications. Validation is based on adequacy of the end result and not on its adherence to pre-conceived requirements. The results of the validation experiments will be used to make recommendations on how the framework can be converted from an exploratory model to a predictive model. The framework can be seen in Figure 8.

The framework is derived from the works of Bruce Siddle and David Grossman on the psychophysiological responses to combat stress situations, and the works of White and Harary on the operationalization of cohesion as networks. The framework consists of five parts:

1. *The stressors* - These are the main stressors that have an immediate impact on the soldier's stress levels during a combat incident. These will be the inputs into the model of the individual soldiers as they perceive events on the battlefield.

2. *The Individual soldier* – This entity is defined by the cultural and social factors that will mediate any of the effect of the stressors. The entity will also have the heart rate variable, so as to determine the soldier's stress state at any given time. This will also include a variable to indicate the confidence in the leader.

3. *The stress state of the soldier* – This is the value that will show the stress condition of the soldier and influence the rest of the members of the unit.

4. *The unit effects* - These are the factors that are from being in a combat unit, such as the effect of the cohesion in the unit as well as the effect of the leadership on the soldier.

5. *The unit network* – This is the interconnected web of relationships among the members of the combat unit. It will include variables and modifiers to represent the effect of social and task coehsion.

6. *Implicit stressors – These are stressors that affect the heart rate but do not acivate the SNS.*

7. *Implicit cohesion factors – These are factors that are a result of how a combat unit is oragnized and maintained.*

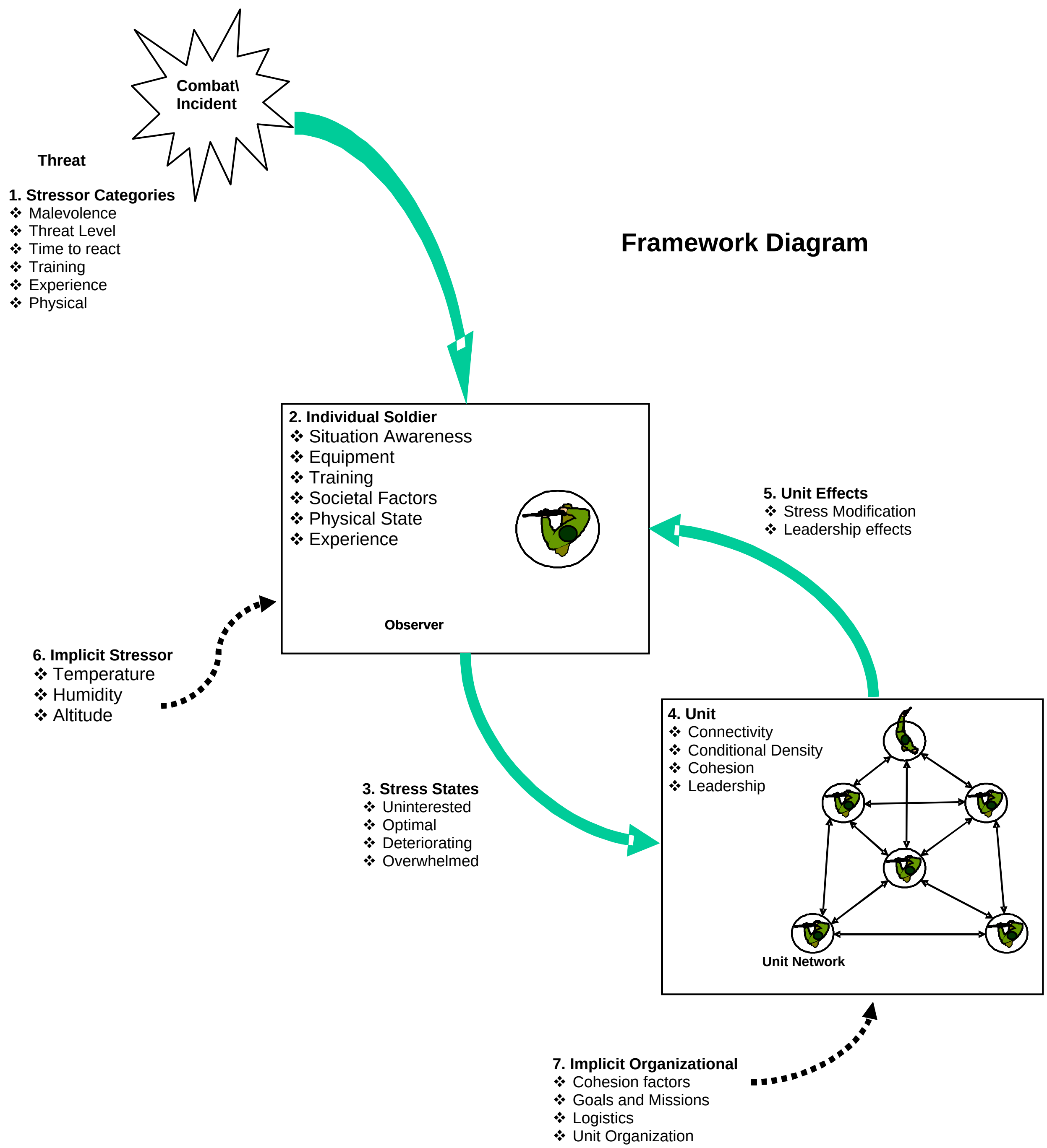


Figure 8. Model Framework. *Each menber of a combat unit sees the battlefield events and influences the others in the unit. The unit and its stabilty affect the individual soldier and either make his stress increase or decrease. The implicit stressors and cohesion factors are factors that influence the soldier before the incident begins and thus are multipiers to the effect the soldeir experiences during the combat incident.*

3.1.1 The stressors

When combatants are confronted with an unanticipated deadly threat and the time to respond is minimal, the activation of the SNS will eventually cause psychophysiological reactions. These reactions will increase the individual's arousal and eventually cause catastrophic failure of the visual, cognitive, and motor control systems if not addressed. Although there are numerous variables that may trigger the SNS, there are six key categories that have an immediate impact on the level of SNS activation. These stressors activate the SNS of an individual, (Grossman, psychological, 147):

- The degree of malevolence, human intent behind the threat
- The perceived level of threat, ranging from risk of injury to the potential for death
- The time available to respond to a threat
- The level of confidence in personal skills and training in overcoming the threat
- The level of experience in dealing with the specific threat
- The physical effect of injury and fatigue

The framework provides these categories to allow the user the ability to input their own model of the category as required fro individual needs. The summation of the effects of all the categories will adjust the level of the SNS and be measured by the individual soldier's heart rate. Later in this work a suggested implementation will be provided to get an idea of how to incorporate a model of the stressors into the framework.

3.1.2 The individual soldier

Soldiers reacting to the events on a battlefield by internalizing the effect of the stressors will do so based on their personality dispositions. Soldiers bring their own personality dispositions and their sense of general well being with them to the battlefield. These, together with previous combat experience, training and ideology profoundly affect the stress reaction (Gal, 135). Soldiers' individual factors that define their dispositions should include:

- *Situational awareness* – The knowledge of where the observer is located, where other friendly elements are located, and the status, state, and location of the enemy within a coordinate system needs to be dfeined.This is so that various inferences can be made from the change in the proximity of a threat to the soldier.

- *Equipment type* – The weapons and protection a soldier has in combat are important factors in a soldier's confidence. If the weapons available are obsolete, in bad working order or defective or if the protection against a threat is inadequate the soldier's confidence in victory will be affected.

- *Training and Experience Levels* –If the soldier's training is adequate, stress will be lower. If the soldier is being faced with new tactics by the enemy not encountered before stress will increase. Experience will determine if the soldier has encountered the threat before and is adequately prepared to react appropriately. If a threat has defeated the soldier before stress will increase; conversely, if the enemy has been defeated before stress will decrease.

- *Societal factors* - This is the factor that will encompass a soldier's ideology, values and commitment. Whether the soldier is committed to the cause will affect the stress level. Factors providing multipliers to the stressor effect can be intorduced through definitions of societal cohesion, based on the nationality, culture or faction of the soldier in a simulation.

- *Physical Factors* – Physical factors such as fatigue or avaliable injury level need to be provided to the soldier's definition. Fatigue and an injury level need to be incorporated to take into account the effects on the stress of the individual soldier. The physical size of the soldier gives a reference to the size of a threat or opponets to determine a confidence level to affect stress. A heart rate variable also needs to be included, because this is the measure of the effect of the stress upon the soldier and will determine the stress level that is perceived by the members of the soldier's unit.

- *Leader confidence* – If a soldier is defined to also be a leader, a leader confidence variable needs to be included. This factor will determine if the individual soldiers of a unit will have confidence in the leader and affect the way in which the leadership influences their stress state.

3.1.3 The stress state of the soldier

The next component of the framework is the stress state of the individual soldier. This state will be derived from the perceived battlefield threats encountered during a combat incident. As the soldiers observe threats they will react based on the nature of the stressors and their individual factors. The internalization of the stressors will cause the heart rate of the soldier to vary. As the soldier's heart rate varies the following stress states will be triggered at the appropriate heart rate level as seen below:

- In control minimal stress – normal unit activity such as standing or moving when there is not a threat. This is similar to Janis and Mann's unconflicted change. 60-115 beats per second (BPS) heartbeat

- In control optimal performance – Unit is entering or is in combat and soldiers' senses are at optimal levels; combat threat is manageable. This is similar to Janis and Mann's Vigilance. 115-145 BPS heartbeat

- Deteriorating – Unit is in combat and the perception is that the threat in becoming unmanageable. This is similar to Janis and Mann's defensive avoidance. 145-175 BPS heartbeat

- Irrational conduct – Unit is in combat and perception of threat is unmanageable. This is similar to Janis and Mann's hypervigilance or panic. 175 + BPS heartbeat

- Death – catastrophic cardiac failure or death from injuries. 220+ BPS heartbeat

As these stress states are attained by a soldier the effects of the state will be sent to all soldiers that have a defined connection with that individual. In turn the stress state received by the individual from the other soldiers with defined connections will be used to influence their stress state. These connections will be a function of the definition of the unit network.

3.1.4 The unit network

The military unit can be conceptualized as a network of nodes connected by the cohesive ties that bind the members into a common purpose. The social solidarity of a combat unit can be divided into two components. The first one refers to the psychological identification of members within a group and the second one refers to the observed connections among the members in a group. Models that represent cohesion need to distinguish between the individual components and the connective components of a group to adequately operationalize the concepts of cohesion (Moody and White, 1, 4).

Based on White and Harary's network concepts, a combat unit will be defined based on the relationships of either their historical or an experimental organization. The nodes in a White and Harary's style network are the individual soldiers of a combat unit. The connections need to be defined as the specific relationships of the military unit in which the framework is being implemented. Once the connections are established strength of each connection is determined by the stress level of the individual soldier sending their status to the others in the unit. The strength of the connections within a unit can be added as an average stress state to the network size.

3.1.5 The unit effects

In most cases a soldier will not operate alone but will be part of a unit. The group characteristics have important implications for combat behavior. Analysis by the Israeli army has revealed four factors that are important to determine the unit's state. These are cohesion, confidence in the commanders, confidence in weapons, and soldier's ideology, values and commitment (Gal, 135).

Unit cohesion has repeatedly been found to be important for supporting individual's coping behavior and unit performance. A low level of morale and weak bond with comrades and leaders may elevate the perceived level of stress of combat and ultimately result in severe combat reactions (Gal, 139).

The soldiers' confidence in their leader is a critical factor in protecting them from overwhelming battle stress. Three elements inspire confidence in a commander:

- Belief in the competence of the leader.
- Belief in the leader's credibility.
- Perception that the leader cares about the troops (Gal, 138).

The soldier perceives his welfare in combat mainly on the actions of the immediate leader or necessary leadership figure. When there is no leader or leadership figure the individual must rely on his on training and experience and how well he can mediate stress on his own (Yukl, 176).

3.1.6 Implicit stressors

Implicit stressors are those stressors that cause increases in heart rate but do not activate the SNS. Those would be a result of environmental conditions such as temperature, altitude and humidity that influence the heart rate about 2 BPM in the range of hours and allow the body to acclimatize itself to some degree.

3.1.7 Implicit cohesion effects

Implicit cohesion effects are those that will not be specifically modeled or implemented in the framework. These are the factors that come from the organizational cohesion aspects of a combat unit, such as the objectives, logistics and the organization of the unit. These are inherent in the design of the military that is being modeled for any given simulation.

3.2 Implementation

Connectionist models are ultimately evolutionary. They involve the evolution of connection strengths over time.

Daniel C. Dennett, the Third Culture

Nothing is more practical than a good theory.

-- Ludwig Boltzmann

This section will describe in detail needed to implement the cohesion framework and suggest how that implementation could be accomplished. The concepts for these implementations are based on the premise that individual soldiers will perceive the situation and make decisions based on their stress level. The interpersonal relationships will moderate the stress level of the individual soldiers and reduce negative reactions. The implementation presented in this work is not the definitive representation of the stress factors and if future models more adequately describe the psychological behaviors they could be substituted into the appropriate interfaces of the framework.

The implementation of the framework will be explained by first discussing the theories behind the decisions made for the implementations, followed by suggested functions to explain the proposed theories. There is only a minimal amount of research on how each of the stressor factors affects the heart rate individually; therefore, there will be a wide field of assumptions based on literature sources as well as observational data on how the stressor factors will be implemented into the application created to illustrate the framework.

Each section shall describe the basis for implementing each part of the framework and an appropriate function that models the reaction of the described stressor as well as the basic assumptions that went into the selection of the specific function. When possible, research data will be used to support the assumption and selections; otherwise, the selection will be based on inferences and implied phenomena as described by researchers in the specific fields.

The implementation is based on the principle that the individual soldier's perceived stress rate is measured by the heart rate. The individual soldier's heart rate will correlate to accepted performance to stress relationship as described by Selye (Selye 64-67) and Gray (Gray 61-63) (see Figure 2). The individual's heart rate will be changed by the summation of the effects of the stressors as represented by mathematical functions.

The ability of an individual soldier dealing with a stressful situation and his ability to perform what is required during combat will change as the amount of stress increases. It has been described previously that at certain stress points the blood moving through the heart optimizes motor skill, but at higher stress the physical performance drops rapidly. Based on this, a relationship can be established for the correlation between performance and heart rate. This can be seen in Figure 9.

3.2.1 Selecting functions for implementation

The incorporating scientific knowledge into selection of the function used in a process model is clearly critical to the success of the model. When a scientific theory describing the mechanics of a physical system can provide a complete functional form for the process, then that type of function makes an ideal starting point for model development. There are many cases, however, for

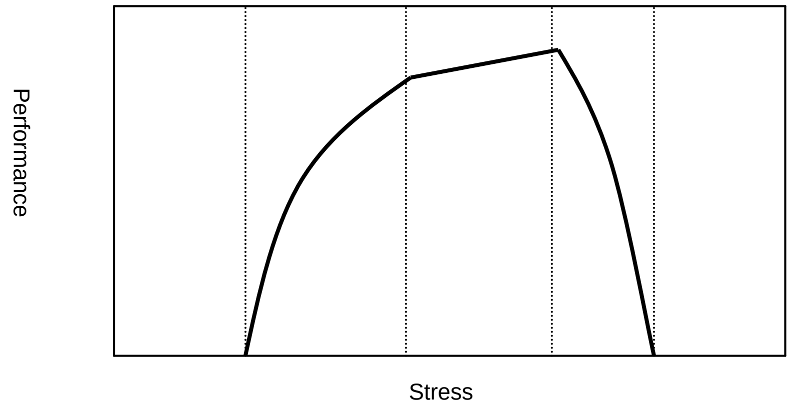


Diagram 1

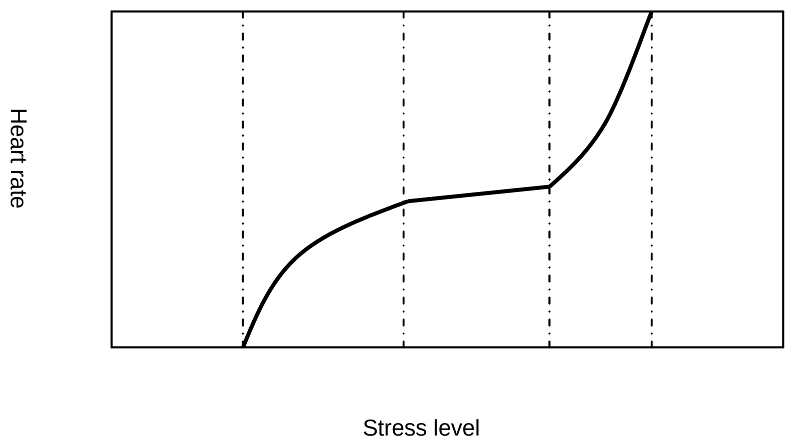


Diagram 2

Figure 9 Heart rate, performance and stress reactions correlations. Diagram 1 shows the relationship between the performance of an individual and the amount of stress that will affect that performance. Diagram two shows the heart rate correlation to stress level as described by Siddle (1982).The model of the heart rate reaction of an individual soldier in a combat incident will follow diagram *2.*

which there is incomplete scientific information available. In these cases it is considerably less clear how to specify a functional form to initiate the modeling process. A practical approach is to choose the simplest possible functions that have properties ascribed to the process.[4]

The following are the six key stressor factor variables that have an immediate impact of the level of SNS activation that will be discussed:

- Malevolence
- Time to react
- Threat Level
- Confidence in training
- Confidence in experience
- Physical factors

These variables will be presented as approximate functions of observations of reality. The functions selected to represent these variables will have as much data and literary support as possible and it is suggested that any future implementation take into account any supporting documentation.

The overall assumptions described in this section will drive the particular implementation selected for this work. These assumptions will be referred to when appropriate as the stressor factors are discussed. This implementation of the stressor factor variables are based on the following assumptions:

---

[4] *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook /pmd/section4/pmd421.htm, 2005.

- The variables are interrelated, because they all deal with how an observer perceives a threatening situation, but the specific interrelation is at this point unknown.
- The variables all influence the SNS equally, because there is no research at the present time that indicates how much each variable is affected.
- David Grossman and Bruce Siddle state that the variables described here cause the activation of the SNS and will drive the heart rate from an average of 70 beats per minute (BPM) to more than 200 BPM in seconds. Other variables affecting the heart rate, if included, will be implemented as multipliers or dividers of the heart rate resulting from the six main factors.
- The average resting heart rate is 66/72 beats per minute (bpm). We will assume that the soldier will be in a state above the resting state and set the lower end of the heart rate at 90 bpm. The maximum heart rate is estimated by HRmax = 217 – (0.85 x age) (Indiana University). So if we assume the average age of a soldier is 19 for the sake of this work we will set the maximum heart rate at 201.85 bpm.
- If we assume the time interval in a simulation to be one second then the total range of heart rate for an individual is 111.85 beats (that is the result of 201.85 bps – 90 bps). Divide this number by six and we designate that as the maximum change each of the factors will influence the heart rate for each second of the simulation that they are in effect. This will be 112/6 = 18.67 beats.

Therefore each of the defined situational stressors will add to the heart rate of an individual soldier an amount of at maximum 18.67 beat per minutes. These changes will be adjusted by a scaling factor to take into account variations based on the assumptions of equal weight for each factor.

3.2.2 The individual soldier

The first thing needed to implement the cohesion framework is a definition of the individual soldier. A series of attributes must be defined so that one can implement the individual and unit factors. There are certain attributes that will be influential from the individual's perspective and others that will be relevant from the group level. The individual attributes to be assigned to a soldier for the incorporation of the stress level part of the cohesion framework are as follow:

- Situational awareness variables
    - Location of the soldier in a coordinated system
    - Speed
    - Number of friends within relevant distance
    - Number of enemies within a relevant distance
- Equipment variables
    - Weapon type or level in relation to the context of a simulation scenario
    - Armor or personal protection level in the context of a simulation scenario
- Societal variables

- Nationality or faction designation
- Ideology
- Nationalism
- Leadership trust
- Stress level of friends

- Training and Experience variables
  - Experience based on the context of a simulation scenario
  - Training based on the context of a simulation scenario
- Physical variables
  - Physical aspect of the soldier such as strength, size, fatigue and health level
  - Heart rate
  - Stress level

The impact of each of these of these variables on the stress of an individual soldier will be will be described in details as the suggested implementations for the six key SNS activating categories that have an immediate impact on a soldier's level are described in detail in the next section.

3.2.3 Implementation of individual stressors

When a soldier is included as part of a cohesive group, there will be pressure on him to behave according to the needs of the group. When he sees himself as an individual, his behavior will primarily depend on what he feels to be the best for his own survival or according to his emotional needs (Shalit 142).

These emotional needs will be reflected in the individual soldier's stress level. This level will determine how well he copes with events on the battlefield. This stress level is due to the perception of the soldier's situation at the time of a battlefield event. This perceived level of stress can be measured by the heart rate of the individual during a combat incident.

To implement these concepts it is necessary to represent the heart rate of a soldier as a variable that would cleanly and unequivocally equate to the physiological reactions that are manifested by the previously defined levels of stress. This heart rate variable is a result of stressor factors perceived and experienced by the individual. The stressor factors that will influence the heart rate variable will be those that are identified as having the effect of increasing or decreasing heart rate based on physical and mental reactions to situations. There are factors that will result in the increase of heart rate. The ones that which have an immediate impact of the level of SNS activation are:

- Malevolence
- Threat Level
- Response Time
- Training Level
- Experience Level
- Physical Level

The stress on an individual soldier begins at the time an event on the battlefield is observed. At this time each soldier will make an internal appraisal of how to deal with the event. The first thing that needs to be appraised is whether or not the event constitutes a threat. The soldier will be designated as the **observer** of the event that is perceived as being one that has the potential to cause harm; the event will be designated as the **threat**. When the observer feels threatened, the implicit and explicit factors will add or subtract to the heart rate variable and a stress state will be calculated based on the levels as described in section 3.1.1. Other factors that affect heart rate, such as temperature, altitude and humidity, will be implicitly represented by a multiplier factor because they will not specifically activate the SNS. These factors will be determined at the beginning of any scenario and will contribute to the initial heart rate level. Each of the six explicit factors as well as the implicit ones will be described in detail and a recommendation on how they should be implemented in a simulation will be explained. The six SNS activating categories all contribute to the changing level of the soldier's heart rate. Because they all contribute to some degree it is proposed that a summation of all the levels will ultimately determine the instantaneous heart rate during a simulation. The factors that will be used for the implementation of the heart rate are factors that are considered to be individual effects and not interactive. Therefore, the following is the suggested function of an observer's heart rate:

Let heart rate (HR) be defined by =

$$f(M) + f(T) + f(L) + f(TR) + f(E) + f(P)$$

M = Malevolence

L = Threat Level

T = Time to React

TR = Training

E = Experience

P = Physical factors

There have been no studies that indicate the exact amount of heart rate increase from each of the six categories, but a set variables will be defined that should be validated experimentally. This will provide the framework with variables that can be adjusted as new research comes to light, thus providing a beginning for a method to study this psychophysiological reaction.

Malevolence

Malevolence is the “quality” of a threat to cause harm to an individual. As an observer experiences an event, such as encountering a stranger, one of the first things to be determined is whether the threat has a detrimental effect upon the observer. It is sufficient for the observer to perceive an event as threatening to perceive the threat’s desired purpose. The event becomes a threat when it is perceived as behaving in a mode that actually threatens our aims, a threat actively challenges our desired state or actions, and the threat’s gain is perceived to be the observer’s loss. A threat becomes malevolent when it is perceived to threaten the observer actively. The person who happens to stand in our way is an opponent if he refuses to move, and then becomes a threat (Shalit 84).

A threat can be anything that soldier perceives as danger; the threat can be an enemy soldier advancing on their position or an explosion going of in their proximity. In the case of the soldier the threat would end as soon as the solider disappeared from site or is eliminated. In the case of the explosion the threat begins and ends with the shock, noise and effect of the explosion.

If the distance between an observer and a threat is reduced, either by moving towards or not moving away as the observer advances, the perceived malevolence will increase. If the threat moves away from the observer the level of malevolence would be perceived as decreasing.

This level of malevolence can be implemented into a simulation by providing the observer some situation awareness. A scale of malevolence should be based on the combination of relational movement between the observer and the threat. Therefore, to be made operational in a model the observer would need the following operations:

- A method for ability to “see” the threat and determine if that threat is getting closer. This may be in the form of a line of sight algorithm or other situational awarness techinques
- Variables for the position coordinates of the threat and observer
- A method for sighting distance calculation

The proposed definetion for the factor of malevolence is decribed below:

Let (m) be defined by

$$\boldsymbol{f}\ \mathbf{(M)} = \begin{cases} -\mathrm{M} & \Delta d > 0 \\ +\mathrm{M} & \Delta d \leq 0 \end{cases}$$

M = Heart rate change per time step due to malevolence

d = Distance between the observer and the threat

At every time-step of a simulation, the distance between the threat and the observer will be calculated. A negative difference in distance will add a positive malevolence factor to the heart rate which will indicate the threat is moving away from the observer and thus becoming less of a threat. A positive difference in distance will add a negative malevolent factor to the heart rate number, which indicates that the threat is coming closer and its threat potential is increasing.

The basic assumption of the malevolence factor is that an observer must decide upon the intention of an identified threat. This should be represented by an awareness of whether the threat is moving towards the observer, moving away or staying still.

The variable of malevolence will be based first, that the threat must be with in the sight distance of an observer and secondly, on a change of distance between a threat and an observer. Therefore, the following rules will depict malevolence:

- If the distance between the observer and the threat is beyond the sighting distance there will be no change to the heart rate.
- Upon initial sighting of an identified threat the observer's heart rate will be increased by 18.67 beats (i.e. the change in heart rate as defined above).
- If in the next time step the distance between the threat and observer is less than the previous distance the heart rate will be increased by 18.67 beats.

- If in the next time step the distance between the threat and observer is greater than the previous distance the heart rate will be decreased by 18.67 beats.

The resulting function for the malevolence factor will be as follows:

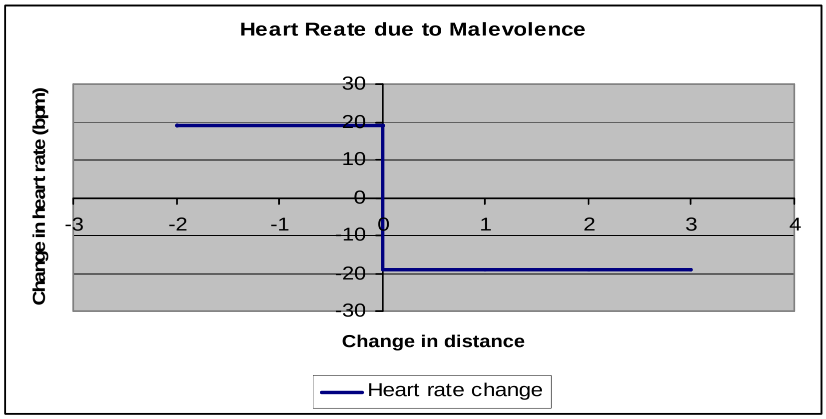


Figure 10. Malevolence to heart rate change. *In this example an individual whose age calculates a change of 18.67 in heart rate as the distsnce between the observer and the threat is reduced by 2 every time step, until it becomes 0. When the change in distance increases by a distance greater than 0 the heart rate change is -18.67.*

Time to React

If the observer has determined that the threat has malevolent intent and has perceived a threat level based on the confidence to overcome the threat, the time the observer perceived to deal with the threat will add to the level of stress. The time to respond to the threat will need to represent the following items:

- A variable for the distance between the observer and the threat
- A variable for the speed the threat approaches the observer

As in the two previous factors the following representation for response time is suggested:

Let (*T*) be defined by

$$\boldsymbol{f\ (T)} = \quad f : T \rightarrow \frac{\Delta D}{ds}$$

T = Heart rate change per time step due to response time

D =Distance between the observer and the threat

s = Apparent Speed of the threat

The basic assumption in the time to react variable is based on the perceived time an observer has to react to the threat. Once an observer identifies a threat, the more imminent that threat is, the greater the stress on the observer (Patterson and Neufeld 410). This is to be represented by the distance between a threat and an observer and the perceived speed at which the threat is moving towards the observer. The following rules will be used to depict time to react:

- The faster the observer perceives the threat approaching the less time the observer will believe there is to react.
- The effect of the amount of time available to react to a threat on the SNS will be represented by decreasing logarithmic function. This is based on the idea that human perception of the time available to react is based on the distance between the observer and the perceived speed at which the threat is closing on the observer. This relationship follows the Fechner[5]

---

[5] **Fechner's Law** – Law developed by Gustav Fechner, explains the relationship between the physical intensity of a stimulus, and the sensory experience that it causes. He said that sensation increases as the logarithm of stimulus intensity:

$$\mathbf{S} = \boldsymbol{k}\ \mathbf{log}\boldsymbol{I}$$

where **S** = subjective experience, ***I*** = physical intensity, ***k*** is a constant.

law which states that a subjective sensation such as how close and how fast a threat is approaching increases proportionally as the threat is gets closer.

The following equation is proposed to represent the heart rate changes based on the observer's perception of the approaching threat:

$$Heart\_rate\_change = 5 * \log\left[\frac{distance(feet)}{Speed(\frac{feet}{Second})}\right] + Maximum\_Heart\_change$$

Equation 1. Calculation to determine the heart rate change due to perceived time to react.

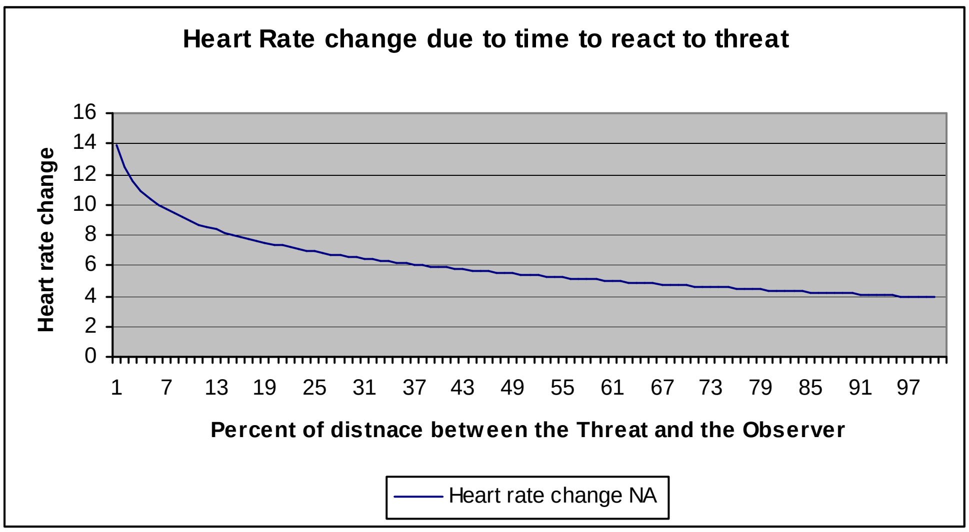


Figure 11. Time to react to heart rate change. *As the distance between and observer and a threat decreaes over time the percieved time the observer has to react will incerese logarithmicaly.*

The distance in feet will be a percentage of the sighting distance. As seen in table 1, if a threat is sighted at 800 feet distance, that total distance will be divided into percentages of 0 to 100%. The speed will be in a ratio of feet per second of time. The maximum heart rate will be the 18.67 number discussed earlier. Here is an example of a threat that would be at 800 feet distance and traveling at a rate of 40 feet per second towards an observer.

Table 1. Example calculation of the effect on a soldier's heart rate based on the perception of time to react formula. *If a threat was approaching an observer at a constant speed the heart rate change would become larger as the threat closed the distance between them. Percent distance indicates the percent distance of the total sighting distance as described for the situation.*

Number	% distance	feet	Feet/minute	Feet/second	seconds	Heart rate change
0	0.00%	0.000	40	0.666666667	0	18.67989
1	1.00%	8.000	40	0.666666667	12	13.90409
2	2.00%	16.000	40	0.666666667	24	12.39894
3	3.00%	24.000	40	0.666666667	36	11.51849
4	4.00%	32.000	40	0.666666667	48	10.89379
5	5.00%	40.000	40	0.666666667	60	10.40924
6	6.00%	48.000	40	0.666666667	72	10.01334
.	.	.	.	.	.	.
.	.	.	.	.	.	.
98	98.00%	784.000	40	0.666666667	1176	3.947963
99	99.00%	792.000	40	0.666666667	1188	3.925918

Level of threat

An observer will categorize the threat as an enemy with a certain potential. The observer organizes the perception of the threat's aspect into a hierarchy. Perceiving its ability to cause harm as increasing, as more information about its nature is revealed, the observer can modify the perceived challenge or threat value of an enemy (Shalit 87).

The larger a threat is in size the more potential to inflict harm on the observer. Thus a tank will be perceived as a greater threat than an infantryman. But, it can easily be said that a larger, more physically imposing infantryman could be seen as a greater threat than one of smaller stature (87).

The level of threat is also influenced by the perception of the quality of weaponry an observer possesses. A soldier who believes he possesses the better weapons feels less threatened and vice-versa; the belief that one has the poorer weapon is sufficient to reduce the effectiveness of the soldier (87).

Time is also to be considered in the perception of the level of a threat. If the threat is not neutralized in a timely manner, the observer will perceive the threat as being greater, the longer it has influence. The feeling that the threat can cause injury while the observer's action is ineffective will increase the threat level factor.

The level of threat can be implemented into simulations by a comparison of the ability of the observer to cause and receive damage from a threat. The level of threat can be represented by the following factors:

- A method for calculation of the size difference between the threat and the observer. This can be the physical size of the threat or the numerical size of the threat. A multitude of levels could be implemented to calculate the perceived size difference between an observer and a threat. A simple representation could be whether the threat is perceived as larger, equal or smaller than the observer. The following levels are suggested as a starting point in implementing this factor.

    - Level S1 – The physical size of the threat is smaller than the observer or the force ratio is less than 1 to 1.
    - Level S2 - The physical size of the threat is equal to the observer or the force ratio is 1 to 1.
    - Level S3 - The physical size of the threat is greater than he observer or the force ratio is greater than 1 to 1.

- A method for determining the ability of the observer to be damaged by the threat. This is the perception of the damage caused by the threat upon an observer. The longer the threat exists, taking less damage then the observer the threat level will increase. This can be represented as the difference between the damage levels of an observer versus the damage level of the threat over time. If a given damaged algorithm is used in a simulation the numerical calculation of a damage level of the threat can be compared to an observer and determine a ratio over a given time. The following levels are suggested as a starting point in implementing this factor.

- Level O1 - the offensive capability of the threat is lesser than that of the observer
- Level O2 - offensive capability of the threat is equal to that of the observer
- Level O3 - offensive capability of the threat is greater than that of the observer

- A method for determining the ability of the threat to be damaged by the observer. This is the perception that the observer is not causing significant damage to a threat. This ability is based on damage over time. The longer the threat is attacked and appear not to be damaged will increase the threat level. As above this factor can be represented as the difference between the damage levels of an observer versus the damage level of the threat over time. The following levels are suggested as a starting point in implementing this factor.

    - Level D1 - The defensive capability of the threat is lesser than that of the observer
    - Level D2 - The defensive capability of the threat is equal to that of the observer
    - Level D3 - The defensive capability of the threat is greater than that of the observer

These dimensions can be listed in rank order of degree of threat level such as smaller threat that is lesser armed and with lesser defense to be designated as S1O1D1 up to a larger sized threat that is better armed and with better defense designated as S3O3D3. Therefore the threat level can be defined as follows:

Let (*L*) be defined by

$$\boldsymbol{f(L)} = f : L \rightarrow TL$$

TL = Size factor + Threat factor + Observer factor

L = Heart rate change per time step due to threat level

Every time-step the specific combinations will be checked and the appropriate threat level factor will be incorporated into the heart rate variable. If the offensive and defensive capabilities of the threat change during a simulation, the appropriate level of threat will be applied to the heart rate. For example, if a threat is armed with a spear and that spear is lost in combat, the offensive capabilities of the threat will be decreased and the appropriate combination will be used for the increase in heart rate for the next time-step.

Also the specifics as to how a threat is lesser-armed or better defended needs to be determined based on the specific experimental scenario that will be implemented. Thus a scenario in which a Greek hoplite with full panoply is pitted against a Persian archer will have its own definitions of threat level and a scenario in which an American infantry man is pitted against a tiger tank will have its own specific definitions.

The level of threat is defined across a range from the risk of injury to potential for death. It has been described in this work as a function of the size of a threat, and the offensive and defensive potential of the observer. The assumption is that as any perceived advantage of defensive or offensive power changes, the level of the threat will be perceived to change accordingly. The heart rate change based on the threat level is assumed to be based on a logarithmic function similar to the time to react variable, assuming that the perceived level of threat increases with the increase logarithmically as the threat size and its injury potential increase.

The following equation gives a heart range change within the range of 0 to the maximum 18.67:

$$\text{Heart\_rate\_change} = 18.67 * \text{Log(Threat level)}$$

Equation 2. Calculation to determine the heart rate change due to threat level.

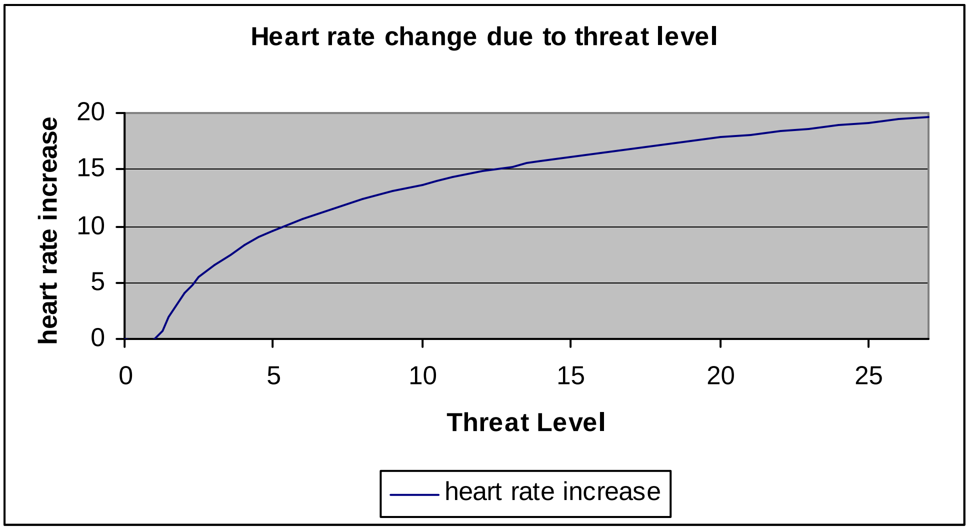


Figure 12. Threat level to heart rate change.

The threat level variable is based on combinations of the following factors which will combine into a level code to determine the threat level. These categories can be increased to a given level of complexity as needed for an analysis purpose.

1. STH (Smaller than Human) – this would be if there was a threat such as an attack dog that would be generally smaller than a human.
2. SAH (Same as Human) – this would be a threat that would be the same general size as the average human.

3. LTH (Larger than Human) – this would be threat the size of horses such as cavalry.
4. OL (Overly large) – this would be size of a war elephant or a combat vehicle.

So, to determine whether the threat is smaller than , equal to or larger than the observer, one could add up the opponents and find the category and compare it to category 2 (assuming the observer is human) and determine the size component of the threat level, i.e. a soldier is confronted by a pack of dogs. The dogs would have a size factor of 1 each; the sum would be a total of 5 which would be greater than 2 therefore the size of the threat would be S2.

The factor Offensive and Defensive capability is based on how confident an observer is in causing more damage than they would take. This will be affected by a time factor based on whether the threat caused damage or the observer takes damage over a range of time. The more injury caused on the observer the greater the threat will be perceived, which assumes that the observer's confidence in any protection is reduced, making the defensive capability less. The same applies to the observer's offensive weapons, the less damage the weapon has on a threat the less the confidence in the observer's offensive capability will remain.

For operationalizing these concepts a soldier's initial threat level must be determined by a size comparison and an assumption that the observer believes that they are superior to the opponent. So, for an example, a Roman legionary fighting a Saxon will be equal in size and initially believe that they are better armed and protected. That would give the observer a threat level of 10 with a level code of S2O1D1. This would increase the Roman's heart rate by 13.0 beats every time step based on the given equation. As the fight proceeds, if the Roman fails to defeat the Saxon in a given time the threat rate will increase to the next level of 11 and increase the heart rate of the Roman by 14.9 beats, which would be a level code of S2O2D1.

These factors due to threat level combine into 27 different levels that would indicate how an observer would perceive a situation. The following table defines 27 different levels of threat and the associated heart rate changes:

Table 2. Threat level definitions correlated to the heart rate change. *Each category(more to be added later).*

Threat Level (TL)	Level code	Description of threat level	Change in Heart rate
1	S1O1D1	Smaller threat that is lesser armed and with lesser defense	0.0
2	S1O2D1	Smaller threat that is equally armed and with lesser defense	3.9
3	S1O3D1	Smaller threat that is better armed and with lesser defense	6.2
4	S1O1D2	Smaller threat that is lesser armed and with equal defense	7.8
5	S1O2D2	Smaller threat that is equally armed and with equal defense	9.1
6	S1O3D2	Smaller threat that is better armed and with equal defense	10.1
7	S1O1D3	Smaller threat that is lesser armed and with better defense	11.0
8	S1O2D3	Smaller threat that is equally armed and with better defense	11.7
9	S1O3D3	Smaller threat that is better armed and with better defense	12.4
10	S2O1D1	Equally sized threat that is lesser armed and with lesser defense	13.0
11	S2O2D1	Equally sized threat that is equally armed and with lesser defense	13.5
12	S2O3D1	Equally sized threat that is better armed and with lesser defense	14.0

Threat Level (TL)	Level code	Description of threat level	Change in Heart rate
13	S2O1D2	Equally sized threat that is lesser armed and with equal defense	14.5
14	S2O2D2	Equally sized threat that is equally armed and with equal defense	14.9
15	S2O3D2	Equally sized threat that is better armed and with equal defense	15.3
16	S2O1D3	Equally sized threat that is lesser armed and with better defense	15.6
17	S2O2D3	Equally sized threat that is equally armed and with better defense	15.9
18	S2O3D3	Equally sized threat that is better armed and with better defense	15.7
19	S3O1D1	Larger sized threat that is lesser armed and with lesser defense	16.0
20	S3O2D1	Larger sized threat that is equally armed and with lesser defense	16.3
21	S3O3D1	Larger sized threat that is better armed and with lesser defense	16.9
22	S3O1D2	Larger sized threat that is lesser armed and with equal defense	17.2
23	S3O2D2	Larger sized threat that is equal armed and with equal defense	17.7
24	S3O3D2	Larger sized threat that is equally armed and with equal defense	17.9
25	S3O1D3	Larger sized threat that is lesser armed and with better defense	18.2
26	S3O2D3	Larger sized threat that is equally armed and with better defense	18.4
27	S3O3D3	Larger sized threat that is better armed and with better defense	18.6

Training

Controlling stress is within the reach of well trained combat soldiers. Training provides soldiers the advantage in the struggle of natural instincts for self preservation against real or perceived threats (Daddis, 24). Soldiers who train under stressful conditions will react well when confronted with threatening situations on the battlefield. Research shows that soldiers succeed in managing stress on the battlefield when the uncertainty of combat is reduced. The more familiar the situation the less stress will be experienced by the soldier (Orasanu and Baker 106).

In the military/combat situation, to be able to respond instantly to a combat situation without conscious thought is critical to survival. However, the situation in which a threat that has not been trained for is encountered may cause the observer's stress level to increase. This is because the confidence to overcome the unexpected threat is less than if the threat matched the observer's skills. This would also apply to a known threat using a tactic that the observer is not expecting or has not seen before (Williams, 100).

To represent the comparison between what an observer has been trained to deal with and the type of threat that is being experienced, a method of classifying level of training and types of threat needs to be developed. As the observer reassesses the condition of a battlefield event the training level would be compared to the threat type and the threat's action and the difference between them would affect the observer's heart rate. This would be a component of the stress level of the observer.

To implement the training elements of the framework the following items will need to be represented:

- A method of classifying the threat
- A method of classifying the observers training level

- A method to compare the type of threat to the training of the observer
- A method of determining the emotional stress caused by the confidence in training.

Therefore the training factor can be defined as follows:

Let (TR) be defined by

$$\textbf{\textit{f(TR)}} = \ f : TR \rightarrow TL_{Obsever} - TL_{Threat}$$

TR = Heart rate change per time step due to training

$TL_{Obsever}$ =Training level of the Observer

TL_{Threat} = Training level of the Threat

The assumption of the level of confidence in an observer's skills is based on the level of training that has been achieved. It is assumed that the level of skill factor is a representation of the effect that the skill has on the individual's ability to cope with the stress of a combat incident and that the confidence will be reduced the longer it takes for the threat to be eliminated.

It is also assumed that if an observer's confidence falters, it will continue to falter at an ever decreasing rate down to a level where it will drive the heart rate to the maximum change of 18.67 bpm. This would appear to be represented by a decreasing exponential function similar to a standard decay function.

The decay function that describes this effect based on training level will be as below:

$$Y \ = Y_0 e^{-k}$$

Equation 3. Decay function used for the confidence in training equation.

The equation defines change in heart rate Y as a function of time t which is the time is takes to decay the confidence from 100 to 0 percent, the maximum value of change in heart rate, Y_0 (in this case is 18.67), and the emotional stress an observer feels from the effect of the loss in confidence, k. The emotional stress is represented by an equation developed by P.V. Simonov to quantify the effect of fear in the soviet space program. The emotional stress is calculated from the equation:

$$k = -M(I_n - I_r)$$

Equation 4. Calculation for the emotional stress factor in confidence in training.

In equation 4, emotional stress is a function of the motivation *M,* which for a nominal value will be set for this work. This nominal value is to generate a result that will range between a 1 and the maximum defined bpm heart rate change. It does not reflect an experimental value. The value I_n is the difference between the information necessary for the observer to act, which equates to the training level of the observer, and the value I_r if the information received by the observer in a given situation, which equates to threat level of the threat identified by an observer (P.V.Simonov, 255). Therefore, the equation will be implemented as follows:

$$Heart\_rate\_change = 18.64e^{-(-.05(observer\_trainning - threat\_type))}$$

Equation 5. Calculation to determine the heart rate change due to confidence in training.

The observer's and threat's training level to be implemented are as shown in the following table:

Table 3. Explanation of the training level in the implementation.

Training Level	meaning	
1	no training	No training
2	proficient	Able to apply the appropriate concepts, skills, and strategies to perform given tasks
3	expert	Able to apply the appropriate concepts, skills, and strategies to perform given tasks
4	specialized	Marked by or characteristic of specialization in a mechanical or scientific subject
5	mastery	Command: great skillfulness and knowledge of some subject or activity
6	grand mastery	A person of the highest competence or achievement in a field

An observer might be a level 6, or grand master, and the threat might be a level 3, or an expert, then the factor would be 6 minus 3 or a 3. The number would be entered in the part of the equation that was a subtraction of the observer training and the threat training.

Experience

Even though soldiers may be well trained in a technique or doctrine, if this has never been put into practice their heart rate will be affected by inexperience. The fear that they are not doing things correctly in a life-and-death situation will increase the stress they are experiencing. Their confidence in defeating the enemy will be low and if the SNS drives the heart rate to above 145 bps, their loss of motor skills will further erode their confidence and drive their stress level higher.

Studies conducted by Biernser and Larocco (1987) found that more experienced divers showed fewer signs of psychological stress than inexperienced divers. Experienced competent subjects mentally prepare for stressful events, thus reducing anxiety when performing the task and increasing their ability to perform.

Experience will also manifest itself in the memory of previously experienced results from previous encounters. If the observer has encountered the threat before and that encounter was negative to the observer, the confidence in defeating that threat will be low and consequently the stress level will rise. Inversely if the previous encounter with the threat was positive the increased confidence will maintain or reduce the observer's stress level.

Representation of the experience of an observer would be similar to the method to represent training, a database of threat types similar to the one used for the training; but this database would be compared to an experience database. This comparison would affect the heart rate variable and determine the stress level of the observer.

To implement the experience elements of the framework the following items will need to be represented:

- A method of classifying the threat
- A method of classifying the observers training level
- A method to compare the type of threat to the experience of the observer
- A variable that will set if the threat level matches the observer's experience

- A method of determining the emotional stress caused by the confidence in training.

Therefore the training factor can be defined as follows:

Let (E) be defined by

$$\textbf{\textit{f(E)}} = f : E \rightarrow EL_{observer} - EL_{Threat}$$

E = Heart rate change per time step due to training

$EL_{Obsever}$ =Training level of the Observer

EL_{Threat} = Training level of the Threat

The assumption of the level of confidence in an observer's experience is based on whether the observer has encountered and experienced the threat and what the result of that encounter will do to his stress level during a combat incident. The assumption for the implementation of this factor will based on whether he has faced this threat before and if the encounter was negative, such as having been defeated, or if it has been positive, such as having defeated the threat before.

The heart rate of the observer will be adjusted by the corresponding heart rate change as shown in the table below. The heart rate change is based on an exponential function to produce a range up to the maximal heart rate change of 18.67 bpm. Therefore, the equation will be implemented as follows:

$$Heart\_rate\_increase = 18.67e^{(-.05*Observer\_Expreivne\_level - Threat\_Type)}$$

The level of experience is defined as shown in the following table:

Table 4. Explanation of the experience level in the implementation.

Experience Level	meanings	heart rate increase
1	none	Never been on the battlefield; first time facing enemy fire.
2	green	A soldier with training with minimal experience on the battlefield
3	regular	A well trained soldier with limited experience on the battlefield
4	veteran	An experienced person who has been through many battles; someone who has given long service.
5	old veteran	A veteran of extremely long service, probably past their prime.

Physical Stressors

Stressors that derive from the physical state of the observers contribute to their stress state. There are two types of stressors that will be considered when examining the physical stressors. The first one is the effect that fatigue has on the stress level and the second is the effect of physical injury.

Fatigue from physical exertion during combat affects the soldier's ability to function well. Lack of sleep or overwork lessens the soldier's ability to process information and to make decisions, which in turn leads to confusion and a deterioration of the soldier's will (Gabriel 93).

Fatigue and fear affect the body in similar ways. Fear, like physical work, drains the body of energy. This creates a self-perpetuating cycle. The overloaded soldier, feeling tired, becomes more susceptible to fear. The more fearful he becomes, the weaker he feels, and the more quickly he becomes fatigued (Department of the army 37).

To implement the effect of fatigue in the model the following items need to be included in a model of an individual's stress:

- An index of the exertion level of the observer based on an exertion scale such as Borg Rating of Perceived Exertion (RPE).[6]

Table 5. Borg Rating of Perceived Exertion (RPE)

Rating	explanation
6	No exertion at all
7	Extremely light
8	-
9	Very light - (easy walking slowly at a comfortable pace)
10	-
11	Light
12	-
13	Somewhat hard (It is quite an effort; you feel tired but can continue)
14	-
15	Hard (heavy)
16	-
17	Very hard (very strenuous, and you are very fatigued)
18	-
19	Extremely hard (You can not continue for long at this pace)
20	Maximal exertion

- A variable for the time the observer is at a particular exertion state
- A variable for the observer's initial fatigue level

For the fatigue factor the following representation for is suggested:

Let (*F*) be defined by

$$\boldsymbol{f\ (F)} = \ f : F \rightarrow (EL)$$

---

[6] The Borg Rating of Perceived Exertion (RPE) is a scale developed to rate how hard you feel your body is working. It is based on the physical sensations a person experiences during physical activity, including increased heart rate, increased respiration or breathing rate, increased sweating, and muscle fatigue. Although this is a subjective measure, a person's exertion rating may provide a fairly good estimate of the actual heart rate during physical activity* (Borg, 1998)

F = *Heart* rate change per time step due to fatigue

EL =Observer exertion level

Injury during combat also affects the observer's stress level. As the observer takes damage from a threat, the physical trauma will activate the SNS and drive the heart rate up. The trauma from combat damage can be classified into closed wounds such as contusions from blunt objects, open wounds such as lacerations and puncture wounds, special wounds such as crushing and amputations and wounds caused by burning or chemical sources (U.S. Marines, B8603).

To implement the effect of trauma in the model the following items need to be included in a model of an individual's stress:

- A variable for the health state of the observer
- An index of types of injuries and their severity
- A method to cause damage by the threat
- A method to asses the current trauma state of the observer
- A variable for the time the observer is injured

Let (*I*) be defined by

$$\boldsymbol{f(I)} = f : I \rightarrow (PT)$$

I = *Heart* rate change per time step due to injury

PT =Observer physical trauma state

The physical factor that determines the increase or decrease on the heart rate variable will be a summation of the fatigue factor and the injury factor such that:

Let (P) be defined by

$$\boldsymbol{f\ (P)} = (I) + (F)$$

There are two physical factors, which are: the effect of fatigue and the effect of bodily injury. The basic assumption of fatigue is that if a soldier exerts himself, after a time the physical effect of this exertion will be perceived as exhaustion and will produce a rise in heart rate. This perceived level of exhaustion can be mapped to a fatigue index such as the BORG perceived fatigue scale. The basic assumption for physical injury is that after a certain number of injuries the soldier will become concerned and the heart rate will rise. However, after a certain combination of injuries the soldier will become incapacitated or die. This combination of injuries will be based on the abbreviated injury scale (AIS).

Based on a study done by the Australian armed forces[7], the equivalent heart rate change that corresponds with the perceived exertion rate can be extrapolated. As seen in the table below the heart rate can be indexed with the perceived fatigue rate as well as the BORG scale.

---

7 Soldier Performance and Heat Strain during Evaluation of a Combat Fitness Assessment in Northern Australia, James D. Cotter, Warren S. Roberts, Denys Amos, Wai-Man Lau and Stephen K. Prigg, Combatant Protection and Nutrition Branch, Aeronautical and Maritime Research Laboratory DSTO-TR-1023.

Table 6. BORG perceived fatigue index correlation to heart rate change.

BORG Rating	Heart rate change	BORG perceived Fatigue Scale
20	0.041398221	Maximal exertion
19	0.034437218	Extremely hard (You can not continue for long at this pace)
18	0.02864669	
17	0.023829824	Very hard (very strenuous, and you are very fatigued)
16	0.019822901	
15	0.016489732	Hard (heavy)
14	0.013717027	
13	0.011410545	Somewhat hard (It is quite an effort; you feel tired but can continue)
12	0.009491892	
11	0.007895855	Light
10	0.006568187	
9	0.005463764	Very light - (easy walking slowly at a comfortable pace)
8	0.004545046	
7	0.003780809	Extremely light
6	0.003145076	No exertion at all

The Australian study measured the heart rate of soldiers exerting themselves at a rate of 17(very strenuous activity). The results showed that the heart rate would rise from 90 to 160 in 49 minutes. This confirms Grossman's contentions that heart rate from physical exertion is gradual. The fatigue factor will be implemented by defining an activity level based on the action of the individual soldier. The heart rate change based on this implementation will be based on the following function extrapolated from the Australian fatigue study:

$$Heart\_rate\_change = .0010421e^{.1841*fatiguelevel}$$

Equation 6. Calculation to determine the heart rate change due to fatigue.

The physical injury factor will be implemented by applying the AIS to a similar function to the fatigue. The result can be seen in the table below:

Table 7. Injury damage correlations

AIS Score	Injury	Hit points	Heart rate change
1	Minor	0-16	1.648721271
2	Moderate	17-32	2.718281828

3	Serious	33-49	4.48168907
4	Severe	50-66	7.389056099
5	Critical	67-83	12.18249396
6	Un-survivable	83-100	18.67553692

It should be noted that there is a heart rate change for an un-survivable injury. This would indicate that although the soldier receiving this level of injury will die his heart rate would still rise to the highest level and trigger the SNS.

The fatigue heart rate increase as well as the injury heart rate increase will be added to the overall heart rate to influence the stress state of a soldier.

Implicit Stressors

The environment in which an observer exists also affects stress levels. Environmental factors such as temperature, altitude and humidity are factors that slowly raise the heart rate over a longer period of time, to which the body can acclimate over time; these do not explicitly activate the SNS. They need to be taken into account if the model is being used to simulate any combat event in a hot, humid or high altitude environment.

Environmental factors that increase heart rate without the effect of fear induced effect result in an amplifying effect (Grossman, On Combat, 32). Therefore a multiplier that takes into account the environmental effects should be added to the heart rate change calculation as needed for the specific scenario that would be modeled in a simulation.

3.2.4 Coping and stress reactions based on stress level

As the observer reacts to the stressors described above, the ability to cope with the situations during a combat incident will depend on the ability to internalize what is perceived. The observer will constantly be re-appraising the situation and trying to determine the proper course of action until the conditions that force the reaction end. There are three basic actions for coping with a situation (Shalit 17):

1. One can act on the situation
2. One can abstain from action during the situation
3. One can withdraw from the situation

And there are three basic aims for any action on the situation:

1. Change the situation
2. Maintain the situation
3. Adapt to the situation

This can be expressed by the following mapping:

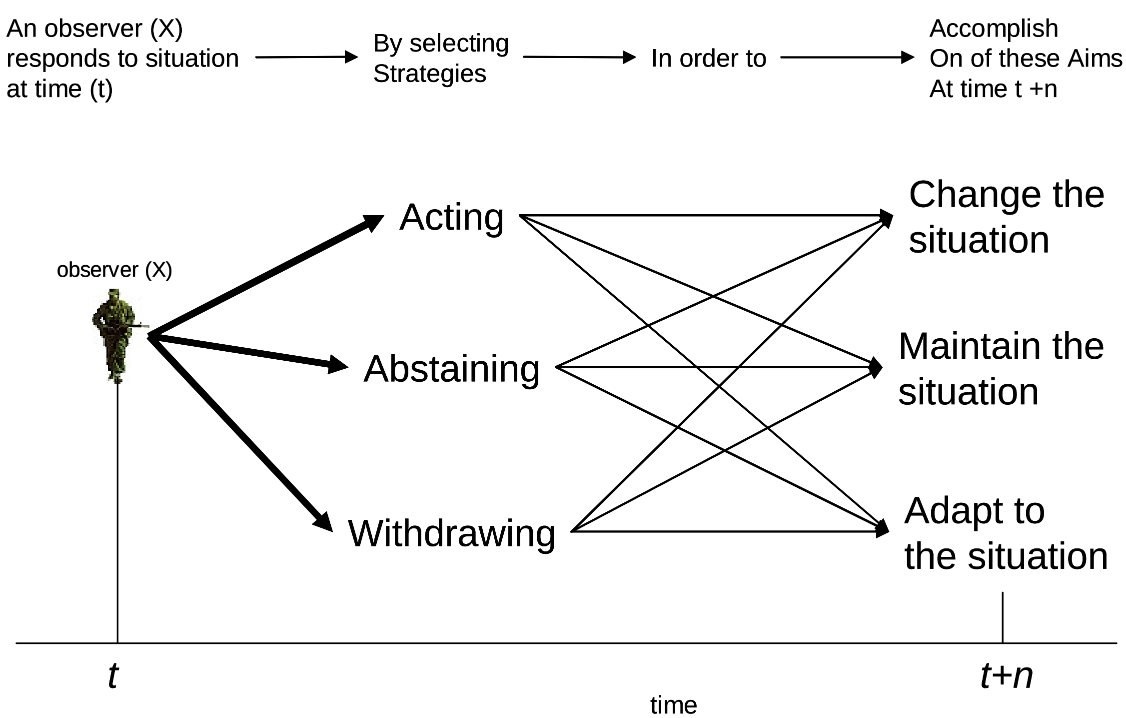


Figure 13. An observer (X) can respond to any situation at any time (T). *The observer will attempt to choose the situation that best affects his welfare.*

These coping choices will be available to the observer during the time of the combat incident, with the observer choosing the combination that would offer the most advantageous situation to accomplish the task. The choices made by the observer can be directed according to the specific implementation of tasking in a simulation. If the simulation is based on a human in the loop, such as a player in the game, the human will make the decision choice. If the implementation is an agent-based implementation, the artificial intelligence in the agent will make the decision. In an agent based implementation a method of determining the most advantageous situation needs to be developed.

If the stress level is below the optimum range of 145-175 bps the observer will not be sufficiently aroused and the act of choosing a response will be done in a slow and sluggish manner. This should be represented by additional time devoted to the process of acting on a task.

If the stress level increases to above the optimum performance level the response will be affected by the loss in physical ability to perform tasks. This should be represented by a decrease in whatever task performance measure is implemented in a simulation.

If the stress level reaches the range of 175 bps +, the observer exceeds his ability to cope and as a defense he ceases to relate all together. Failing to cope with the situation will have one of three results:

- The observer will freeze and be unable to react when faced with a sudden threat. This will affect up to 20 percent of the combatants (Shalit 34).
- The observer will move around the battlefield until the threat is perceived to have ended. This could be leaving cover because it is believed that

someplace else is safer, or fleeing the area of the combat incident all together, as fast as possible (Grossman, Psychological, 144).

- The observer will charge the enemy irrationally. The observer attempts to end the threat by charging the threat without regard for his own well being. (Grossman, Psychological, 144).

This should be implemented by randomly generating a value between 1 and 3. The value of 1 will indicate a freezing reaction. A value of 2 will indicate a move away from the threat reaction. A value of 3 will indicate a charge the enemy reaction.

3.2.5 Variability in stress reactions

To the observer's idiosyncratic perception to the universe, reactions to the stresses encountered in a combat incident are basically in the eye of the beholder. Although the phenomena of psychophysiological responses are common to most people (this work deals with the majority of people, not any extreme individuals who might enjoy violence or are incapable of reacting to it), the degree to which an individual reacts to the situation can vary from person to person (Shalit 40).

This fact should be reflected in any implementation of the framework. A variable amount of increase to the heart rate from each of the described stressors would be a closer approximation to reality. However, because little research has been done to determine how much variability is realistic in the application of the stressors, an initial implementation of a deterministic nature would be the best approach. The numbers for the described variables should be experimentally determined based on a validation example. The values for the variable affecting the stress can be tuned until they are within an acceptable confidence value. Once the values have been derived, a stochastic experiment should be conducted, although the amount of variability would also need to be tuned through a series of experiments.

Unit Moderators

The horizontal cohesion in the group and the vertical cohesion affect the stress level of an individual in combat along with their leaders. The stress level of each member of a unit will be moderated by the trust among them. The leader will also moderate the stress in the unit if the members of unit have trust in the leader's ability to lead them during a combat incident. These moderating factors will be more specifically examined in the next section that deals with the unit models of horizontal and vertical cohesion.

3.2.6 The unit model implementation

The cohesion framework will consist of a number of individual soldier stress models connected together into a unit model. The unit model will take the stress level of the individuals and transmit that value to the other individual soldiers. This transmission of stress levels will moderate in turn the rest of the unit's individuals.

The implementation of the unit model of the cohesion framework is based on the premise that there is an interconnected network of bonds among the members of a combat unit. This network represents, as S.L.A. Marshall states, "the near presence or perceived presence of a comrade that enables a soldier to keep going in combat" (Marshall, 135). This is the essence of cohesion. When a soldier perceives himself as a member of a unit, he will be pressured to behave according to the needs of the group. When he sees himself as an individual, his behavior will primarily depend on what he feels to be best for his own survival or his own emotional needs (Shalit 142). For a soldier to perceive himself as a member of a unit, it is required that he perceives at least one other as relevant to him and as one he can rely on and interact with. Unless that channel of communication exists, the individual cannot form a link with the unit (Shalit 142).

After a certain proportion of a unit has either been destroyed or separated, it will lose effectiveness and eventually collapse. Reports vary on what proportion of the unit can be destroyed before it will affect the combat performance, but it is clear that there comes a point when the unit will not function as a group (Shalit 142). The cohesion framework will enable an analyst to study this precept and may provide insight into the unit disintegration point.

How then, can the concept of the social bond network be operationalized into an implementation? At what level do the relational bonds need to be represented? What constitutes a bond between two soldiers, within a unit and outside of a unit? To explore these questions and to better frame this explanation, definition of a bond or connection between soldiers in reference to the framework needs to be discussed.

3.2.7 Definition of connection between soldiers.

The bonds between members of a combat unit during a combat incident are based on the assumption that soldiers expect that other nearby soldiers will support them. This support is based on how much soldiers trust each other.

The definition of trust is paraphrased as the willingness of a soldier to expect another soldier to perform the necessary actions to support the unit's objective during a combat incident (Holmes and Rempel, 273). Holmes and Rempel propose three dimensions that will build trust between individuals. The first dimension is the predictability, which is the subjective probability by which an individual expects that another individual performs a given action on which a soldier's welfare depends. The second dimension is dependability, which is the expectation that the soldiers are technically competent in the performance of the activities during a combat incident. The final dimension is faith which is the generalized belief that the other soldiers will perform in a future combat incident (Holmes and Rempel, 220).

These dimensions of trust take time to develop. If a soldier arrives to a unit, fresh from boot camp, none of the exisitng members will have enough information to develop high levels of trust. If the unit goes into combat they might expect or assume that the new replacment will perform their nessesary function. However, until the recruit performs the trust would be low. On the other hand the new recruit will have the collective history of the unit to generate their subjective trust in the veterans.

This dynamic is exemplified in the following model of the development of small groups. Bruce Tuckman in his work "Developmental Sequence in Small Groups" defines four stages for a group to be in:

- **Forming** - at this stage, group members will be uncertain of the group's structure and its goals or a strategy for achieving them; they will as a result be quite dependent on the leader;
- **Storming** - at this stage, conflict and disagreements between the group members and the leader will arise, as well as between various sub-groups; there will be a tendency to rebel against the rules which have been established. If you accept the basic premise that membership of a group is motivated by a desire to achieve one's own ends more effectively than a person could as an isolated individual, then this 'storming' stage, where each individual competes for the dominance of his ends, should come as no surprise.
- **Norming** - the group becomes more mature and cohesive; group norms develop beyond any formally established rules
- **Conforming** - conflicts between individuals are resolved; the group works constructively on problem-solving and energy is directed towards the task.

In a unit history, as new recruits or transfers are integrated into the organization of the unit, the individuals can be defined into similar categories that are based on their social cohesion:

- **Recruit** – The individual has just arrived into the unit and will be uncertain of the group's structure and its goals or a strategy for achieving them; he will as a result be quite dependent on the leader. He will have little impact on the veteran members of the unit.

- **Green** – The individual has been in the unit a short time but has not yet formed strong ties to all the units' members. The emphasis is on his individual needs. He will have begun to form ties with some of the more experienced members of the unit.
- **Normal** – The individual has developed bonds with the members of the unit. The group becomes more mature and cohesive; group norms develop beyond any formally established rules.
- **Veteran** – The individual has been with the unit a long period of time. Conflicts between individuals are resolved. Will be looked upon for leadership roles by the more recent members of the unit. Will regard the new members as just temporary replacements.

The group bonding can now be operationalized given the concepts of communication that Shalit describes and the classification based on Tuckman. The first thing a soldier in a unit needs to perceive is that he is in communication with others in his unit. Whether it is looking over his shoulder in a Greek phalanx or in cell phone contact in Baghdad, that connection will be the first factor in establishing the cohesion network that will mitigate his stress level. If the solider is in communication with another his stress level will affect those soldiers with whom he is in contact.

The second factor that will determine the connection can be based on the social cohesion level. If a veteran soldier is in contact with a green soldier the strength of the bond between them will be at some defined level. If two veterans are in contact the bond should be much stronger. This follows the concept that a cohesive unit has been together much longer than a green unit and that a unit with mixed times of membership will have varying levels of cohesion.

The third factor in the definition of bond between members of a unit is the stress level. Once communication and the social relation are established then the stress level will affect the members of the cohesion network as described in the previous section.

Therefore, the operationalization of the bond in the members of a unit will be as follows:

1. The definition of contact is defined based on the context of the period being used for the implementation.
2. Determine if the soldier is within the range of the defined contact parameters
3. Once the soldier is in contact a comparison of the social cohesion level is determined and a connection is established
4. The stress state of the connected soldiers will be used to modify the heart rate variable of the soldier
5. The soldier’s stress state then will affect all the soldiers who have established a connection

Once the connections between soldiers are determined, the network that is formed will be designated as the “unit”. This “unit” can be described by a directed weighted graph. The direction of the arcs (or edges) from one node to another will represent the stress level that is transmitted from the soldier to those with whom he is connected. The weights of each arc will represent the factor associated with the stress level moderated by the social cohesion value of the connected soldiers (see Figure 10).

The unit network graph will dynamically change as the situation in a

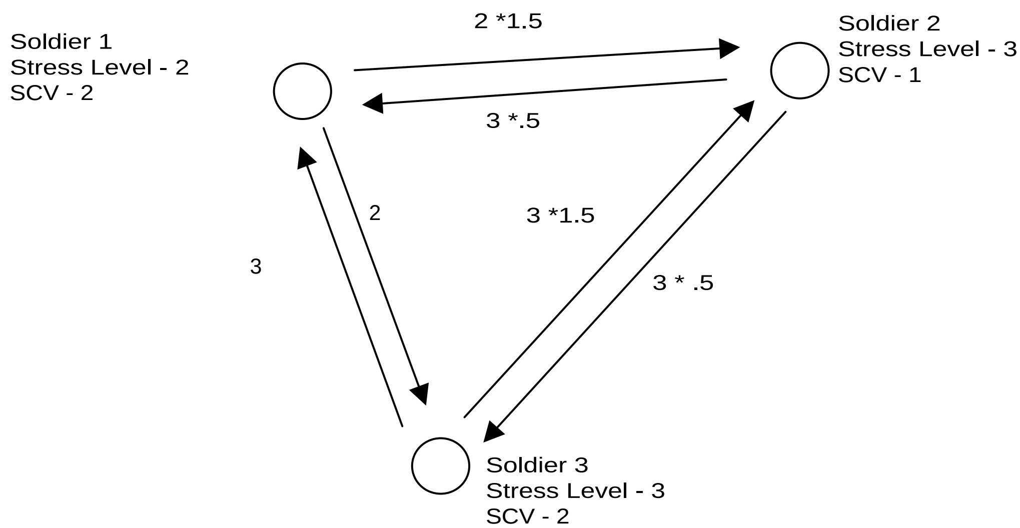


Figure 14. A directed weighted graph describing a unit of three soldiers. The social cohesion value (SCV) is a multiplier to the effect the soldier receives from the other soldiers. The higer SCV would indicate a more veteran solider thus providing a positive effect icrease to the less veteran soldier.

simulation changes. As each soldier's heart rate changes in relation to the stress state he perceives from the other soldiers that are connected to him, he will send his stress level to all those to whom he is connected. The moderation from the social cohesion value will moderate the effect of the stress level. If the soldiers who are connected have the same social cohesion value the stress level effect will be equal for both individuals.

If the connected soldier has a higher social cohesion value then he will be less affected by the stress level effect. Finally, if the connected soldier has a lesser social cohesion value he will be more affected by the stress effect. This represents the situation that when a veteran runs the green troops are more likely to run with him and if the green troops run the veterans are less likely to care. Also, the veterans will improve the green troops' stress levels when their stress levels are positive. Of course the theory is put forth that there is a point at which everyone will run.

3.2.8 Measuring the cohesion of the soldier network

Having described the constituent part of the unit network graph, a method of measuring the cohesion is presented. The theories and method described by White, Moody and Harary can now be incorporated into the framework to provide a measure of cohesion at any given time of a small unit simulation. White and Harary introduced a scaleable aggregate measure of cohesion based on the connectivity of a graph and the conditional density. Recalling some definitions from White and Harary's works, one gets the following:

- *Connectivity* - The minimum number *k* of a group's actors whose removal would no allow the group to remain connected or would reduce the group to a single member. An example of this can be seen in Figure 11 in which graph A shows a connectivity of 2 based on the minimum number of nodes that would split the graph. When graph A gets reduced, the increased ratio of connections to node increased the connectivity to 3.

- *Conditional Density* - a measurement of the ratio of the differences between the maximum number of edges and the actual number of edges in a graph. Using the formula: Conditional density (ρ) = 2*m/n (n-1) (see Figure 12).

Cohesion is defined as a combination of the connectivity of a graph plus its conditional density. For graph A in Figure 1 the cohesion value would be 2.667 and in graph B the cohesion value would be 3.700. This shows that the cohesion of the depicted unit was increased by the removal of the members that had fewer bond connections with the other members of the unit and made the unit stronger cohesively. Therefore, any given time of a simulation the minimum number of casualties that would split the unit can be calculated. The conditional density for the connected group can also be calculated

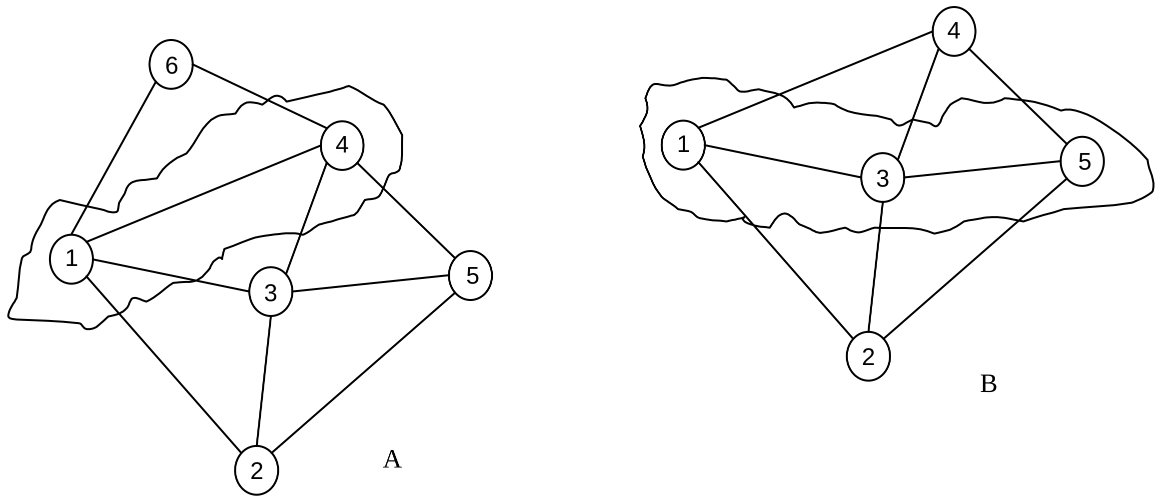


Figure 15. Examples of graph connectivity calculation. The connectiviety of the unit in graph A is increased by the loss of soldier 6. It would take the loss of three connection to break up the unit in graph B; it would take only two to break the unit in graph A.

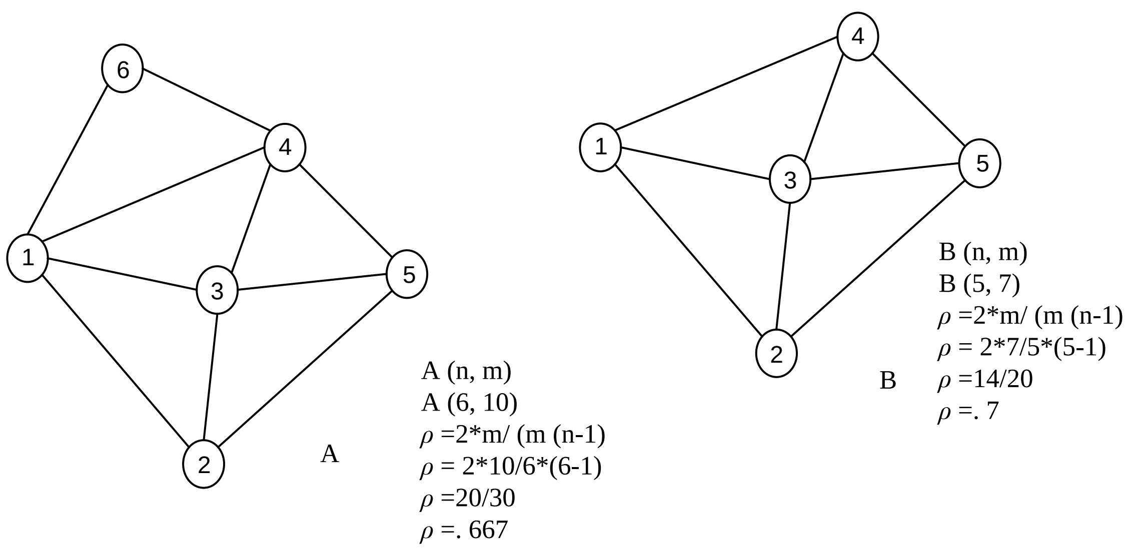


Figure 16. Examples of graph conditional density. This Figure shows the conditional density of the graph shown in Figure 12. The conditional density is shown to have increased with the loss of soldier 6. The ratio of soldiers to connections has increased and thus, increased the density of the unit.

In a simulation the cohesion level can be observed and recorded to allow analysts to make inferences about the performance of achieving an objective for a given scenario.

3.2.9 Implementing implicit cohesion factors

The factors of organizational and societal cohesion will be implemented implicitly. Models for these aspects of cohesion for analysis of the military have not been developed to a level where they can be operationalized.

Organizational cohesion is a factor of the specific structure of the combat units that are being represented. The structure of the army from which the unit comes will provide the effect of representing organizational cohesion. When a combat is specified for a simulation the following aspects should be inherent to its nature:

- **Goal or objective**. A scenario that requires a unit to take an objective in a dense forest would affect a unit whose mode of combat was open order differently than a unit whose nature was close ordered formation. An example would be the battle between the German tribes and the Roman legions in the Teutenburg forest in 480 B.C. The broken and forested terrain affected the Romans adversely in their tight ordered formations and the Germans' looser war bands were less affected.

- **Personnel and Supply Logistics.** A scenario will specify the supply level a unit will have during a simulation. If the unit does not have the material to perform its goal or objective the confidence of the soldiers will be reduced. If a line of colonial British infantry runs out of ammunition during a charge of a spear-armed tribal combat unit it will have it cohesion affected. Along with the proportion of veteran to green troop the replacement system of the army the unit represents will affect its ability to perform.

- **Unit Organization**. A scenario will dictate the type of unit that will participate in the simulation. If a unit is organized like a Greek hoplite unit it would promote cohesion. On the other hand, a unit where men are to fight in loose or open formation would have less cohesion.

Initially, an analyst might wish to set these values to 1 so that they would not have an effect on the simulated scenario. The analyst could then gradually increase the level of these factors to investigate the effect of the organizational and societal cohesion on the unit during combat.

3.2.10 Implementing leadership

Leadership has been identified as one of the most important factors that mitigate the stress on the battlefield. Leadership, in the form of vertical cohesion, is very important in the maintenance of a unit's cohesion during a combat incident. Soldiers have to establish and maintain trust in leadership's ability to get them through the travails during combat. However, in the event that a leader's trust is lost or if the leader is eliminated, the cohesion of the unit will determine how it will perform.

In implementing the influence of leadership into the cohesion framework the following precepts will be considered:

- A leader is a soldier in the unit; therefore all conditions and calculations used for the other members of the unit apply.
- The leader's influence on the other members of a unit is based on trust that the leader will make the correct decisions to protect the unit and to attain an objective.
- A leader's influence has already been established at the moment of a combat incident.
- A leader's influence, during a combat incident, extends to only those soldiers in a unit with which communication has been directly established.
- Once a member of the unit has panicked the trust in the leader is reduced.

Therefore, the leadership influence needs to be implemented by defining a selected individual with a leadership rating based on historical, random or experimental parameters. This rating will influence any connected solider in a unit with an increase or decrease to their overall heart rate calculations. If the individual soldier reaches stress level 5 then the leadership influence will be reduced permanently during the time of the combat incident.

If the leader is eliminated or flees from the field, the unit will react to the situation without the influence of the leader while continuing to follow the objective task it is doing within its overall stress state and condition.

The next sections of this work will use the ideas presented so far and produce an implementation. It will describe the scenarios used as well as the experimental plant to be used for testing. The specific implementation is intended to validate and establish the cohesion framework as a useful tool for exploring cohesion.

3.2.11 Measures of merit and performance

Major Brendan McBreen[8], researcher at the Marine Corps Warfighting Laboratory, identifies these measures as the most important results of cohesion during a combat incident:

- Perform better in combat
- Suffer fewer casualties
- Do not fracture under stress
- Require less command

Therefore the implementation of the cohesion framework will track the following measures of performance:

- The cohesion of each combat unit

[8] Major McBreen spent 3 years at the Marine Corps Warfighting Laboratory developing Marine Corps infantry small combat unit tactics. The Lab's purpose is to improve current and future naval expeditionary warfare capabilities across the spectrum of conflict for current and future operating forces

- The number of casualties taken
- The number of casualties inflicted on the enemy
- The number of leaders in a unit

The explained stress factors, groups factors and measure of merit will be implemented into an application that will be able to test the principles and properties that have been presented thus far. The next section will explain the design of the application and the Experimentation plan to validate and verify the implementation of the cohesion framework.

4.0 Experimentation

The experiments are intended to focus and demonstrate the ability of implementing the cohesion framework. The experiments will be designed to incorporate the stress and cohesion factors and to provide feedback to various stakeholders. A key component of the experiments will be the identification of metrics to measure the effect of the group cohesion on the performance on the battlefield. [9]

4.1 Experimentation plan

The goal of the experimentation to be conducted is to verify and validate the cohesion framework presented in this work. The goal of these experiments is to test a computer application, and identify relevant behaviors and to gain insight in the approach taken by the author to study cohesion in small combat units. This goal will be pursued by a research plan that includes the following:

- Create a computer program that allows the experimenter the ability to set up two opposing military forces to perform combat in order to study the feasibility of implementing the cohesion framework presented in this work. Provide the computer program the ability to perform rudimentary combat behaviors such as move, fight and react to situations that occur during combat.

---

[9] A CD of all scenarios and generated data will be included with this work for reference purposes (see appendix 4).

- Use the computer program to build, operate and test different configurations of military units set up to test their performance and measure the effect of cohesion.
- Measure, via empirical experimentation, the cohesion of the unit and investigate whether the advantage described in the literature is available to be reproduced.

4.2 Experimental framework

The computer program will demonstrate the effects of the trust relationships or cohesion between the members of a combat unit. The cohesion of a unit designed for the experiment will be measured and correlated to its performance against an opposing designed unit.

The specific combat unit selected to be modeled in the computer program will be the classical Greek phalanx circa 650-338 B.C. This particular unit was selected for experimentation for of the following reasons:

- The cohesion that existed among the individuals within a phalanx, known as hoplites, accounts for much of its success on the battlefield. The confidence that grew out of the bonds between the hoplites allowed them to endure the sight and sound of combat (Hanson 1089, 117-118). Therefore, if the cohesion among the hoplites in a phalanx can be modeled and measured, insight can be gained into how cohesion affects the performance of combat units.
- Phalanx combat during the selected historical period tended to be between similarly armed combatants. A hoplite within a phalanx from any

given Greek city state would be armed alike, with a rounded three foot shield, called a *hoplon*, and an eight foot spear. The hoplite fight with similar tactics of forming into a column, usually eight ranks deep, where protection would be found in the form of the accumulation of shields to the front rear and sides (Hanson(1995), 297). Therefore, if the opposing phalanxes are modeled with similar organization and tactics, the differences in technology, weapons and tactics can be removed from the equations and ignored. A direct comparison of the effect of the cohesion within the units and its effect on the performance can be better studied.

- The phalanx formation was closely affected by the stress and fear each hoplite experienced during a combat incident. Hoplites experienced battle fear ranging from violent heart pounding, to a sinking feeling in the heart, to involuntary urination. In Greek warfare each man in the ranks had to confront the horror of close combat and be able to stand or run depending upon the psychological state at any given time (Hanson (1989), 191). Therefore, the stress effects within a phalanx become important factors for the cohesion during combat and if modeled will add to the understanding of the overall phenomenon.

A key component of the experiments will be the use of detailed metrics to measure scientific as well as functional progress in developing the program to demonstrate the principle detailed in this work. The experiments will be programmed using the JAVA programming language. This is to make use of the object oriented capabilities of the language, so that a multi-configurable application can be developed to provide flexibility in the desired development.

4.3 Experimental methodology

The computer program written to implement the cohesion framework will be verified that it conforms to the suggested implementation described in this work and validated by applying historical scenarios in which plausible historical outcomes can be produced. A series of experiments will be carried out to ascertain if the framework can produce results consistent with the ideas and principles described in this work.

Experiments will be based on the design of two phalanx units. These phalanx units will be designed based on possible population demographics for a specific Greek city state of the classical period. The individual soldier's training, experience and social cohesion value will be determined based, as much as possible, on historical references or on historical reconstructions. The resulting phalanx will be at most a plausible unit of the Greek classical period. When specific data is possible this information will be used.

The phalanxes will be laid on a graphic of a battlefield and the program will be stated. The two phalanxes will be allowed to fight (see appendix 2 for combat model), while collecting desired metrics, until a pre-designed stopping point and then the collected metrics will examined and analyzed. Inferences as to where the result is plausible within what is known of a classical phalanx battle will be assessed as well.

The verification experiments will consist of two phalanx formations composed of 31 hoplites and one *enomotarch* (leader). One unit will maintain its classification levels, such as social cohesion value, training and experience levels, and the other will be varied according to the classification levels described before. The two phalanxes will be pitted against each other and data will be analyzed.

Three validation scenarios will be constructed to see if the implementation of the cohesion framework can produce plausible results based on historically expected results. The scenarios will be as follow:

1. City State of Sparta versus City State of Athens

   This scenario will pit the best quality phalanx of classical combat, the Spartans, against the city of Athens, that maintained an exceptionally well-trained army but did not dedicate itself to the art of war, as the Spartans did.

2. City State of Sparta versus Minor City state

   This scenario will pit the Spartans against a city state that has lesser quality troops. The lesser city state troops many be those of a city that would not call up the phalanx other than on occasional large wars.

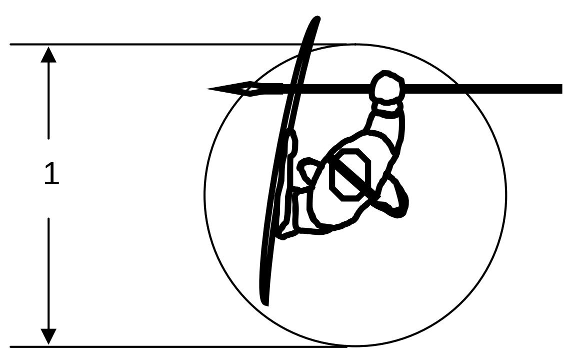
3. City State of Sparta versus City state of Thebes

   This scenario will pit the Spartans against the Theban deep column. This was tactic that was employed at the battle of Leuctra (371 B.C.) and has been the subject of research and speculation for many years (Devine 207, Buckler 136). The Theban Phalanx defeated the Spartans by utilizing a deep 50 man deep column, but the specific reasons why are debatable. Some historians believe it was the depth of the column while others blame the quality decline of the Spartan soldiers. It would be interesting to see if the framework provides any insight into the effect of such a tactic.

4.4 Experimentation Set-up

All the scenarios for this experimentation of the cohesion framework will be similar in construction. The specific variable will change based on the nature of the scenarios. The specific make up of each combat unit will vary as described in the individual verification experiments or validation scenario.

In each scenario a collection of hoplites will be organized into a phalanx based on the best information from ancient and current sources. Each hoplite will have attributes that will be used by the computer application to control and respond to situations in the combat as the scenario runs. The attribute each hoplite has are shown in the following Figure:



Attributes
Social Cohesion Value
Stress State
Offensive Class
Defensive Class
Experience
Training
Health

Figure 17 Hoplite Attributes

Each hoplite receives support from the hoplite directly behind as well as the hoplite to the right. Each hoplite supports the one in front as well was the one to the left. A space of two meters was maintained between hoplites on the march, and as the phalanx closed for combat the distances became tighter. This means that the phalanx would retain its integrity if the hoplite had two meters or less between them. These relationships will be indicated by connection as shown in Figure 18. These will be the connections that will be used to calculate the connectivity as well as the conditional density of the unit to establish the cohesion value.

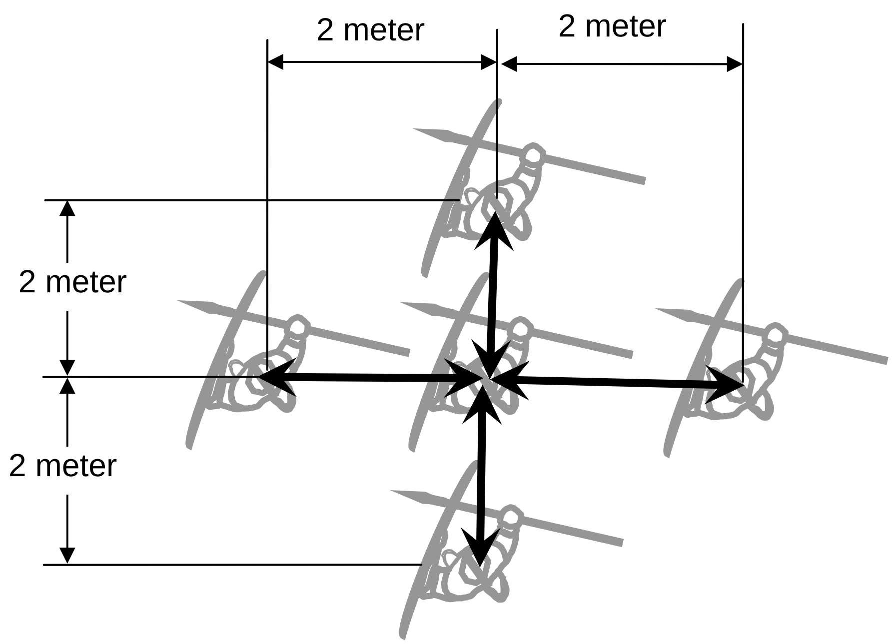


Figure 18 Cohesion connections for a Greek Phalanx

The connections seen in Figure 19 then will be combined to form the basic unit the *emonotia.* The full *emonotia* is made up of four rows of eight hoplites. This formation can be seen in Figure 19. The specific organization of the *emonotia* may vary from one Greek city state to another. The individual differences will be described in the specific scenario information.

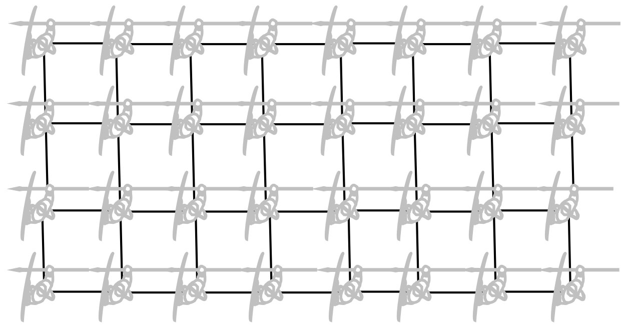


Figure 19 Hoplites formed into an example emonotia sub unit of a phalanx. *The emonotia marched behind each other in a big row. Before the battle the last troops of each emonotia positioned themselves left behind their leader to form a phalanx of four columns, in total 16 rows wide and 8 rows deep. A space of two meters was maintained between the columns, but on the order 'close the rows' the last troops walked to the left front to close gaps in the front row. Now the phalanx was in a closed formation and ready for the battle.*

The program will include various aspects that are specific to Greek hoplite warfare. The effect of pushing within the phalanx and the weapon length will be included in the application program.

As a hoplite is pushed back by an opponent the motivation factor will be decreased and the overall emotional stress will increase, thus causing an increased effect on the level of confidence factors (see equations 4 and 5 on page 16). Also, because the length of a hoplite's spear reaches beyond the length of one hoplite, the application will require that the first two rows of hoplites inflict damage on their opponents (see appendix 2 for combat model).

4.4 Verification Experiments

4.4.1 Requirements for verification

To verify the computer application it must be shown that the implementation ideas proposed in this work were incorporated as described and that program results are statistically significant to the model space being investigated. To determine the results, two nominal Greek phalanx units will be set up on the battlefield and will engage in combat. Specific capability variables will be changed and the performance will be measured until one unit is either destroyed or runs from the battlefield.

To test the implementation suggestions the following data will be recorded and analyzed to see how close it matches to the proposed functions described in chapter 3:

- Heart rate
- Stress level
- Malevolence factor
- Time to react factor
- Threat level factor
- Training and experience factor
- Physical factor
- Cohesion factor
- Hoplite coordinates
- Damage caused
- Hit points

These factors will be analyzed and graphed. The expected result is that the trends of the data will match the suggested function implementations. The verification experiments need to determine whether the application represents the model space that is investigated. The two nominal units need to move towards each other, fight, and react to the situation that develops during a specific fight. These behaviors will be observed during the verification experiments to see if they perform as expected.

The nominal experimental units will be designed so that variables of social cohesion, training and experience drive the results of the cohesion in each combating phalanx. The experiments will determine whether the difference in cohesion of the test phalanx is due simply to random error or whether it is a systematic effect of the combination of the variables. This will accomplished by using ANOVA. If the factor's effects on the unit cohesion are significant then the model will be determined to be adequate to be used to study the model design space. The multiple iterations necessary to run the ANOVA will be used to see if the model runs without any errors. If these two conditions exist the model will be designated as verified.

4.4.2 Experimental set up for verification

The verification experiments will be set up in a general factorial matrix. Three unit factors will be varied in each experiment. These will be Social Cohesion value, Experience and Training. Each of these factors shall have the following levels:

Social Cohesion Value 4 levels

1. Recruit
2. Green
3. Normal
4. Veteran

Experience level 5 levels

1. none
2. green
3. regular

4. veteran
5. old veteran

Training level 6 levels

1. no training
2. proficient
3. expert
4. specialized
5. mastery
6. grand mastery

The phalanxes will be set up on the battlefield, and will have consistent factors of 3 for each of the three unit factors. This will be designated as the “control unit.” The other unit will vary its unit factors for each experimental run and it will be called the “test unit”. A general factorial design of this will create 120 experimental runs that will measure the cohesion for each unit and the casualties caused and taken from the “test unit.” The 120 experimental combinations can be seen in appendix 3.

The expected results are that as “test unit” cycles though the combination of factors and its cohesion values increase above the level of the “control unit,” which is always set to a value or three, it will cause more casualties and take fewer casualties. If the cohesion value of the “test unit” reaches a level below that of the “control unit,” results should be reversed. When the “test unit” cohesion value is equal to that of the “control unit”, either unit will have an equal chance to win, so casualties for both units should be equal.

This test is not expected to represent complete realism, because other than the three unit factors, all other variables such as age of the soldiers, the offensive and defensive armament will be kept the same. When the historical composition of the unit is depicted in the validation experiments these factors will be taken into account and it will be expected that historical result will be seen.

When the results of these experiments are analyzed the decision will be made if the application is a good approximation; if this is not apparent the computer program will be modified and another set of validation experiments will be conducted.

4.5 Validation Experiments

The computer application will be validated by examining whether it can approximate results described in scientific and historical sources. For the application to be valid, first it must model the most commonly accepted aspects of classical Greek infantry warfare. Second, it must show that the measures of performance identified in sections 3.3.10 can be demonstrated in the model.

To see if the application approximates the expected results, three historically based scenarios have been designed. As these scenarios are run the observations will be matched with the measures of performance described in section 4.5.4. If they match up reasonably with the expected behaviors then the application will be declared valid.

4.5.1 Scenario 1 Sparta versus Athens (battle of Mantinea 418 BC)

This scenario models a situation between the best practitioners of hoplite warfare, the Spartans, and the city state of Athens, with the manpower and military history of a steady, well-experienced military. These two city states did engage in conflict during the Peloponnesian wars between 431 BC and 404 BC.

There is enough historical evidence in the classical sources to be able to reach a plausible re-creation of combat between these enemies for tacit validation of the cohesion framework.

4.5.1.1 Sparta scenario set up

Sparta was the most feared city state in Greece. It was accepted that one Spartan was worth several men from other city states, and none of the other city states, unless forced, would dare oppose Sparta on the battlefield (Connolly 38). Spartan citizens were trained from an early age to be soldiers and the society was geared towards a military lifestyle. The Spartan hoplites were divided into two classes, the *Spartiates* and the *Peroeci*. The *Spartiates* were full Spartan citizens trained from childhood to be soldiers. The Peroeci were the non-citizen merchant class who were called up in time of war to serve their military obligation. At the time of the Persian war (500 B.C. to 449 B.C.) the percentage of *Spartiates* to *Peroeci* was about 0% to 50% but as time when on the percentage of *Peroeci* increased. At the battle of Mantinea, the ratio was 41% *Spartiates* and 59% *Peroeci.* During the Persian wars the *Spartiates* and *Peroeci* formed separate units, but by the time of Mantinea (418 B.C.) they were combined into units containing both types due to the lack of *Spartiates*.

The basic Spartan unit was an *emonotia* divided into 4 files of 12 hoplites. These were combined into a unit called a *Pentekostes*, which was made up of four 36-man *emonotia*. The *emonotia* was analogous to a modern day platoon. Each *emonotia* was commanded by an *enomotarch*, who was positioned at the head of the right-most file of the unit. The right-most *emonotia* contained the *Pentekostomarch* who commanded the four *emonotia.*

4.5.1.2 Sparta Set up

The basic unit for the scenario shall be the *Pentekostes.* This will be made up of four 36 man *emonotia*. Each *emonotia* shall be made up of 15 *Spartiates* and 21 *Peroeci (*This will keep the 41% to 59% ratio mentioned above*).* The hoplites in the *Pentekostes will* be classified as follows*:*

Table 8. Spartan hoplite type specification

Type	Experience	Training
Spartiates	4 - Veteran	5 - Mastery
Peroeci	3 - Regular	3 - Expert

These values are based on categories as shown on table 3 and table 5

Each of the Spartan hoplite types in the *Pentekostes* will be given an age based on models of Mediterranean population (Coale & Demeny, 448). The population breakdown shall be as shown in the table below:

Table 9. Spartan hoplite population distribution.

Age of Hoplite	Percentage(%) in *Spartiates*	Percentage (%) in *Peroeci*
20-24	7	11
25-29	7	9
30-34	6	8
35-39	6	8
40-44	5	7
45-49	4	6
50-54	3	5
54-55	3	5
Total	41	59

Three of the *emonotia* shall have an *enomotarch* leader and the right-most *emonotia* shall have a *Pentekostomarch,* both rated as respected.

4.5.1.3 Athens scenario set up

Unlike Sparta, Athenian citizens from families with enough economic resources to equip hoplites were called up at age 18 for a two-year military training. This training included instruction on the use of arms and tactics. After that they remained registered for the purpose of being called up in case of war until the age of 60.

The Athenian organization for this scenario will be based on what is called the archaic *Lochos*, which is made up of 4 *emonotia* composed of 3 files of 8 men deep. Each *emonotia* was commanded by an *enomotarch* as well an officer known as an *Ouragos* at the rear of each *emonotia.*

4.5.1.4 Athens Set up

The basic unit for the scenario shall be the *Lochos.* This will be made up of four 24-man *emonotia*. Each *emonotia* shall be made up of some percentage of older hoplites and some percentage of younger hoplites. The hoplites in the *Lochos* will be classified as follows:

Table 10. Athenian hoplite Specifications

Type	Experience	Training
older hoplites	3 - Regular	3 - Expert
younger hoplite	2 - Green	2- Proficient

These values are based on categories as shown on table 3 and table 5

Each of the Athenian hoplite types in the *Lochos* will be given an age based on models of Mediterranean population (Coale & Demeny, 448). The population break done shall be as shown in the table below:

Table 11. Athenian hoplite population distribution.

Age of Hoplite	Percentage(%) of hoplites
20-24	18
25-29	16
30-34	14
35-39	14
40-44	12
45-49	10
50-54	8
54-55	8
Total	100
The delineation between older hoplites and younger hoplites will be at 30-34 population range (Hanson (1989), 90)	

Three of the *emonotia* shall have an *enomotarch* leader and an *Ouragos* at the rear of each *emonotia,* both rated as respected.

4.5.1.5 Scenario set up

The scenario will begin with two opposing phalanxes at an equivalent scale of 200 yards distance apart. When the start button is pressed the phalanxes will move toward each other at normal speed. When the phalanxes reach 100 yards distance from each other, they will move at double speed and crash into each other. There the individual hoplite will fight, react or die according to the situation that develops.

The scenario will end as soon as either all the hoplites of one side are either dead or fleeing the battle. As the scenario runs its course it will record the measures of performance into data file which will be used to asses the results of each scenario run.

4.5.2 Scenario 2 Sparta versus Minor city state (battle of Mantinea 418 BC)

4.5.2.1 Sparta scenario set up

The set-up for the Spartans will be the same as the setup for scenario one.

4.5.2.2 Sparta Set up

The set-up for the Spartans will be the same as the Set up for scenario one.

4.5.2.3 Minor city State scenario set up

The Minor city state designation refers to any other city state that is not referred to as having any special characteristics in the historical sources. This could also be described as a ubiquitous hoplite unit for the average Greek city state. It was assumed, for this scenario and for simplicity sake, that the organization of the Minor city state would be similar to that of the Athenians.

4.5.2.4 Minor City State Set up

The following differences are assumed in the internal set up within the organizations of a Minor city state hoplite unit:

Table 12. Minor Citystate hoplite Specifications

Type	Experience	Training
older hoplites	2 - Green	2- Proficient
younger hoplite	1 - Green	1- Proficient

These values are based on categories as shown on table 3 and table 5

Each of the Athenian hoplite types in the *Lochos* will be given an age based on models of Mediterranean population (Coale & Demeny, 448). The population break done shall be as shown in the table below:

Table 13. Minor Citystate hoplite population distribution	
Age of Hoplite	Percentage(%) of hoplites
20-24	18
25-29	16
30-34	14
35-39	14
40-44	12
45-49	10
50-54	8
54-55	8
Total	100
The delineation between older hoplites and younger hoplites will be at 30-34 population range (Hanson (1989), 90)	

4.5.3 Scenario 3 Sparta versus Thebes (battle of Leuctra 418 BC)

4.5.3.1 Sparta scenario set up

The set-up for the Spartans will be the same as the setup for scenario one.

4.5.3.2 Sparta Set up

The set-up for the Spartans will be the same as the Set up for scenario one.

4.5.3.3 Thebes scenario set up

The city state of Thebes developed a very interesting tactical technique during the period of 371 B.C and 362 B.C. A phalanx column 50 hoplite deep was used during the battle of Leuctra (317 B.C.). This formation was very successful and has been a subject of historical debate for many years,

The question arises from the ability of the Thebans to defeat the Spartans, the premier troops of the historical period. Was the victory due to numbers or quality, and what factor might cohesion plays in the results?

4.5.3.4 Thebes Set up

The Theban army was composed of

Table 14. Theban hoplite Specifications

Type	Experience	Training
older hoplites	3 - Regular	3 - Expert
younger hoplite	2 - Green	2- Proficient

These values are based on categories as shown on table 3 and table 5

Table 15. Theban Saced Band hoplite Specifications

Type	Experience	Training
older hoplites	4 - veteran	4 - Expert
younger hoplite	4 - veteran	3- Regular

These values are based on categories as shown on table 3 and table 5

Each of the Athenian hoplite types in the *Lochos* will be given an age based on models of Mediterranean population (Coale & Demeny, 448). The population break done shall be as shown in the table below:

Table 16. Theban hoplite population distribution

Age of Hoplite	Percentage(%) of hoplites
20-24	18
25-29	16
30-34	14
35-39	14
40-44	12
45-49	10
50-54	8
54-55	8
Total	100

The delineation between older hoplites and younger hoplites will be at 30-34 population range (Hanson (1989), 90)

4.5.4 Measures of performance

The purpose of the validation experiments is to see if the implementation of the cohesion framework approximates the historical description of the behaviors of phalanx warfare. Of course, the historical descriptions of phalanx warfare during the classical period are few and the ones that are available are vague. However, a few well known and accepted characteristics of phalanx warfare will be selected to test.

Two sets of attributes will be necessary for the model validity. The first set will be historically based and the second set will be based on the identified benefits of being a cohesive unit.

The historical based attributes will be as follows:

- **Two rank combat** – Because hoplites fought with 9 foot spears, the possibility of inflicting damage would extend beyond the first rank, therefore; the application must demonstrate that the hoplites beyond the first rank are taking damage.
- **The othismos** – a typical technique of hoplite warfare is the shove after the initial contact of the phalanxes. The back ranks would push their shields into the back of the hoplites in front of them, thus producing more force and momentum against the enemy. The application should show the back ranks shoving into the rank in front.

- **Effect of the stress of combat** – The hand to hand fighting in phalanx combat was harsh and grueling. The application should show the stress level of the hoplites increasing and decreasing as the conditions on battle change. It should also show the hoplites reaching a stress level such that they will run from the battlefield.
- **Approximation to historical casualty levels** – The application should either match the accepted historical losses for winner and loser in phalanx combat.

The cohesion attributes are based on the notion that the more cohesive a unit the better it will perform on the battlefield. The performance of the units depicted in the application will be as follows:

- The more cohesive unit should win the combat – this will be determined when the opposing side has either all be killed or routed away.
- The more cohesive unit should inflict more casualties – this should be a combination of dead enemy and routing enemy.
- The more cohesive unit should take less casualties – this should also be a combination of dead friends and friends routing.
- The winner of the combat should maintain a lower average unit stress level.
- The more cohesive unit should still perform with a lower ratio of hoplites to leaders.

The next section will show the data collected from the experiments as well as present the results and inferences of the experiments run in support of this work.

4.6 Results

4.6.1 Results of Verification

4.6.1.1 Implementation factors

The results of the implementation factors were based on observing a representative hoplite as the combat between phalanxes was conducted. The hoplite selected was hoplite number 8 which is on the front rank of each phalanx in the experiment. Because there are no specific models for these factors some of the results needed a scaling factor to produce the correct behaviors of the over all phalanx. The results for each factor are as follows:

Stress

The expected result for the overall stress should show an initial increasing curve with a flat section in the middle and a rapid increase as the heart rate reaches stress level 4. This would be consistent with the curve in Figure 9, which are the postulated reaction for heart rate correlated to stress level. The result for Spartan and Athenian hoplite stress can be seen in Figure 20 and 21.

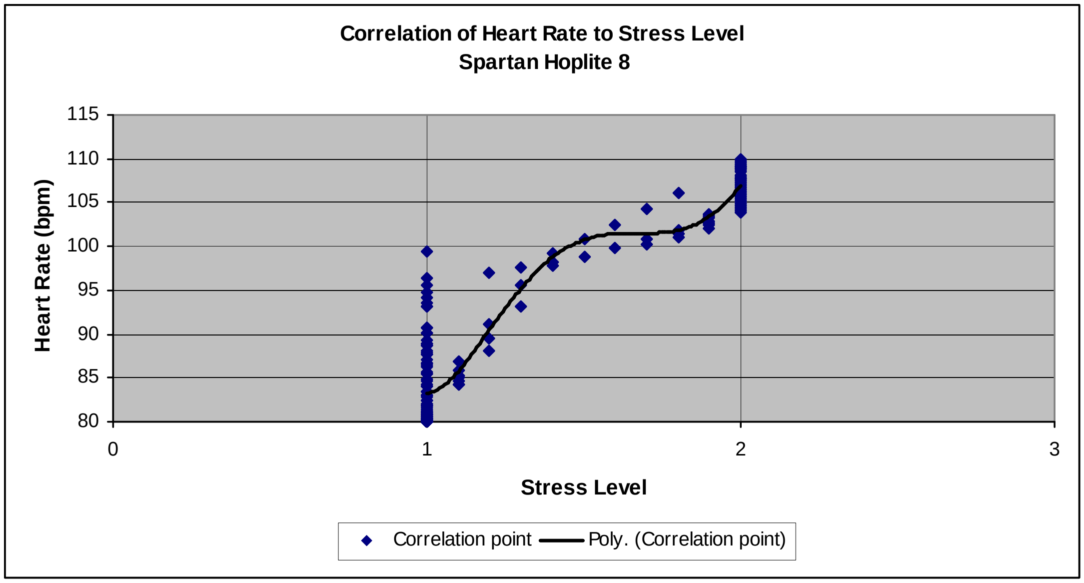


Figure 20. Correlation of heart rate to Stress level Spartan Hoplite 8. *The Spartan hoplite 8 never reached a stress level over 2: however, the pattern produced is in agreement with the curve in Figure 9.*

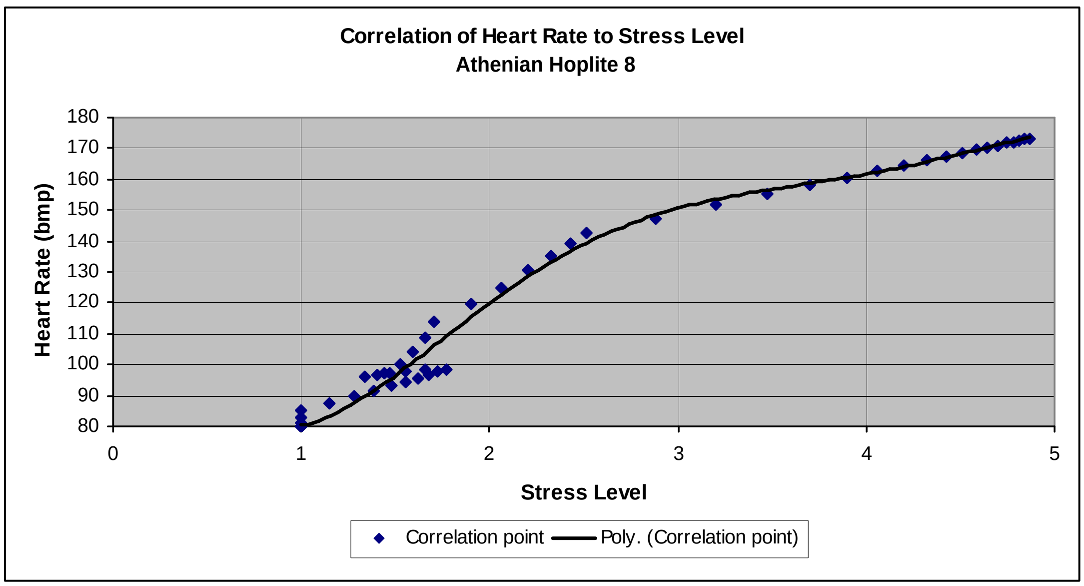


Figure 21 Correlation of heart rate to Stress level Athenian Hoplite 8. *The Athenian hoplite 8 routed during the battle and shows a flatter curve than was expected: however, the curve is evocative of the pattern expected.*

Malevolence

Malevolence should indicate a positive, value while the change in distance is negative. This would indicate the observer and threat are getting closer. If the change in distance is positive malevolence factor would be negative. Figure 22 shows the result.

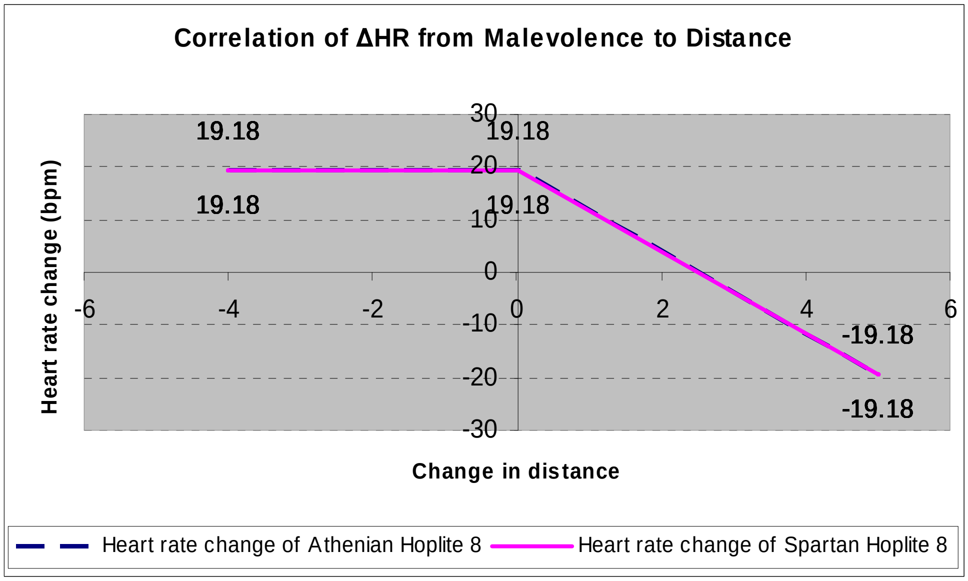


Figure 22 Correlation of Malevolence to Distance. *Movement during the validation scenario was 4 for charging, 2 for normal move and 5 for rout.*

Time to react

Time to react should be decreasing logarithmic curves. This would indicate that the longer the time to react, the less impact the factor would have on stress. Figure 23 shows the trends for the verification experiment.

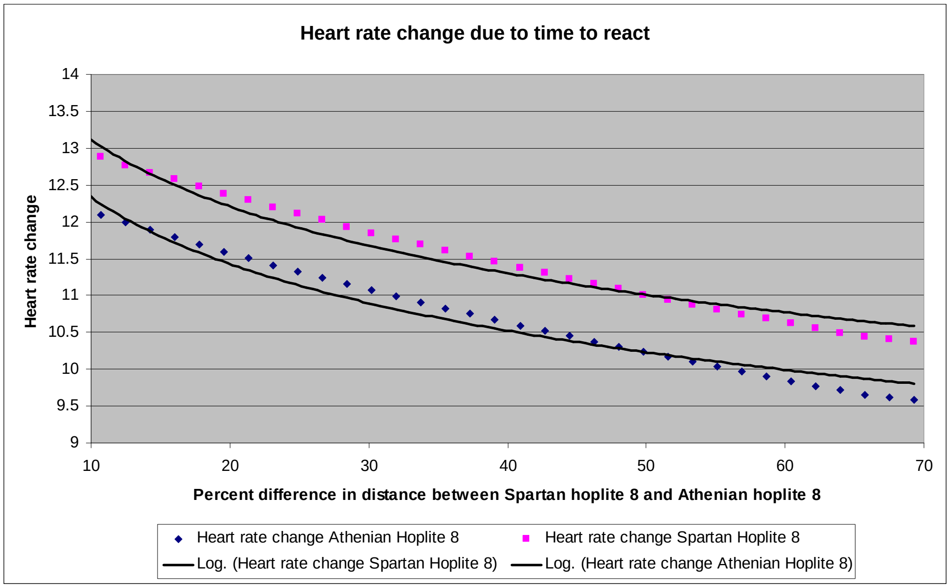


Figure 23 Correlation of heart rate to time to react

Threat level

Threat level curve should shows an increasing exponential curve. Figure 24 shows that the greater the threat level the grater the impact on stress.

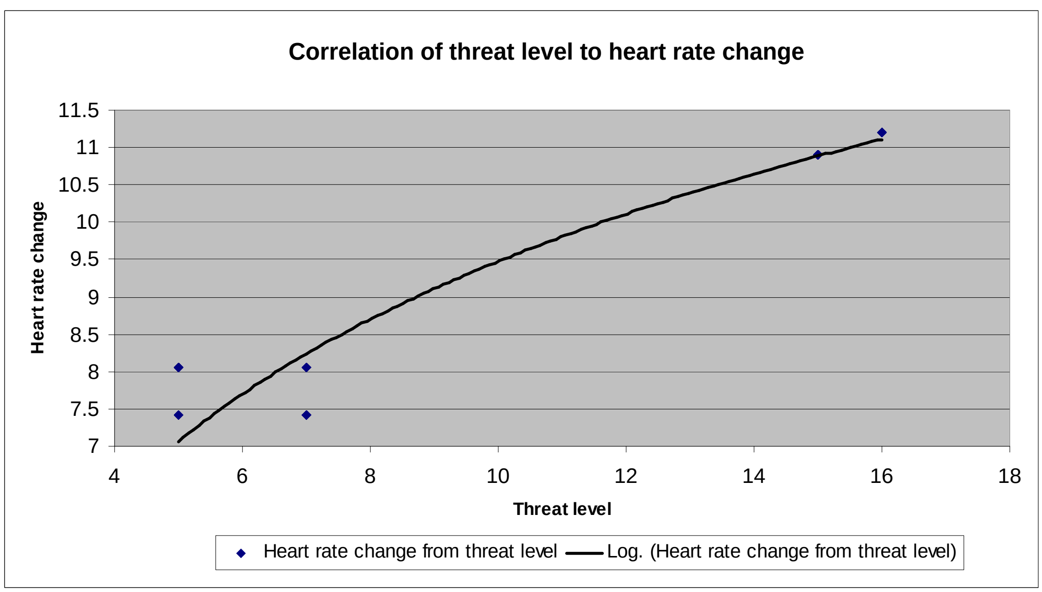


Figure 24 Correlation of heart rate to threat level

Training and Experience

Training and experience have similar implementations. Each one should show a straight line during the experiment. In the specific implementation they were combined into one factor for simplicity. Figure 25 show the result.

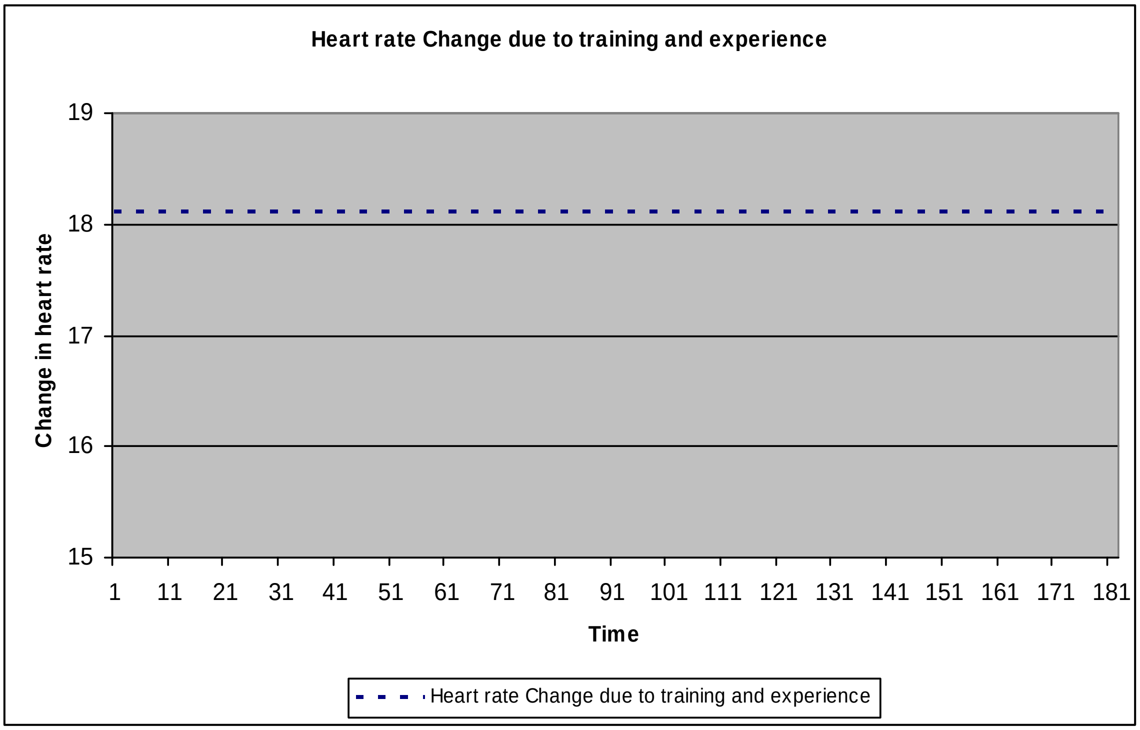


Figure 25 Correlation of heart rate training and experience

Physical

The physical factor should show a increasing exponential curve, showing that the more fatigue the more the impact on the stress. The results are shown in Figure 26.

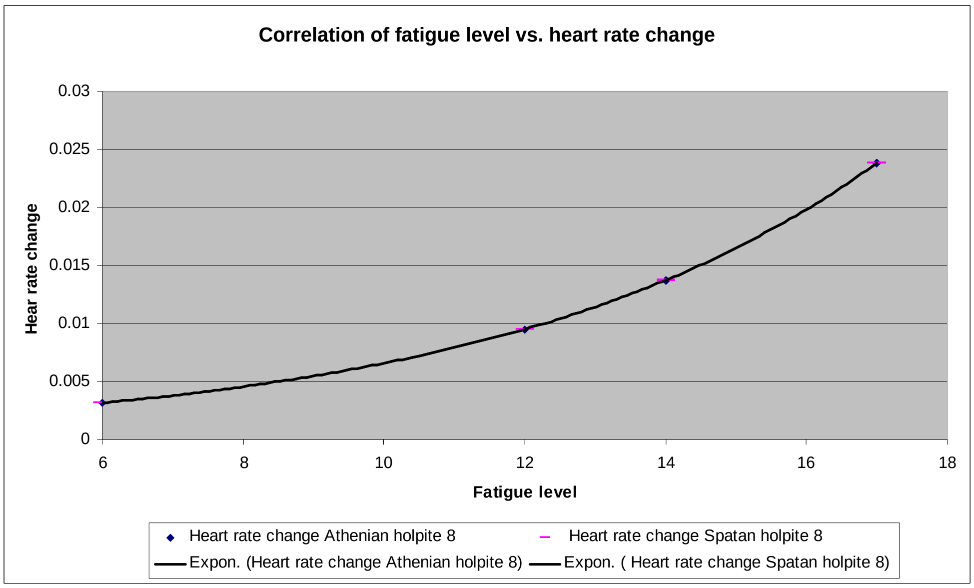


Figure 26 Correlation of heart rate to fatigue levels

Cohesion

The application's main function is to calculate cohesion for the unit as it progresses during a combat. To show this, Figure 27 depicts a screen capture from the verification experiment. The calculation for the cohesion can be seen in the textbox labeled *Red_Cohesion_Value*. That result was calculated using the following information:

52 number of connections

32 number of hoplites

Connectivity is 2

Conditional density is .104

The average social cohesion value is 4

Cohesion is 6.10

The cohesion was calculated as follows:

$$Conditional\_Density = \frac{Number\_of\_Connections(n) * 2}{Number\_of\_Hoplites * (Number\_of\_Hoplites - 1)}$$

$$Cohesion = Conditional\_Density + Conenstivity + Average\_social\_Cohesion\_value$$

$$Coditional\_Density = .104 = \frac{52 * 2}{32 * (32 - 1)}$$

$$\text{Red\_Cohesion\_Value} = .104 + 2 + 4 = 6.104 \approx 6.10$$

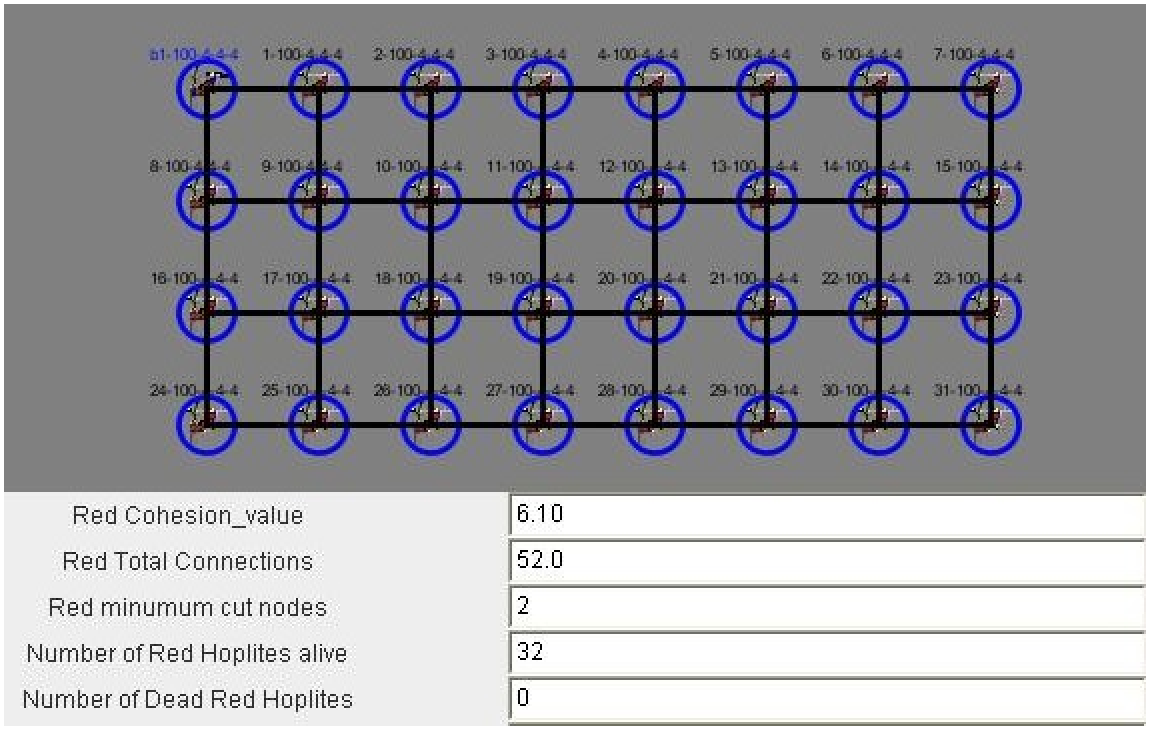


Figure 27. Verification unit with cohesion metrics.

Based on the output from the verification experiment, we can see that the application approximates the suggested functions described in section 3.2. We can see that the unit cohesion is shown to be calculated as described in section 3.2. Therefore it can be said that this aspect of the application is valid and the ANOVA experiments can be run.

4.6.1.2 ANOVA

The experimental analysis is based on design of experiments general factorial design 4 factors. These factors are social cohesion, training and experience test at various levels (levels are detailed in Table 3 and 4). The results, for the statistical verification ANOVA are summarized below in tables 18 thru 21:

Table 17. ANOVA for selected factorial model Response 1 - cohesion

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	13.60	12	1.13	2.06	0.0260
A-Social Cohesion Value	*11.30*	*3*	*3.77*	*6.83*	*0.0003*
B-Experience level	*0.82*	*4*	*0.20*	*0.37*	*0.8291*
C-Training level	*1.48*	*5*	*0.30*	*0.54*	*0.7471*
Residual	72.58	119	72.58		
Cor Total	34.07	119			
Std. Dev	0.74		R-Squared	0.1874	
Mean	5.22		Adj R-Squared	0.0963	
C.V. %	14.23		Pred R-Squared	-0.0221	
PRESS	74.18		Adeq Precision	5.935	
The value of the model F-value of 2.06 implies that the model is significant. There is only 2.60% change that the model F-value could occur due to noise. The value for Social Cohesion Value is less than .05 which indicates that it is a model significant term.					

Table 18. ANOVA for selected factorial model Response 2 - Opponet cohesion

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	23.25	12	1.94	19.16	< 0.0001
A-Social Cohesion Value	*21.67*	*3*	*7.22*	*71.45*	*< 0.0001*
B-Experience level	*0.34*	*4*	*0.084*	*0.83*	*0.5064*
C-Training level	*1.24*	*5*	*0.25*	*2.45*	*0.0385*
Residual	10.82	107	0.10		
Cor Total	34.07	119			
Std. Dev	0.32		R-Squared	0.6824	
Mean	1.45		Adj R-Squared	0.6468	
C.V. %	21.95		Pred R-Squared	0.6006	
PRESS	13.61		Adeq Precision	13.816	
The value of the model F-value of 19.16 implies that the model is significant. There is only .01% change that the model F-value could occur due to noise. The value for Social Cohesion Value and training level are less than .05 which indicates that they are model significant terms.					

Table 19. ANOVA for selected factorial model Response 3 - caulaties caused

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	15211.07	12	1267.59	17.85	< 0.0001
A-Social Cohesion Value	*12016.03*	*3*	*4005.34*	*56.41*	*< 0.0001*
B-Experience level	*402.20*	*4*	*100.55*	*1.42*	*0.2335*
C-Training level	*2792.84*	*5*	*558.57*	*7.87*	*< 0.0001*
Residual	7596.93	107	71.00		
Cor Total	22807.99	119			
Std. Dev	8.43		R-Squared	0.6669	
Mean	17.84		Adj R-Squared	0.6296	
C.V. %	47.23		Pred R-Squared	0.5811	
PRESS	9555.05		Adeq Precision	15.679	
The value of the model F-value of 17.85 implies that the model is significant. There is only .01% change that the model F-value could occur due to noise. The value for Social Cohesion Value and training level are less than .05 which indicates that they are model significant terms.					

Table 20. ANOVA for selected factorial model Response 4 - casualties taken

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	16295.38	12	1357.95	17.71	< 0.0001
A-Social Cohesion Value	*13967.96*	*3*	*4655.99*	*60.71*	*< 0.0001*
B-Experience level	*620.38*	*4*	*155.10*	*2.02*	*0.0965*
C-Training level	*1707.04*	*5*	*341.41*	*4.45*	*0.0010*
Residual	8206.21	107	76.69		
Cor Total	24501.59	119			
Std. Dev	8.76		R-Squared	0.6651	
Mean	22.69		Adj R-Squared	0.6275	
C.V. %	38.59		Pred R-Squared	0.5787	
PRESS	10321.37		Adeq Precision	15.401	
The value of the model F-value of 17.71 implies that the model is significant. There is only .01% change that the model F-value could occur due to noise. The value for Social Cohesion Value and Training level are less than .05 which indicates that they are model significant terms.					

Based on the results summarized above, the Social cohesion value is the most significant term in the model, followed only by the Trainning level. This could indicate that the experience term could use some adjusting; however, the signal to noise ratio or *Adeq Precision* for each of the response factors is greater than a four, which indicated that the model is adequate to navigate the model design space.

The application has been shown to oprate as designed as well as being adequate to be used in the design space; therefore, the validation experiemsnt can proceed and the resutls can be seen in the next section.

4.6.2 Results of the validation experiments

For the application to be considered valid it must do three things. First, it must model the most commonly accepted aspects of classical Greek infantry warfare. Second, it must show that the measures of performance identified in sections 3.3.10 can be demonstrated in the model. Third, it must show that the stress factors described in this work have been implemented as described.

4.6.2.1 Historical attributes

There are three attributes that need to be re-created to show that the application is following the historical representation of the type of combat that has been implemented. Figure 21 shows the two combat units during a run of the first scenario. It can be noted that two aspects of classical Greek warfare are being demonstrated. First, the combat push or *Othismos* that is described to happen after the initial contact of a phalanx battle. It can be seen that the second rank is pushing on the back of the front rank, assisting in the momentum of the attack. The second aspect that can be seen is that damage from combat extends beyond the first rank. Because the typical hoplite would have been armed with a nine foot spear and the area covered by the physical body would have been about 3 feet, the possibility of damage to an opponent should extend to the third rank.

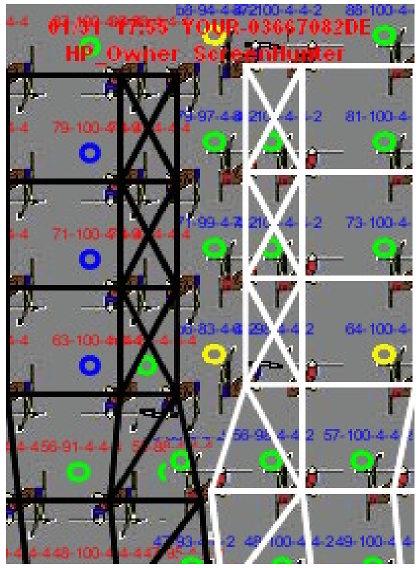


Figure 28. Screen shot of an application scenario showing the *Othismos*

The typical phalanx was quick, grueling and violent. One side would falter and collapse from the physical and psychological effect of the close combat. Figure 29 shows the unit on the left breaking and beginning to run away. The unit on the right will pursue and kill any opponent that cannot outrun it.

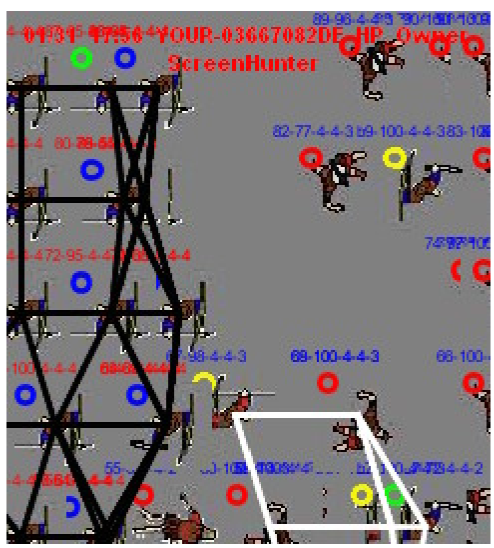


Figure 29. Screen shot showing a unit breaking from combat

Historically phalanx combat produced few actual combat casualties. Most of the deaths occurred during the pursuit of the routed enemy, mostly by the light auxiliary troops and cavalry. The information in table 22 shows the percent of casualties described by historical data and the result of running the application multiple times.

Table 21. Comparison of historical casualty percentages to those from scenario one results

	Historical casualty percentage	Casualty percentage of scenario one	Casualty percentage of scenario two	Casualty percentage of scenario three
winner	7.00%	11.08%	1.62%	14.00%
looser	14.00%	17.61%	4.12%	17.61%
Casualty % differential	7.00%	6.53%	2.51%	3.61%
Historical casualty percentages are based on P. Krentz study on hoplite casualties in 1985 “Casualties in Hoplite battles”. It is a currently accepted number by historians.				

Although none of the scenarios resulted in the exact casualty Figures, there is only a 3 % difference between the scenario on results and the historical percentages. Due to the little actual record and the simplifications in the model, it is an acceptable level of casualties. Scenario two casualty percentage is quite low. This is due to the other city state phalanx routing before there is much hand to hand combat. This also follows historical records in which some phalanxes never came to contact because one side would break apart due to fear and stress, especially when they facing the Spartans.

Scenario three varies greatly from the historical casualty percentages. This is due to the limitations on the scenario. The two sides have the front of the units populated by the best troops in the classical era. The results of the scenario shows the deep Theban column breaking through the Spartan phalanx, but because the hoplites in the front are rated so high, they tend to not run away and take more damage, thus causing a high casualty count. The causes for this may be because the artificial situations in the scenario may not reflect the historical situation correctly, because the historical information is scarce on the Theban organization. The organization selected for this scenario was somewhat arbitrary based on available information.

It can be seen from these results that the application implementing the cohesion framework reproduces the desired effect of classical Greek infantry combat. This is a good beginning in a method of exploring the historical methods of infantry combat. Having the cohesion framework implemented in a physical model with more fidelity would provide a useful tool for military historians to use for research. However, this work is concerned with demonstrating that the cohesion framework is implementable. The results prove that the application driven by the individual's stress due to the situational awareness and the support of the individuals in close proximity can be created and generate desired results.

The next section will further explore the validity of the results. It will examine the measures of performance and show that the results adhere to the theoretical benefits of having cohesion in combat units.

4.6.2.2 Cohesion Attributes

The performance in combat can be determined by a unit causing more casualties then its opponents, maintaining its cohesion and maintaining a satisfactory average stress in the unit during combat. Table 22 shows a summary of the results of the three scenarios.

Table 22 Results from the three historical scenarios

Scenario combatants	Number of Hoplites in unit	number of leader in unit	Average cohesion	Average casualties	Average Leader casualties	Average Heart rate	Average stress level	Average Number of hoplites routing	Leader to hoplite ratio
Scenario 1									
Spartan	**97**	**4**	**5.53**	**4.86**	**0.51**	**109.65**	**2**	**0.74**	**24.25**
Athenian	102	9	2.26	7.55	0.00	185.40	4	47.11	11.33
Scenario 2									
Spartan	**97**	**4**	**5.27**	**0.88**	**4.00**	**115.22**	**1**	**1.08**	**24.25**
Other	102	9	1.15	2.20	9.00	201.79	5	61.76	11.33
Scenario 3									
Spartan	97	4	3.84	10.80	0.00	152.34	3	57.57	24.25
Theban	**129**	**5**	**4.19**	**13.37**	**2.00**	**129.53**	**2**	**33.39**	**25.80**
The bold text indicates the winner of the scenario. Each scenario was run for 30 iterations with is the point at which the average value did not vary sufficiently to need more model runs.									

As seen in table 22 the Spartans had the higher average cohesion in the first two scenarios and defeated the opponents every time. When the Spartan units won the combat they maintained lower average casualties, numbers routing as well as a lower stress level. Figure 23 shows the average cohesion of the Spartan units in Scenario 1. As can be seen, the cohesion of the unit increases as the two phalanxes crash into each other as about time 51. This is because as the phalanxes close the second ranks push into the first rank. Each connection between hoplites increases as the rear ranks push their shoulders into the backs of the first rank, thus increasing support. As the two phalanxes battle each other cohesion begins to deteriorate. A time 121 the Athenian phalanx is less than 1 and it breaks and routs. The Spartan phalanx, disordered from the combat take until time 161 to reorder. The cohesion is slightly higher because the formation has become compressed by the combat.

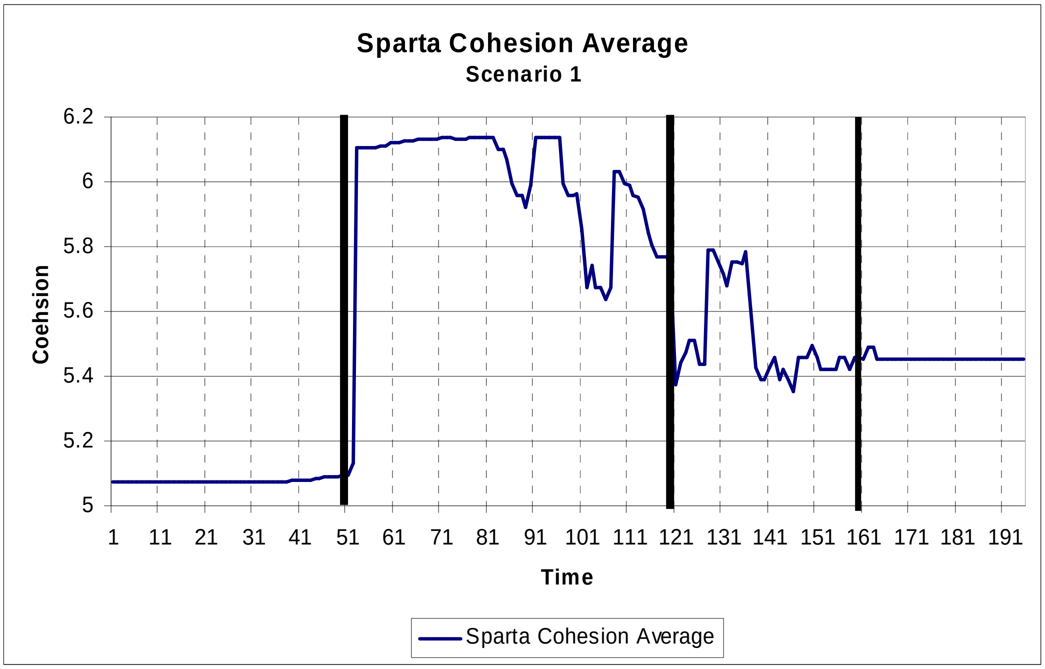


Figure 30. Spartan average cohesion scenario 1.

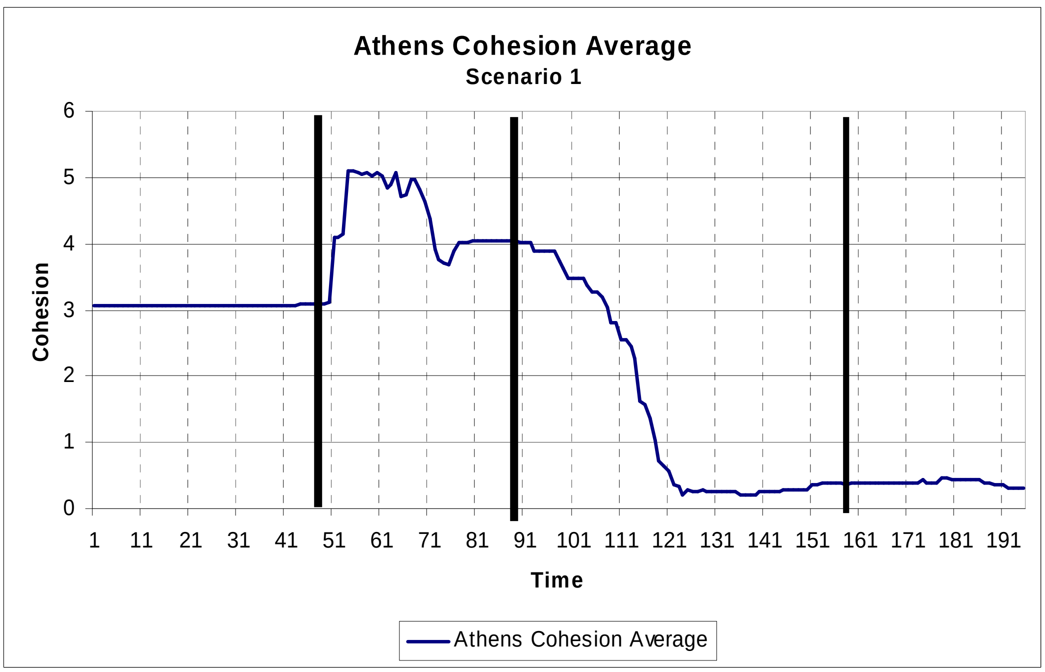


Figure 31. Athenian average cohesion scenario 1.

Figure 24 shows the same combat for scenario 1 as Figure 23, but from the Athenian side. It can be seen that at time 51 when the two phalanxes contact and begin to engage in hand-to-hand combat. The cohesion in the Athenian phalanx increases in a manner similar to the Spartan, but at time 91 the cohesion due to casualties and hoplites running away from high stress level begins to deteriorate to a level below 1, which indicates that the total number of connections is less than one. This indicates that the Athenian phalanx has not completely broken up. The residual cohesion is due to the few individuals that have reduced their stress level by being far enough away from the enemy, but now near to any hoplite that would be in a stress state low enough to create a connection. If the scenario was run longer they would probably be killed or continue running away. Cohesion results for scenarios 2 and 3 can be seen in appendix 1.

Based on the results seen in table 23, it can be seen the units with the highest cohesion usually caused higher casualties than their opponents and took fewer casualties. The unit with the highest cohesion also maintained a higher average stress level while having less of its hoplite rout. The units with the higher cohesion also won with lower leader ratios or with more leader losses. The only anomaly is the Thebans versus the Spartans scenario, where the unit with the better cohesion suffered more average casualties than the unit which lost the battle; however, the Thebans still maintained a better stress rate and had less hoplites rout. The Theban unit caused more casualties if the enemy dead and routes are combined. So overall, the Theban met the measure of performance expected. The results for scenario three could be made better if a more accurate representation of the two sides can be designed.

The application of the cohesion framework produced results that approximated the historical attribute selected to test and matched the expected cohesion results. These results indicate that the application of the framework is a valid model to examine the principles of cohesion presented in this work. The next section shall analyze the information discovered in the research, as well as discuss the implications of the work in relation to the results.

5.0 Analysis and conclusions

"The Sciences do not try to explain, they hardly even try to interpret, they mainly make models. By a model is meant a mathematical construct which, with the addition of certain verbal interpretations, describes observed phenomena. The justification of such a mathematical construct is solely and precisely that it is expected to work."

John Von Neumann

There were three objectives to this research: firstly, to investigate and understand the nature of cohesion with respect to small combat units. Secondly, to develop a framework that defines the parts that make up cohesion. Finally, to create an implementation that demonstrates what has been discovered. All of these objectives will provide a method by which to understand the nature, problems and benefits of cohesion.

Cohesion is complex; therefore, it is not enough simply to build a model. There is a need to construct an overall framework that explains how and why the social dynamics within the primary social group of a combat unit affect its performance. The framework must be flexible enough to allow the representation of any unit whether existing, future or historical. It also must be able to adapt to future enhancement or definition brought to light by future research.

By modeling the individual and his influences on the other members of a unit, we can begin to quantify values that can be used to determine and measure cohesion during combat, and base the results on the psychological aspects and not solely on attrition. This will provide the possibility of a re-thinking of simulations of the socio-technical aspects of combat not just adding more components to the legacy simulation systems.

By providing a socio-technical approach to combat modeling advances the study of combat simulation. A new level of fidelity can be added by using the internal condition of a combat unit instead of an arbitrary breaking point at which a unit fails or performs. The ability to measure the stress level of soldiers and the mitigating effect of cohesion begin to fulfill the requirements of including more psychology and human factor into combat simulations.

The aim of this work was not to reproduce a definitive individual soldier model, but to produce a representation of unit organization and to assess the individual reactions within it. The model presented in this work is an exploratory not predictive model; therefore, more definition needs to be added to provide a useful, predictive model.

The following items need to be considered to migrate the current towards a more predictive model:

- **Specify connections** – The unit part of the cohesion framework is dependent on the physical connection of the soldiers involved. However, the modern work provided the soldier with technologies that allow then to keep in touch with their fellow soldiers at great distance. A better specification that takes into account the nature of modern technologies needs to be defined. There needs to be an assessment of the effect on soldiers of enhanced visual and auditory communications. The question of the difference of a friend being killed within physical proximity of an observer to seeing a friend become a casualty on a video screen needs to be explored.

- **Validation of stressor functions** – The functions used to drive the cohesion framework implementation were based on a wide set of assumptions. There needs to be empirical data on how each of the stressors actually affect the heart rate. There may be a variety of levels to the way the stressors affect the soldier.
- **Better definition of training and experience levels** – The implementation of the cohesion framework relied on some arbitrary level of training and experience. A better definition of how soldiers are trained and a method of determining that they have encountered a threat previously need to be defined. Once evaluated, the solider need to determine that the previous encounter was perceived as successful.
- **Weapon and tactical variety** – The selection of the Greek phalanx for simplicity in implementing the cohesion framework is of limited use, since through much of history a variety of weapons and tactics are used by military organizations. Scenarios with different types of combat units such as skirmishers, missile troops, and cavalry need to be created and tested. The framework would need to be validated with many combinations to prove that it can be universally applied to any combat unit.
- **Validated models in a variety of domains** – The framework should be applicable in any domain in which cohesion is an important aspect. The use of cohesion in firefighting and law

enforcement could be of interest. If the framework was to be translated to a predictive model these domains could provide a rich source of data for validation.

As these items are better defined and incorporated into models based on the framework, data can be accumulated to enhance the accuracy of the framework. This could eventually lead to a robust predictive model to study cohesion.

Further development of the cohesion framework provides many application possibilities. The domains of experimentation, training and historical study can benefit from fully validated models based on the framework.

In experimentation studies of organized groups to be represented by computer entities offer many opportunities to use the framework. Scenarios in which combat units are pitted against other combat units or even scenarios where combat units are confronted by civilian crowds can react to the conditions that emerge from the situation. The cohesion levels can be monitored as the scenario unfolds and decisions either by human analysts or artificial intelligences programs can be implemented based on unit conditions. Combat units that are beginning to fracture due to stress can be withdrawn or reinforced Civilians that are standing cohesively may have to be dealt with by other means than violence.

Combat scenarios are not the only applications that can be investigated. Law enforcement scenarios that involve unit size operations can be represented and evaluated. Situations where police officers need to deal with crowd control and need to maintain order are ideal opportunities to implement the cohesion framework. Similar use of the framework by fire fighting organizations can be beneficial, since the effect of stress and cohesion are important to fighting a fire.

There have been numerous studies that use heart rate to investigate the performance of individuals under stress. Studies such as the 2000 HeartMath study of police officers and the Scanlon study on first responder physiology can be used to generate and validate data. Future training studies in police or firefighting facilities can be used to establish the functions that govern heart rate. In turn the cohesion framework can be used to study cohesion during training events.

The framework also provides an interesting aspect in the domain of training. The framework could be used in one of two ways. A combat unit could be pitted against a computer generated unit. This unit could be designed with the necessary relationships and definition of its particular nature. The training unit can then get a more realistic opponent to train with in a given environment.

The second way that the framework could be used in assessment of a given combat unit is to asses the unit with a cohesion questionnaire and then represents that unit in a computer simulation. The performance of the virtual unit would give insight on the cohesion level of the unit as it performs in the simulation. If the unit's performance is poor due to its cohesion then the "real" unit might need more cohesion building training. After the unit training is improved the questionnaire can be administered and the exercise repeated. The difference in performance can then be measured and assessed. This leads to a more robust model enabling the ongoing study of the effects of cohesion.

Another application for the framework can be identified. Because the implementation for the framework was based on classical Greek infantry combat, aspects of ancient combat could be investigated. A historian could further examine many aspects of ancient combat at the man-to-man level. Historians generally know how the battle tuned out but the mechanics of the individuals are often vague or contradictory. This work used phalanx warfare but the emphasis was to show the stress and cohesion effects on soldiers. Given a more accurate physical model, one could ultimately discover some interesting aspects of long-debated controversies.

The research concludes by restating that it is vital to the analysis computer generated combat force that something other than the arbitrary percentage of force be used to determine the effective state of the combat unit. Simulation is a useful tool, for it provides insight and understanding to the users, owners and analysts. It is only by the continual development of tools like the framework that we can make progress towards understanding the complexities of cohesion, and thereby develop more accurate combat simulation.

There will be continual development of the framework; the end of this dissertation does not mean the end of the author's study of cohesion. Perpetual development of more efficient algorithms, more user friendly interfaces and a more powerful analytical output will allow the dissection of the parameters of stress relevant to unit cohesion in even greater detail.

The ultimate goal is to provide the military a method of addressing the important but not well-understood phenomenon of cohesion. We propose replacing the representation of unit morale level with some aspect of the cohesion framework. It is hoped that it represents a new wave in the understanding of cohesion through the study of combat unit dynamics.

6.0 Sources

Antonovsky, A. & Kats, R. (1967). "The Life Crisis History as a Tool in Epidemiologic Research". Journal of Health and Social Behavior, 8, 15-20.

Behavior Models for Agents in Virtual Worlds: Emotion, Stress, and Value Ontologies, Technical Report, July 2001.

Behavior Representation Workshop (Acquisition Community) Report prepared for Defense Modeling and Simulation Office (DMSO) by IIT Research Institute/A B Tech Group September 14, 2000.

Behavior Representation Workshop (Experimentation Community) Report prepared for Defense Modeling and Simulation Office (DMSO) by IIT Research Institute/A B Tech Group April 3, 2001.

Belenky,George. Shabtai Noy, and Zahava Solomon. "Battle Stress, Morale, Cohesion, Combay Effectivness, Heroism and Psychiatric Casalties: The Israeli Experince. " Comteporary Studies in Combat Psychiatry. Ed. George Belenky. New York: Greenwood Press. 1987.

Buckler, John, "Epameinondas and the "Embolon"", Phoenix, Vol. 39, No. 2(Summer, 1985):pgs 134-143.

Canby, Steven, Bruce Gudmundsson, and Jonathan Shay. "Commandant United States Marine Corps Trust Study." Dumfries, VA: ACS Defense, Inc., 2000.

Cannon, W.B. Bodily changes in pain, hunger, fear and rage. New York: Appleton Press. 1929.

Coale, Ansley J.,and Paul Demeny, Regional Model life Tables and Stable Populations, second edition, Academic Press, New York, New York, 1983.

Cohen, F. (1984). "Coping" In J.D. Matarazzo, S.M. Weiss, J.A. Herd, N.E. Miller & S.M. Weiss (eds.), Behavioral Health: A Handbook of Health Enhancement and Disease Prevention. New York: Wiley, 1984.

Connolly, Peter. Greeks and Romans at War. Greenhill Books, London, 1998.

Cox, T. Stress Research and Stress Management: Putting theory to work. HSE Contract Research Report No. 61/1993. Center for Organizational Health and Development, Department of Psychology, University of Nottingham, 1993.

Daddis, Major Gregory A., "Understanding Fear's Effect on Unit Effectivenss." Military Review July- August 2004: 22-27.

Department of the Army. FM22-51: U.S. Army Combat Stress Control Handbook. Guilford, Connecticut: Lyons Press, 2003.

DeLois Ann Thomas, and Les Knight. “Evaluation of Police Heart Rate in Stress Training Environments”. *Defensive Tactics Newsletter*, October 2001, Volume XI, Number 1.

Devine, A.M., “EMBOLON: A Study of Tactical Terminology”, Phoenix, Vol. 37, No. 3(Autumn, 1983):pgs 201-217.

Durckheim, Emile. (1893) 1933. Emile Durkheim on the Division of Labor in Society, translated by Goerge Simpson. New York: Macmillan.

Festinger, Leon, Stanley Schachter, and Kurt Back. Social Pressures in Informal Groups. New York: Harpers, 1950.

Figueira, Thomas J., “Population Patterns in late archaic and classical Sparta”, Transactions of the American Philological Association, Vol. 116, 1986: 165-213.

Freeman, Linton C. “The Sociological Concept of “Group”: An empirical Test of two Models” American Journal of Sociology 98.1 (1992): 152-166.

Gabriel, Richard A. Soviet Military Psychiatry: The Theory and Practice of Coping With Battle Stress. NY: Greenwood, 1986. 171 p. UM415G33.

Gal, Reuven. "A Psychological Model of Combat Stress (with Franklin D. Jones)". In: F.D. Jones, L.R. Sparacino, V.L. Wilcox, & J.M. Rothberg (Eds.), War Psychiatry. Washington, DC: Office of the Surgeon General, Department of the Army, 1996. 133-149.

Gauthier J. & Marshall, W. “The Determination of Optimal Exposure to Phobic Stimuli in Flodding Therapy”, Behavior Research and Therapy, 15, 1977 pgs 403-410.

Glanz, K., Rimer, B.K. & Lewis, F.M. (2002). Health Behavior and Health Education. Theory, Research and Practice. San Fransisco: Wiley & Sons.

Gray, Jeffrey. The Psychology of Fear and Stress. McGraw-Hill Book Company. New York, 1974.

Grossman, David, "Psychological Effects of Combat." The Encyclopedia of Violence, Peace and Conflict, ed. L. R. Kurtz. Vol 3. pg 159, San Diego: Academic Press, 1999

Grossman, David, On Combat: Psycology and Physiology og deadly Combat in War and Peace. PPCT Research Publications, 2004.

Hagstrom, Warren O., and Hanan C. Selvin. "Two Dimensions of Cohesiveness in Small Groups." Sociometry 28.1 (1965): 30-43.

Hanson, Victor Davis. The Other Greeks: The Family and the Agrarian Roots of Western Civilization. The Free Press, Simon & Schuster. New York, 1995.

Hanson, Victor Davis. The Western Way of War: Infantry Battle in Classical Greece. University of California Press, Berkley, 1989.

Hoggson R. & Rachman, S.J. "Desyncchony in Measures of Fear. II", Behavior Research and Therapy, 12, 1974 pgs 319-326.

Homans, George C. The Human Group. New York: Harcourt, Brace, 1950. 288-290.

Howell, J.P. and D.L. Costley. Understanding Behaviors for Effective Leadership. Upper Saddel River: Prentice-Hall, Inc, 2001.

Hugdahl, K. "The Three System Model of Fear and Emotipn – A Critcal Examination". Behavior Research and Therapy, 19, 1981 pgs 75-85.

Kaurin. Dr. Pauline M. "Identity, Loyalty and Combat Effectiveness: A Cautionary Tale" Joint Services Conference on Professional Ethics (JSCOPE), conference 2006
http://www.usafa.af.mil/jscope/JSCOPE06/Kaurin06.html

Kipps, Robert D., and Jean A. Stack. "Modeling, Simulation Sector to Undergo Change. Technologies will help defense planners adapt to new geopolitical realities." National Defense Journal November 2001.

Krepinevich, Andrew. The Army and Vietnam. Baltimore, MD: The Johns Hopkins.

Laur, Darren. "The Anatomy of Fear and how it relates to survival skills training" LWC Books Website. 2002
http://www.lwcbooks.com/articles/anatomy.html

Lazarus, R.S. & Cohen, J.B. (1977). “Environmental Stress”. In I. Altman and J.F. Wohlwill (eds.), Human Behavior and Environment. (Vol 2) New York: Plenum.

LeDoux, J. E. “Emotion, memory and the brain.” Scientific American 1994: 270:32-9.

Marshall, S.L.A. Men against Fire: the Problem of Battle Command. University of Oklahoma Press, 2000

McBreen, Major Brendan B. “Improving Unit Cohesion: The first step in Improving Marine Corps Infantry Battalion Capabilities” May 23, 2002 http://www.2ndbn5thmar.com/coh/iuc.htm

McCraty, Rollin, Dana Tomasino, Mike Atkinson and Joseph Sundram. Impact of the HeartMath Self-Management Skills Program on Physiological and Psychological Stress in Police Officers, , Publication No. 99-075, HeartMath Research Center, Institute of HeartMath. Boulder Creek CA, 1999.

Moody, James, and Douglas R. White. “Social Cohesion and Embededness: A Hierarchical Conception of Social Groups” From Manuscript Submitted to the American Journal of Sociology.

Norhthouse, P.G. Leadership: Theory and Practice. Thousand Oaks: Sage Publications, 1997.

Orasanu, Judith M. and Patricia Backer. "Stress and Military Performence." Stress amd Human Perfoemance. Ed. James Driskell and Eduardo Salas. New Jersey: Lawrence Erlbaum Associates. 1996.

Paterson, R. J., & Neufeld, R. W. J.,“Clear Danger: Situational Determinates of the appraisal of threats”, Psychological Bulletin Vol. 101 no. 3 , 1987: pgs 404-416.

Phipps, Jeremy J. J., Unit Cohesion: A Prerequisite for Combat Effectiveness. National Security Affair Issue Paper No. 82-3, Washington, DC: National Defense University, 1982.

Putnam, Ted. “The Collapse of Desisionmaking and Organizational Structure of Storm King Mountain. USDA Forest Service. Missoula Technology Development Center, February 1995.

Runciman, W.G., “Greek Hoplites, Warrior Culture, and Indirect Bias”, Journal of the Royal Anthropological Institute, Vol. 4:pgs 731-751.

Scanlon, Michael. "Acoustic Monitoring of First Responder's Physiology for Health and Performance Surveillance. U. S army Research Laboratory, Adelphi, MD.

Schachter, S. "The assumption of identity and peripheralist-central controversies in motivation and emotions" In Feelings and emotions M, Arnold (Ed.) New York: Academic Press. 1970.

Selye, H. "History and Present Status of the Stress Concept" In L. Goldberger and S. Breznitz (Ed.) Handbook of Stress: Theoretical and Clinical Aspects. New York: Free Press.

Selye, Hans. The Stress of Life. New York: McGraw-Hill 1956.

Shils, Edward A., and Morris Janowitz. "Cohesion and Disintegration in the Wehrmacht in World War II" Public Opinion Quarterly 12.2 (1948).

Siddle, Bruce K. Sharpening the Warrior's Edge: The Psychology and Science Of Training. Atlantic Books, 1995.

Siebold, Guy L. and Dennis R. Kelly. Development of the Combat Platoon Cohesion Questionaire. Technical Report 817. Alexandria, VA.: U.S. Army Research Institute, October 1988.

Silverman, Barry G. DRAFT TECHNICAL REPORT: More Realistic Human.

Steckel, Francis. "Morale and Men" Ann Arbor, MI University Micro Films International (1990).

Stewart, Nora Kizner. Mates & Muchachos: Unit Cohesion in the Falklands/Malvinas War. Washington: Brassey's (US), Inc., 1991.

This is a paraphrase of the definition for senior leadership found in Field Manual 22-100: Leadership and Command at Senior Levels, HQ, Department of the Army, Washington, D.C., June 1987, p. 3.

Vroom, V.H. and P.W.Yetton, Leadership and Decision Making,. Pittsburgh: University of Pittsburgh Press, 1973.

Warry, John. Warfare in the Classical World, Barnes and Nobel Books, New York, New York. 1998.

Watson, Bruce. When Soldiers Quit: Studies in Military Disintegration. Westport, CN: Praeger, 1997.

Weinburg, S.Kirson, " The Combat Neuroses." The American Journal of Socialogy" Vol. 51,No.5, Human Behavior in Military Society, March 1946: 465-478.

White, Douglas R. and Frank Harary. "The Cohesiveness of Block in Social Networks: Node Connectivity and Conditional Density", Sociological Methodology, Vol. 31. (2001), pp. 305-359.

Williams, Stephen, Managing Pressure for Peak Performance - the positive approach to stress, Kogan Page London 1994.

Wong, LTC Frederick G. "A Formula for Building Cohesion" Individual Essay. US Army War College, 1985.

Wu, Shelly. "Leadership Theories: Early Trait Approach". Leadership Theories: Definition and framework. March 1, 2002 About.com Psychology archives. . <Last visited March 2004>
http://www. psychology.about.com/library/weekly/aa040102b.htm

Wu, Shelly. "Leadership Theories: Behavioral Approach". Leadership Theories: Definition and framework. March 1, 2002 About.com Psychology archives. <Last visited March 2004>
http://www. psychology.about.com/library/weekly/aa040102c.htm

Xenophon. The Persian Expedition. Trans. Rex Warner. London: Penguin, 1972.

Yagil, Dana. A study of cohesion and other factors of major influence on Soldiers and Unit effectivness. Department of The Behavioral Science, Israeli Defense force, December 1990.

Yerks, RM & Dodson, JD. "The relation of strength stimulus to rapidity of habit formation" Journal of Comparative Neurology, 18. 1908, 459-482.

Yukl, G. Leadrship in Organizations. 4th Edition. New Jersey: Prentice-Hall Inc., 1998

Appendix 1 Results for Scenario 2 and 3

Scenario 2

The following graphs show typical results of scenario 2 of the validation experiments as described in section 4.5. Figure 32 shows the cohesion of the Spartan phalanx during an experimental run. Figure 33 show the cohesion of the other city state phalanx. It can be seen that at time 51 the phalanxes run into each other, producing an increase in cohesion as the ranks compress. At time 81 the Spartan phalanx begins to spread out into pre-contact formation as the other city state phalanx collapses. The Spartan phalanx begins to hit struggles and cohesion increases slightly. By time 111 the other city phalanx is running and the Spartan unit is reorganized and moves forward.

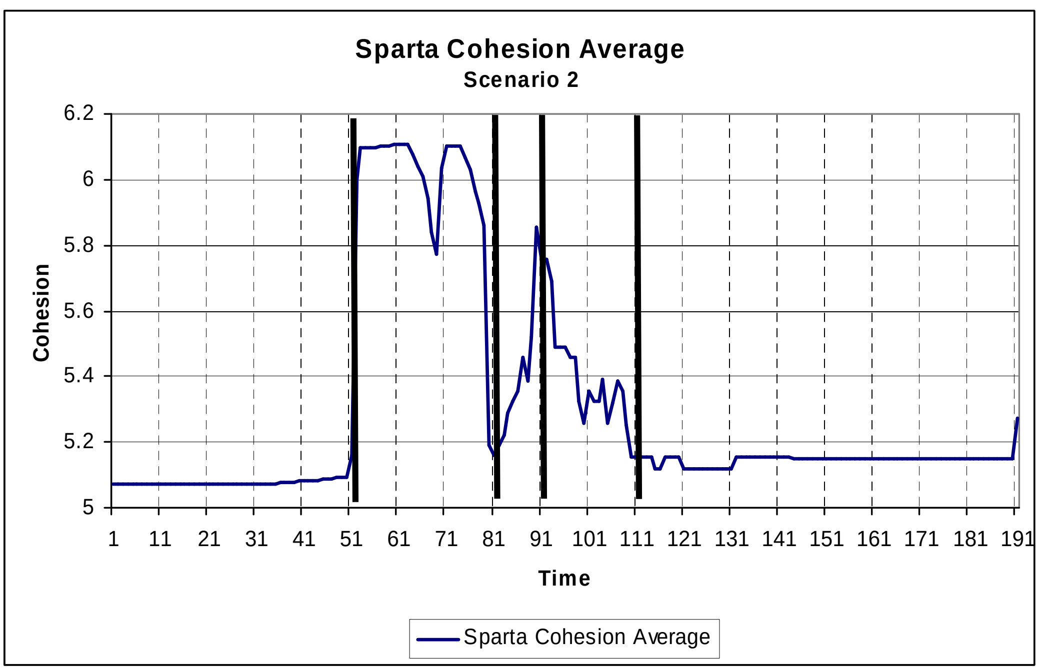


Figure 32. Scenario 2 Spartan Cohesion

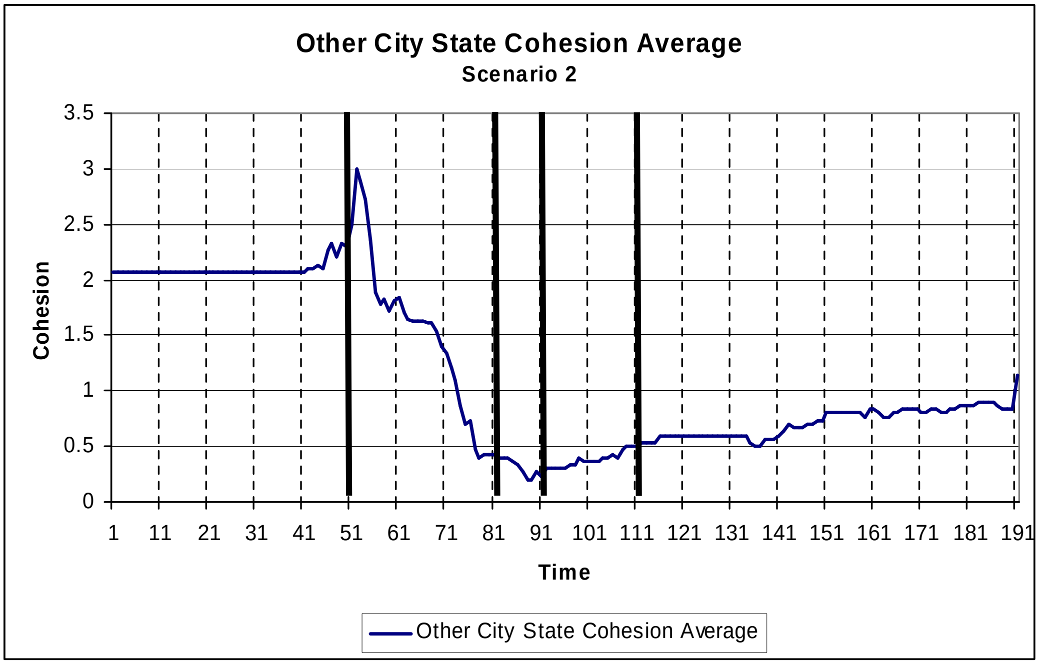


Figure 33. Scenario 2 Other City State Cohesion

Scenario 3

The following graphs show typical results of scenario 3 of the validation experiments as described in section 4.5. Figure 34 shows the cohesion of the Spartan phalanx during an experimental run. Figure 35 show the cohesion of the Theban phalanx. The two phalanxes contact at time 41, where the Theban phalanx gets compressed as seen in previous experiments. The Spartan phalanx does not show the same compression since the Theban column contacts only a small section of the front line. It takes until time 71 for there to be enough compression for the cohesion to increase. As the Theban column penetrates the Spartan phalanx the *Spartiates* troop in the front begin to be killed off and the cohesion drops as the *Peroeci* with lesser quality begin to enter the battle. These *Peroeci* begin to compress at about time 111, but by that time the unit begins to collapse and run. The Theban's begin to reorganize and move forward. The increase of Spartan cohesion at time 151 is due to some of the elite Spartiates grouping together and regaining order.

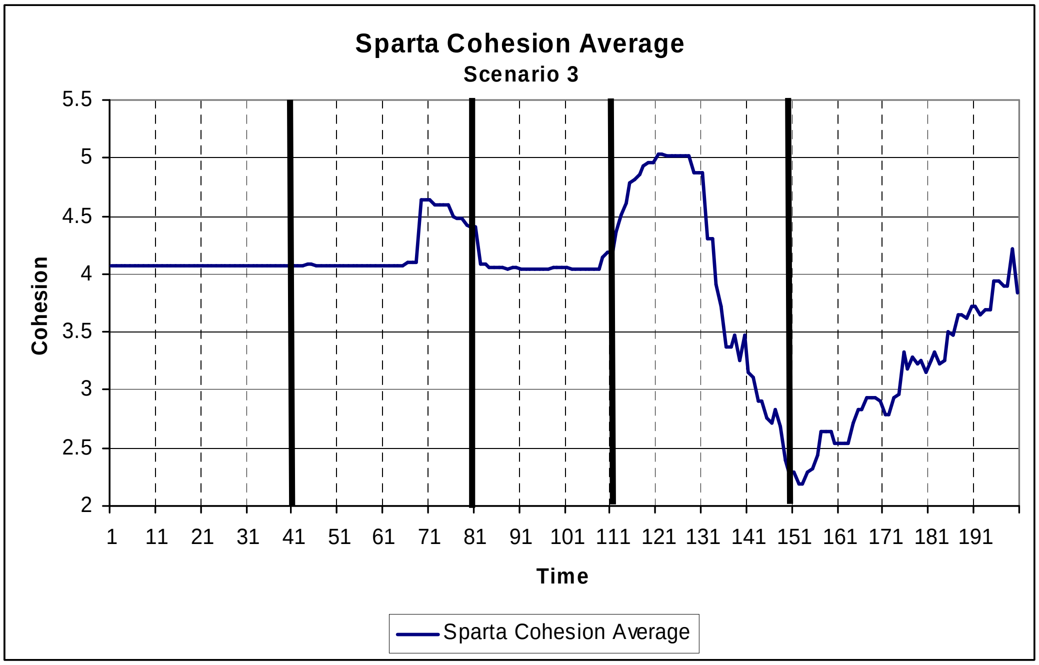


Figure 34. Scenario 3 Spartan Cohesion

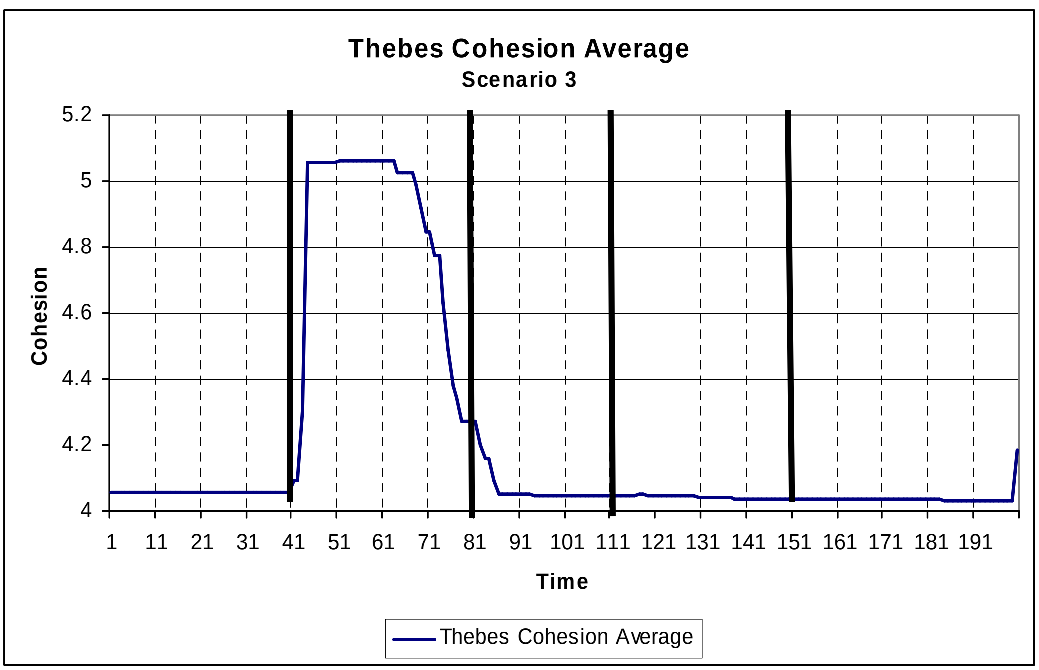


Figure 35. Scenario 3 Theban Cohesion

Appendix 2 Description of the Combat Model

The computer application created for this work depends on model of hand to hand combat. The combat model was not designed to be the definitive combat model but for simplicity. It however had to be complete enough to drive the action in the model and represent a reasonable interpretation of the spear armed combat used to implement the cohesion framework.

The combat model is based on three premises. The first is that a soldier must be within a defined combat radius for combat to be initiated. Second, the soldier has a chance of hitting either empty space or some part of an enemy's body when a spear is thrust into the space occupied by that enemy. The third is that once a part of the body is hit by the spear there is a specific amount of damage done depending on what part of the body is hit.

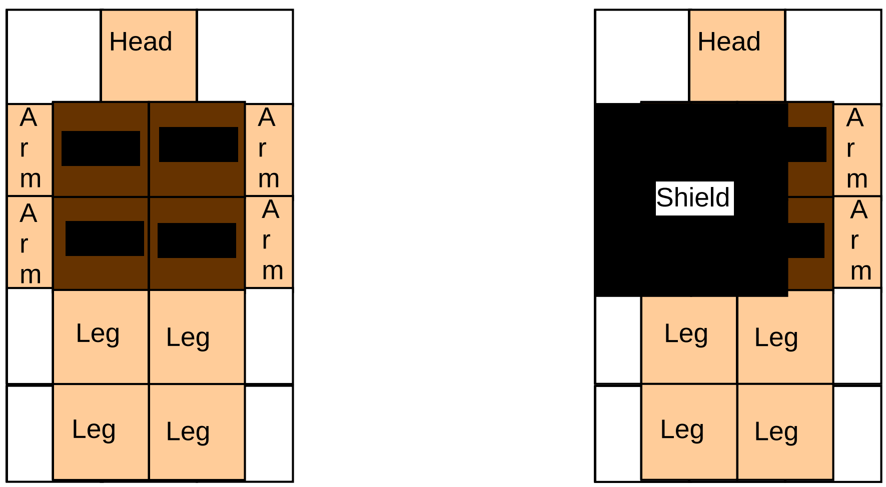
Since this model is designed for simplicity and convenience an ample scaling factor needs to be added to approximate the historical results necessary to validate the model. However once the scaling factor has been sufficiently applied it should be sufficient for any scenario.

Hitting the target[10]

Once a soldier is within the combat radius, combat is initiated and a random number is compared to a probability to hit an enemy. The chances of hitting an enemy on any given spear thrust is based on the relationships as seen in figure 36. The main target area is based on a graphic made up of 15 squares.

A representation of a soldier is overlaid on the squares and each body target part takes up a percentage of the total squares. Probability of hitting is 100% - chance of hitting space * scaling factor= 100% - 27% = 73% * .25 = 18.25%

Probability of hitting is modified by the stress level, training level and experience level to get a total chance to hit. The total chance to hit is compared to a random number from 1 to 100.   If the random number is less than a total chance to hit then damage is scored.



Total number of squares = 15
Number of empty spaces = 4
Number of head spaces = 1
Number of arm spaces = 2
Number of leg spaces = 4
Number of torso spaces = 4
Number of shield spaces = 5
Percent chance of hitting space = 4/15 = .27 * 100 = 27%
Percent chance of hitting body = 11/15 = .73 * 100 = 73%

Figure 36. Hit probability graphic. The graphic on the left shows the regions that could be hit. The graphic on the right show the regions that could be hit when a shield is added.

---

[10] This methodology is based on ideas presented by Andreas Tolk, in section 8 of MSIM620 - Introduction to Combat Modeling : "Human and Organizational Behavior Modeling," from the ODU M&S curriculum.

Once damage is successfully caused, the amount of damage is assessed and a location and the amount of damage inflicted need to be calculated. First, there is a 40% chance that the hit location will be the shield. If this occurs there will be no damage. This indicates the shield has protected the soldier. If the shield is not hit the location on the body is based on the ratio of possible spaces that can be hit.

Table 23. Chances to hit a shield during an attack

Location	Chance to hit
Shield	40%
Non shield	60%

Table 24. Chances to hit a given body part during an attack

Location	Chance to hit
Head	10%
Chest	18%
Abdomen	18%
Arm	18%
Leg	36%

Causing damage

Damage to an area that is to be hit can range from severe to critical. The type of injury is based on the AIS trauma assessment score used by trauma clinics to assess damage (see table 25). The amount of damage is incremental as the severity of the injury increases (see table 26). The amount of damage is based on a random number representing the amount of damage (i.e. if the hit is in the head there would be a possibility of receiving from 40 to 60 hits). This amount would them be subtracted from the total 100 hit points given to each soldier. When the hit points reach zero, the solider is designated as dead and an appropriate graphic is displayed to represent that state.

Table 25. AIS trauma injury score

AIS Score	Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical

Table 26. Amount of damage based on severity of injury

Hit Location	Damage range				
	minor	moderate	serious	severe	critical
Head	40	48	52	56	60
Chest	20	28	32	36	40
Abdomen	10	12	14	16	20
Leg	5	6	7	8	10
Arm	1	2	3	4	5

Future combat models

To improve the combat in this application a more realistic combat model could be created. This would include a higher level of fidelity of the action between the soldiers. In reality the soldier would fence each other with spears and move to avoid injury. The physics of the penetrations and the protection of armor could be recreated. However, this is not in the scope of this work.

An additional component that would improve the combat model is the improvement of the physical fidelity of the combat. Having the momentum of the pushing of opponents shield against each other and the additional force of soldiers in the second rank pushing their comrade in the front rank would add more fidelity to the combat model. Below are some references that can assist in future combat models of this type.

- *For models of the physics of phalanx warfare:*

Modeling Hoplite Battle in Swarm [Thesis]
Robert McDermott, Massey University, New Zealand. November 2004.
www.ddv.co.nz/**hoplites**/media/rob_mcdermott_honours_modelOfHopliteBattle.pdf

- *For the physics of spears in ancient warfare*

An evaluation of the effectiveness of three methods of spear grip used in antiquity.
Peter Connolly, David Sim and Celia Watson. Journal of battlefield technology, Vol. 4 No2 July 2001. pages 49-54.

- *For force of impact of ancient weapons*

How hard does it hit? A study of AtlAlt and dart ballistics.
Daryl Hrdlicka. Jeffers Petroglyphs Historical site October 29 2004.
http://www.thudscave.com/npaa/artcles/howhard.htm

- For effectiveness of armor against missile weapons

The metallurgy and relative effectiveness of arrow heads and armor during the middle ages.
Peter N. Jones. Material Characterization. Vol. 29 Issue 2 September 1992 pages 111-117

Appendix 3 Factorial experiment combinations

Table 27 The 4x5x5 Full Factorial Replicated Twice and Presented in Random Order

Experiment number	Social Cohesion Value	Experience level	Training level
1	2.Green	4.veteran	6.Grand mastery
2	4.Veteran	3.regular	2.Proficient
3	1.Recruit	2.green	6.Grand mastery
4	1.Recruit	1.none	1.No training
5	2.Green	3.regular	5.Mastery
6	2.Green	2.green	3.Expert
7	4.Veteran	2.green	3.Expert
8	2.Green	5.old veteran	5.Mastery
9	1.Recruit	5.old veteran	1.No training
10	1.Recruit	3.regular	1.No training
11	3.Normal	5.old veteran	5.Mastery
12	2.Green	1.none	2.Proficient
13	2.Green	3.regular	3.Expert
14	1.Recruit	1.none	2.Proficient
15	3.Normal	2.green	5.Mastery
16	3.Normal	4.veteran	4.Specialized
17	4.Veteran	4.veteran	3.Expert
18	1.Recruit	3.regular	3.Expert
19	3.Normal	2.green	4.Specialized
20	1.Recruit	4.veteran	3.Expert
21	3.Normal	3.regular	1.No training
22	2.Green	1.none	6.Grand mastery
23	4.Veteran	1.none	1.No training
24	3.Normal	1.none	6.Grand mastery
25	1.Recruit	2.green	2.Proficient
26	1.Recruit	5.old veteran	6.Grand mastery
27	2.Green	1.none	1.No training
28	4.Veteran	1.none	4.Specialized
29	3.Normal	5.old veteran	2.Proficient
30	1.Recruit	2.green	1.No training
31	3.Normal	4.veteran	1.No training
32	4.Veteran	3.regular	6.Grand mastery
33	1.Recruit	3.regular	6.Grand mastery
34	3.Normal	4.veteran	6.Grand mastery
35	3.Normal	3.regular	5.Mastery
36	3.Normal	3.regular	3.Expert

Experiment number	Social Cohesion Value	Experience level	Training level
37	1.Recruit	1.none	4.Specialized
38	1.Recruit	2.green	5.Mastery
39	4.Veteran	4.veteran	5.Mastery
40	3.Normal	5.old veteran	4.Specialized
41	4.Veteran	2.green	1.No training
42	3.Normal	1.none	4.Specialized
43	3.Normal	1.none	1.No training
44	4.Veteran	4.veteran	2.Proficient
45	1.Recruit	5.old veteran	4.Specialized
46	4.Veteran	5.old veteran	2.Proficient
47	1.Recruit	2.green	4.Specialized
48	1.Recruit	1.none	5.Mastery
49	1.Recruit	4.veteran	4.Specialized
50	3.Normal	3.regular	6.Grand mastery
51	3.Normal	1.none	5.Mastery
52	1.Recruit	4.veteran	2.Proficient
53	3.Normal	5.old veteran	1.No training
54	2.Green	4.veteran	1.No training
55	3.Normal	1.none	2.Proficient
56	2.Green	3.regular	6.Grand mastery
57	1.Recruit	3.regular	2.Proficient
58	1.Recruit	5.old veteran	3.Expert
59	3.Normal	4.veteran	2.Proficient
60	4.Veteran	1.none	2.Proficient
61	4.Veteran	5.old veteran	1.No training
62	4.Veteran	3.regular	3.Expert
63	4.Veteran	1.none	3.Expert
64	4.Veteran	3.regular	1.No training
65	1.Recruit	5.old veteran	2.Proficient
66	3.Normal	3.regular	4.Specialized
67	2.Green	2.green	6.Grand mastery
68	4.Veteran	1.none	5.Mastery
69	4.Veteran	2.green	5.Mastery
70	3.Normal	4.veteran	3.Expert
71	2.Green	1.none	3.Expert
72	3.Normal	3.regular	2.Proficient
73	3.Normal	2.green	2.Proficient
74	2.Green	5.old veteran	3.Expert
75	1.Recruit	3.regular	4.Specialized

Experiment number	Social Cohesion Value	Experience level	Training level
76	3.Normal	4.veteran	5.Mastery
77	2.Green	4.veteran	3.Expert
78	2.Green	5.old veteran	2.Proficient
79	4.Veteran	5.old veteran	6.Grand mastery
80	2.Green	5.old veteran	6.Grand mastery
81	4.Veteran	5.old veteran	5.Mastery
82	4.Veteran	2.green	6.Grand mastery
83	1.Recruit	4.veteran	1.No training
84	3.Normal	5.old veteran	6.Grand mastery
85	1.Recruit	2.green	3.Expert
86	2.Green	3.regular	1.No training
87	2.Green	4.veteran	4.Specialized
88	4.Veteran	4.veteran	4.Specialized
89	1.Recruit	3.regular	5.Mastery
90	2.Green	2.green	2.Proficient
91	4.Veteran	3.regular	5.Mastery
92	4.Veteran	5.old veteran	3.Expert
93	4.Veteran	4.veteran	6.Grand mastery
94	1.Recruit	1.none	3.Expert
95	2.Green	4.veteran	5.Mastery
96	3.Normal	5.old veteran	3.Expert
97	4.Veteran	2.green	4.Specialized
98	2.Green	3.regular	4.Specialized
99	4.Veteran	2.green	2.Proficient
100	2.Green	5.old veteran	4.Specialized
101	3.Normal	2.green	1.No training
102	2.Green	2.green	4.Specialized
103	2.Green	2.green	5.Mastery
104	1.Recruit	4.veteran	6.Grand mastery
105	2.Green	1.none	5.Mastery
106	2.Green	5.old veteran	1.No training
107	2.Green	2.green	1.No training
108	4.Veteran	1.none	6.Grand mastery
109	1.Recruit	5.old veteran	5.Mastery
110	3.Normal	2.green	6.Grand mastery
111	3.Normal	1.none	3.Expert
112	2.Green	3.regular	2.Proficient
113	3.Normal	2.green	3.Expert
114	1.Recruit	1.none	6.Grand mastery

Experiment number	Social Cohesion Value	Experience level	Training level
115	4.Veteran	5.old veteran	4.Specialized
116	2.Green	1.none	4.Specialized
117	2.Green	4.veteran	2.Proficient
118	4.Veteran	4.veteran	1.No training
119	1.Recruit	4.veteran	5.Mastery
120	4.Veteran	3.regular	4.Specialized

Appendix 4 Source code and Data files

The source code for the three validation experiments as well as the data for the experimental runs are provided on the CD included with this work. To run the application Java runtime Environments SE v1.4.2_03 is required. This can be downloaded through the Sun Microsystems site:

http://www.java.com/en/download/index.jsp

The CD that accompanies this work contains:

- ❖ Java source code fro the three validation scenarios
- ❖ Jar executable files of the three scenarios
- ❖ Data files of the results of the validation experiments
- ❖ Graphics used for the visualization of the experiments

The files are organized by subject. Code for the scenario 2 will be stored in Spartavothers subdirectory. The Data subdirectories contain the files in Excel format and are organized similar to the subject folders.

Vita

Curriculum Vita
For
William Eugene Warner

Degrees

Doctor of Philosophy (Engineering with Concentration in Modeling and Simulation), Old Dominion University, Norfolk, VA 2006

Master of Engineering (Modeling and Simulation) Old Dominion University, Norfolk, VA 2000

Bachelor of Science (Mechanical Engineering Technology) Old Dominion University, Norfolk, VA 1998

Professional Chronology

Northrop Grumman Newport News
Senior Engineer March 2000 – present

Ciba Specialty Chemicals
Production Engineer March 1996- March 2000

Allied Colloids
Junior Engineer March 1991 – march 1996

Vansant and Gusler Associates
HVAC Engineer March 1988 – March 1991

Scholarly Activities Completed

William E Warner. 2004 Representation of cohesion in small combat unit during a combat incident. *Proceedings of the 13th BEHAVIOR REPRESENTATION IN MODELING AND SIMULATION.* Pages 359-367