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The Effects of Cold Weather On Tactical Operations

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The study of weather effects on tactical military operations has focused almost exclusively on human factor; with the majority of those efforts addressing the effects of hot temperatures. Considerably less effort has been devoted to man/machine factors, and less yet to integration of known weather effects into commonly used training and analysis simulations. Through a survey of human factors studies, exploration into cold weather effects in a combat simulation, the need is highlighted for additional research.

Four experiments were conducted to measure the effects of snow cover in a widely used Army combat simulation. Experiments focused on degrading the mobility for frozen ground and for 7 and 14 inches of snow. Speed predictions were provided by a high resolution mobility model.

From a mounted operations perspective, cold weather and snow can affect many factors. This study concentrated simply on one of those factors - mobility. Mobility degradation due to snow produced a predictable effect (i.e., the enemy had more time to acquire, track, and kill the blue force). In summary, this study mechanized units move from a no-snow to a snow environment. However there is no significant difference in effectiveness between the 7-inch and 14-inch levels.

This study examined only one factor, mobility due to snow conditions. Further research should be directed towards assessing the synergistic effects of human factors and man/machine effects during cold weather. A studied directed at quantifying the effects of cold weather with regards to countermobility and mine warfare would be of interest. Atmospheric conditions unique to cold weather also warrant attention. Detections and laser effectiveness are two areas that may be studied.

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Acknowledgments

The Department of Systems Engineering (DSE), United States Military Academy (USMA), West Point, New York, is supporting the U.S. Army Cold Regions Research Engineering Laboratory (CRREL) in assessing the effects of cold weather on tactical operations. The DSE developed a combat simulation scenario used to assess how cold weather affected mobility and countermobility during a combined arms operation in North Korea. In addition, the department of Behavioral Science and Leadership (BS&L) conducted a literature survey in an effort to assess how cold weather affects mounted and dismounted operations from a human factors perspective.

The work described herein was conducted by faculty and students in both the DSE and BSL. Cadets Gregory S. Fortier and Kevin D. Lilly along with Mr. Paul West, Director of the Combat Simulation Laboratory, developed the scenario and conducted the analysis of the simulation results. Cadet Gerald D. Ingalls, under the supervision of MAJ Joseph P. DeAntona, BSL, conducted the literature survey as related to the human factors aspects of cold weather. The NATO Reference Mobility Model predictions were provided by the Mobility Systems Divison, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. Dr. John V. Farr, DSE, served as the senior investigator and wrote this report with input from the cadets and Mr. West. This work was conducted under the general supervision of COL James L. Kays, PhD, Professor and Head, DSE, USMA. MAJ Bruce Gwilliam served as the technical monitor of this work at CRREL.

Executive Summary

The study of weather effects on tactical military operations has focused almost exclusively on human factors; with the majority of those efforts addressing the effects of hot temperatures. Considerably less effort has been devoted to man/machine factors, and less yet to integration of known weather effects into commonly used training and analysis simulations. This study begins that integration. Through a survey of human factors studies, exploration into cold weather effects on mobility and countermobility, and analysis of cold weather effects in a combat simulation, the need is highlighted for additional research.

Four experiments were conducted to measure the effects of snow cover in a widely used Army combat simulation. Experiments focused on degrading the mobility for frozen ground and for 7 and 14 inches of snow. Speed predictions were provided by a high resolution mobility model.

From a mounted operations perspective, cold weather and snow can affect many factors. This study concentrated simply on one of those factors – mobility. Mobility degradation due to snow produced a predictable effect (i.e., the enemy had more time to acquire, track, and kill the blue force). In summary, this study suggests there is sharp decrease in offensive effectiveness as mechanized units move from a no-snow to a snow environment. However there is no significant difference in effectiveness between the 7-inch and 14-inch levels.

This study examined only one factor, mobility due to snow conditions. Further research should be directed towards assessing the synergistic effects of human factors and man/machine effects during cold weather. A studied directed at quantifying the effects of cold weather with regards to countermobility and mine warfare would be of interest. Atmospheric conditions unique to cold weather also warrant attention. Detections and laser effectiveness are two areas that may be studied.

Table of Contents

List of Tables

List of Figures

List of Figures (continued)

The Effects of Cold Weather On Tactical Operations

1. Introduction

1.1 Background

Few will argue in the wake of nine years of downsizing the Army, major reductions in overseas bases, proliferation of weapons of mass destruction, the increased potential for major and minor regional conflicts, and the increased number and types of missions presently conducted by the Department of Defense (DoD), that the Army of the 21st Century must be mobile, flexible and operate under a wide range of operational and environmental conditions anywhere in the world. As shown in Figure 1.1, military operations for areas of strategic interest to include the former Soviet States, the Korean peninsula, and other countries along the northern Pacific rim will be conducted during periods of extreme cold weather. Towards this end, this study was undertaken in an attempt to quantify the effects.

A study based upon the results of a combat simulation was conducted using a US style battalion attacking a former Soviet style company using North Korean terrain. The effects of winter conditions were analyzed with regards to mobility. The effects of winter conditions on factors such as sensors, human factors, countermobility (mine warfare) and artillery effectiveness were not modeled in the simulation mainly because of a lack of data quantifying the effects. Also, because cold weather affects military operations differently, the more variables introduced into the problem, the harder it became to quantify any effect. Some preliminary simulations were conducted that included the effects of both mobility and mine warfare. However, these results were inconclusive because, in general from a blue attacking red, cold weather impedes blue mobility, but decreases the effectiveness of red mines. Thus, the aggregated effects of two negating factors contributed to inconclusive simulation results. Some research was conducted into these areas and is presented because of the need to quantify their effects for future simulation and to archive the research.

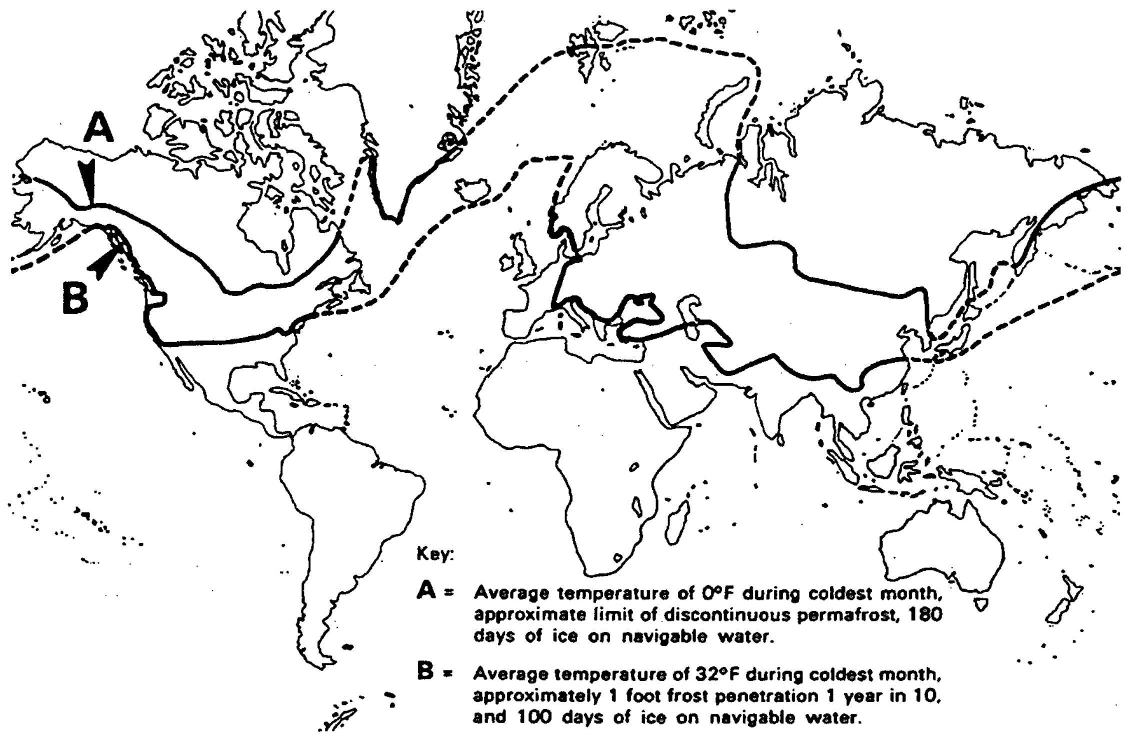

Figure 1.1 Northern regions average temperatures (from Richmond, 1991)

1.2 Scope

Chapter 2 contains an overview of the literature survey of the effects of cold weather on various aspects of military operations. Emphasis was placed on mobility for this effort because the Cold Regions Research Engineering Laboratory (CRREL) has that mission within the DoD. Chapter 3 presents the combat modeling simulation results. Chapter 4 presents the summary and conclusions. Appendix A contains vehicle speed predictions from a high resolution model that were used for input to the combat simulation model. Appendices B through H contain results from the combat simulation model.

2. Overview of the Effects of Cold Weather On Mounted Operations

2.1 Introduction

A significant amount of research has been conducted with regards to the effects of winter conditions as related to human factors (see Section 2.4). Also, research has been conducted into how cold weather affects individual aspects of equipment as part of the test and evaluation process. However, no research was identified that addresses how winter conditions degrade or enhance equipment and personnel during combat in either the defense or offense, how knowledge of cold weather can be used as a force multiplier, and what additional research is needed to capture the "true" effects of cold weather on combined arms operations. This research was directed at trying to address some of these issues.

Because of the complexity of the human factors aspect of the problem and the doctrine of modern warfare, the research contained in this report was directed mainly at mounted combat operations. However, the effects of cold weather on dismounted operations is probably more significant because of human factor issues.

Many issues regarding cold weather need to be addressed for the research and development community. For example, as part of the research for this project, an informal survey of mechanized officers was conducted to determine whether they would utilize heaters in their vehicles during combat operations in extreme cold weather. This was important because human factors type issues would be less relevant if the heaters were utilized. Even though the thermal signature is dramatically increased (Richmond, 1991), some officers stated they would still use their heaters. Simple doctrinal issues such as these, along with equipment and personnel issues, must be resolved before the true capabilities and limitations of the U.S. Army can be ascertained in a cold weather environment.

2.2 Mobility

Modern mechanized combat requires agility, depth, and synchronization - all of which depend on the freedom to maneuver. In addition to steep slopes, vegetation, dry and water-filled gaps, etc., cold weather and snow can also severely affect mobility on the battlefield. Since agility and maneuverability are the keys to survivability, the degradation of mobility due to snow, and in some instances the improvement due to frozen conditions, must be accounted for in planning and modeling tactical operations and evaluating new equipment.

A significant amount of research has been conducted into how winter conditions affect vehicle mobility (see Richmond, 1991). The North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM) has algorithms for predicting mobility under winter conditions (Ahlvin and Shoop, 1995, or Richmond, Shoop, and Blaisdell, 1995). In general

- on well-frozen ground with minimal snow cover, mobility is excellent,
- marginally frozen soils breakdown under traffic and reduce mobility,
- trafficability during thaws or heavy snow deteriorates, especially for wheeled vehicles, and
- for large snow falls, mobility is decreased for all vehicles because of the increased motion resistance.

2.3 Countermobility

2.3.1 Mine Warfare

Mines are an important element of modern warfare. In the defense, mines improve survivability if the mines are effectively employed and covered by direct and indirect fire weapons. The synergistic effects of covering fire and mines are an important aspect of combined arms operations.

Winter conditions in general decrease the effectiveness of mines. However, little physical research has been conducted to quantify the effects. In general the literature and subject matter experts contend that

- heavy snow depths attenuate the blast for both snow surface (on top of the snow) and ground surface (on the ground surface but covered by snow) laid mines,
- the effectiveness of mines buried in the ground and covered by snow is dramatically reduced because of bridging of the frozen ground above the mine,
- as shown in Figure 2.1, snow depth can dramatically affect tilt rod mines,
- magnetic induced mines are very unreliable when covered with snow, and
- the effectiveness of scatterable mines deployed in a layer of snow is dramatically reduced because of reorientation during deployment and snow melting (see Richmond, 1989 and Figure 2.2) and the blast attenuating effects of snow.

Note that no quantifiable values describing the decreases in mine effectiveness either buried or on top of the snow was located in the literature.

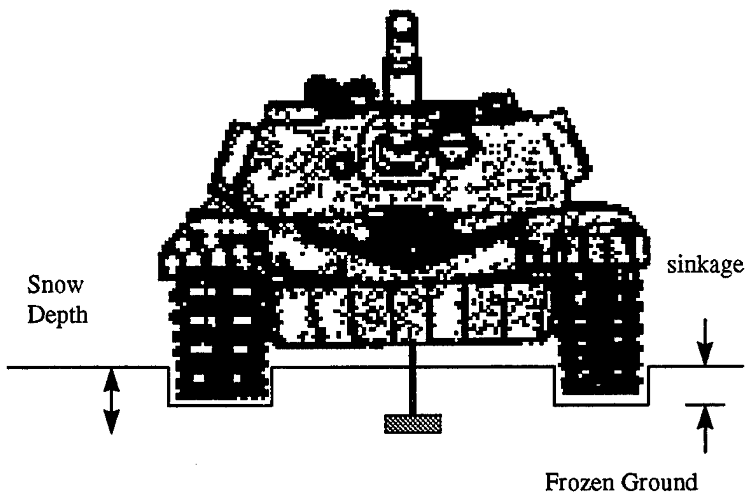

Figure 2.1 Effects of snow on tilt rod mines

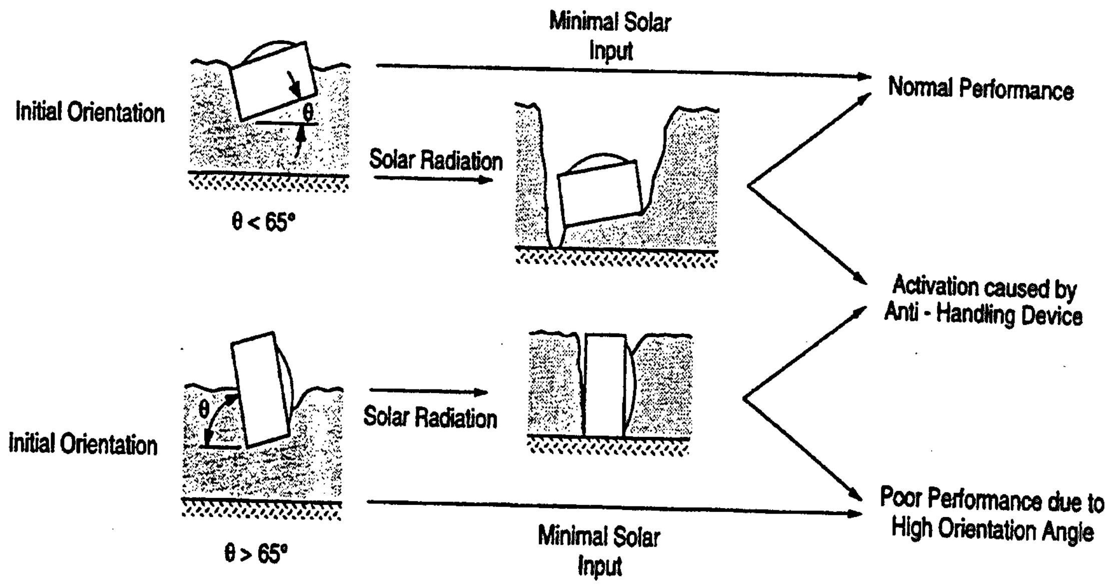

Figure 2.2 Scatterable mines in snow (from Richmond, 1989)

2.3.2 Countermine Operations

The main concern for both the offense and the defense is the ability to quickly and effectively clear mines. If an attacking force clears the mines quickly, they can swiftly move through the obstacle and eliminate heavy casualties. On the other hand, an inability to clear the minefield, especially in snow, gives the advantage to the defending force as they can call in artillery or concentrate their direct fire weapons on the attacking force. Like mine operations, little defensible research has been conducted in this area. For example, plows are probably ineffective when a significant amount of snow exists on the ground. We assert this because of the uncertainty of where the actual mines are as well as the inability to serve as not only a mine-clearing device but a snow plow as well. In general during winter conditions

- mines cannot be removed using either plows or line clearing devices,
- the effectiveness of rollers will be dramatically reduced because the tanks will have a hard time overcoming the motion resistance of the roller, and

- the effectiveness of explosive clearing equipment such as the mine clearing line charge (MICLIC) will be dramatically reduced because the snow will attenuate the blast, and
- hand clearing will also be difficult because of the visual detection problems and the effects snow will have on the equipment.

Again, no quantifiable research was identified to substantiate these assertions.

2.4 Human Factors

2.4.1 Introduction

Historically, soldiers have had to fight their battles and wars under all weather conditions, ranging from the extremely hot to the extremely cold. Vast amounts of research have been done on the effects of the heat on the ability of soldier's to function in hot climates. This research has been beneficial to U.S. operations throughout the world, more recently in the deserts of the Persian Gulf during Operation Desert Shield/Desert Storm. With continued military focus on areas of the world such as Bosnia and North Korea, research on the hindering effects of the cold and determine the effects of the cold weather climate on a soldier's ability to function in both a mechanized and dismounted operations is needed.

2.4.2 Literature Review

Kobrick and Fine (1983) referenced 96 studies focusing on thermal stress and evaluated them to determine the validity of the study's results. Of these, only 17 concerned the effects of cold weather, whereas the other 79 addressed effects of hot temperatures. They concluded that "no conclusions can be drawn about the effects of cold on categories of tasks other than manual dexterity," although trend they found manual dexterity impaired at and below 55°F.

Lockhart, Kiess, and Clegg (1975) developed a table listing the mean percentage of decrement from control performance. As shown in Table 2.1, there is a significant decrement occurring around 55°F with all tasks and a larger decrement at 48°F. The tasks were all manual performance tasks and this article not only gives empirical evidence for a cold weather effect, but it also shows how as the temperature gets colder the performance continues to decrease. The findings from this article distinguish between the different aspects of manual performance and test each with an appropriate task. The manual dexterity task showed a 4% decrement at 55°F and a 10% decrement at 48°F. Other aspects include finger dexterity, wrist-finger speed, aiming, and speed of arm movement. The largest decrement was found in finger dexterity that went from a 21% decrement at 55°F to a 45% decrement at 48°F. All of the other results (e.g. wrist-finger speed, aiming and speed of arm movement) lie between the results of manual dexterity and finger dexterity.

Task	Surface Temperature			
	Cooling Rate	65°	55°	48°
Block packing			4	10
Block stringing	fast			12
	slow		12	30
Craik screw	fast		14	14
	slow		14	27
Knot tying			12	28
Purdue Pegboard	fast		8	29
	slow	8	21	45
Screw Tightening		7	20	37

Table 2.1 Mean percentage of decrement from control performance

Horvath and Freedman (1947) published a report which focused upon the soldier's hands in cold weather and their efficiency in continually using them to handle and repair weapons and personal equipment. In this research, a 7.5% decrement in finger dexterity when writing with a pencil performance was found at a temperature of -20°F. They described finger dexterity as the "abilities to approximate the fingers and to flex and straighten the basal joints." Additionally, they found an average decrease in grip strength of about 28% at a temperature between -10°F and -14°F. Horvath and Freedman (1947) appeared to have found a parallel between strength and dexterity and stated "In general, interference is greater for the man with the smaller grip strength and least for the man with the greater grip strength." This is important to the mechanized soldier in performing his tasks because with a loss of grip strength or dexterity the soldier will not be able to perform to the same level in the cold environment as he does in the warm environment. Whereas with the dismounted soldier, his grip strength will be of less importance since he has less interaction with mechanical devices, so this variable will have less of an impact upon his performance.

Riley and Cochran (1984) used the Purdue Pegboard score and finger tapping ratio to look at manual and finger dexterity respectively. There were decrements in both categories. When the temperature was dropped from 75°F to 55°F there was a 2.2% decrement in manual dexterity and 0.5% decrement in finger dexterity. From 55°F to 35°F there was a 15.5% decrement in manual dexterity and a 2.4% decrement in finger dexterity. From these results, it is evident that there is a significant decrement at 35°F for manual dexterity. From this research, it would be interesting to further examine at what exact temperature the significant decrement occurs.

Rogers and Noddin (1984) presented research that showed finger dexterity, manual dexterity and steadiness tests were significantly degraded by the cold. The worst performance occurred at 14°F, with a gradual decline in performance up to then. These findings are consistent with the results from the findings of Rogers, et al. (1982) study. Bensel and Lockhart (1974) support these results as well in that they found that at 20°F manual performance was adversely affected and performance worsened with continued cold exposure. Additionally, they found that the wearing of gloves decreased finger dexterity and manual dexterity. This interaction states that in the cold environment both finger and manual dexterity are going to be diminished. Although wearing gloves will cause a decrement in performance, it is not to the same extent that mere exposure will cause decreased performance. "The decision to wear gloves or not for finger dexterity, manual dexterity, and wrist-finger speed tasks would depend on the criticality of the task: since performance could be worse with gloves than with bare hands, a particularly critical task might be performed bare-handed to minimize the decrement even though this poses more of an injury threat."

Meese, et al. (1984) stated that "performance in the cold is likely to be affected by reduced dexterity and flexibility, loss of finger-tip sensitivity, lowered muscle temperature and the distraction/arousal effects which probably occurred at [43°F and 54°F]." Morton and Provins (1960) had varying results in their study, stating that they were tentative to announce significant conclusions, nor could one show a general relation between finger numbness and skin temperature, because of the vast individual differences between subjects. Although neither of these articles gave solid conclusions, within them lies information that aids in explaining why manual performance is decremented by the cold. In Enander's (1984) review of cold weather research, she stated that the loss of tactile sensitivity was a common experienced effect of the cold. Enander found that there was a "sharp critical limit" in skin temperature at which performance deteriorates markedly. Provins and Morton (1960) found a significant impairment at 39.2°F, but not at 42.8°F. Hellstrom (1965) found this critical temperature to be higher, around 53.6°F. One gets a more holistic view of the whole process of why manual performance is decremented by the cold when looking at the physiological affects when the hands are cooled to these critical temperatures. As the hands get colder there is a continued decrement in performance.

An additional factor behind the decrement of manual performance is the amount of time required to perform the task. Clark and Jones, (1962) found that "cold exposure resulted in an increase of 3 seconds in manual performance during all phases of training...." They found that the subject's performance in tying knots suffered a 16% decrement when the hands were cooled at 10°F versus under warm-hand conditions.

Payne (1959) published research on monitoring a complex display while simultaneously controlling the activities of four independent instrument systems. The results from this research on cognitively demanding tasks found that the effect on systems due to cold stress were acute under the 40°F condition versus the 55°F and 70°F conditions. Not only was there a 25% decrement in tracking performance, there were also other less empirical and more subjective results. For example, four subjects resigned from the experiment while many other subjects made unflattering remarks about the laboratory, the equipment and the lab technicians. "Many subjects in the 40°F group went through seemingly excessive periods in which they appeared to ignore one or more instrument systems, meanwhile concentrating efficiently on the remaining ones." The subjects complained of pain and stiffness and avoided making contact with the control panels with their fingertips and instead they would use their shoe tips." The general picture of thought and action thus appeared as one of strong desire to withdraw from the situation. As can be seen, there is a definite cognitive decrement, but there is a lack of supporting empirical evidence.

Enander (1987) gives a good basis of understanding in how the cold environment can hinder our cognitive ability to function. She found significant decrements in the cold as there was an increase in the number of errors and speed of incorrect responses. The results of the experiment indicate that the cold is having a negative effect centrally, rather than purely on manual dexterity. The effects of cold on complex performance historically have been explained through the "distraction" and "arousal" theory. According to the theory of distraction, the cold stress causes "momentary switches of attention away from the primary task." Essentially, the distraction theory suggests that cold stress diverts our attention away from the primary task and possibly even transfers the importance of that task as secondary to getting warm. As the temperature gets colder we have a natural tendency to lose sight of our primary goal and get preoccupied by how cold we are and how we would like to find a way to get warmer. The theory of arousal "predicts effects dependent on the degree of stimulation in relation to task difficulty and subject experience." It looks at how a subject's experience level and the task's difficulty level cause the subject to become aroused, hence, at how they perform the assigned task. The theory of distraction is the more prevalent of the two as researchers use it to explain the unknown variable of why our cognitive abilities are decremented in a cold climate.

2.4.3 Summary

As seen, minimal research has been done concerning how the cold affects a soldier's ability to perform mechanized and dismounted operations. Within the research available, a majority of it has been conducted in relation to manual performance, specifically, manual dexterity, finger dexterity, grip strength, and tactile sensitivity. Although some research has been done concerning more central and complex functions such as our cognitive abilities, more research must be done in this area to successfully draw any significant conclusions. This research assists us in our understanding of what happens to a soldier in a cold climate, yet it is not conclusive to the significance or amplitude of its effect. A qualitative assessment of the effects drawn from this research on cold weather on battlefield functions is shown in Table 2.2.

Battlefield Function	Mounted Operations	Dismounted Operations
Manual Dexterity		
- firing weapons	marginal	marginal
- reloading magazine	significant	significant
- manipulating mechanical devices	significant	marginal
- cleaning weapons	significant	significant
- common tasks	marginal	marginal
Sensory Functions		
- acquiring targets	insignificant	marginal
Cognitive Reasoning		
- identifying targets	marginal	marginal
- vigilance tasks	significant	significant
- proper decision making	marginal	marginal

Table 2.2 Qualitative degradation estimates for winter operations

Other concerns during mechanized operations are finger dexterity, grip strength and tactile sensitivity. All of these areas are decremented by colder temperatures. Grip strength has negative implications with the mechanized infantry because of all of the mechanical parts. A limited grip strength can make it very difficult to do the tasks requiring the strength one had initially in the warmer environment. Horvath and Freedman (1947) talk about their concerns with loss of grip strength in mechanized personnel. They provide the following example, "nuts and bolts tightened in a warm environment could not be loosened by a cold hand nor tightened sufficiently to prevent a mechanical breakdown." Due to the lack of proper feedback between the hand and the machinery, the loss of tactile sensitivity as the temperature decreases is a major concern for both the mechanized and dismounted infantry. Since the blood is pooling in the core of the body away from the appendages, and with the changes in the mechanical properties of the skin, we can predict the loss of sensation and nerve conduction in the fingers. Overall, all of these factors come together to cause a decrement in manual performance, which will cause a significant effect on the soldier's ability to perform both mechanized and dismounted operations.

Robust conclusions concerning the cold weather effect upon cognitive abilities are difficult to make. The distraction theory can be used to explain trends in behavior. As the temperature gets colder we have a natural tendency to lose sight of our primary goal and get preoccupied by how cold we are and how we would like to find a way to get warmer. This, in itself, is the distraction theory because the cold stress is diverting our attention away from the primary task and possibly even transferring the importance of that task as secondary to getting warm. It is important to note that this detriment in cognitive abilities can have a large impact on many subjective variables ranging from reaction times to a leaders ability to make a decision or develop a course of action. Dealing with these variables is very complex and difficult to simplify into an equation or trend. A final factor to consider is that every individual is affected differently by the cold in that some individuals have higher tolerances than others. When we can develop research to determine how the cold truly affects our cognitive abilities and how individuals adapt personally, we will be able to generalize to how it affects the soldier's ability to conduct and execute his mission.

2.5 Other

2.5.1 Visual Detection of Mines

In addition to mine effectiveness, detection capability of mines or lack thereof gives the defense a tremendous advantage in battle. Since most mines are surfaced laid, any snow cover restricts the ability of the attacking force to detect them. Tilt-rod, magnetic, and pressure mines are more difficult to detect when covered in snow. However, no quantifiable information exists.

2.5.2 Artillery

During winter operations, deep snow will reduce the effect of impact bursts by as much as 80% (see Richmond, 1991). Also, some types of variable time fuses will malfunction when the temperature drops below 0 ° F. Unfortunately, details of how effectiveness varies as a function of temperature was not found in the literature.

2.5.3 Sensors

The effects of snow cover and actual snowing on visible images, thermal infrared, laser designators, etc., is complex. Richmond (1981) presents some research on how sensors perform in winter conditions. In general for snow covered ground without actual snowfall

- soldiers and equipment are particularly vulnerable to detection and weapons that work on infrared technology because of the difference in temperature between the background, and
- laser range finders and designators should not be significantly affected.

In degraded conditions (snowing), almost all sensors will be degraded if not totally ineffective. Degraded conditions will put the U.S. at a serve operational disadvantage because of their reliance on high technology equipment.

2.6 Summary

The research conducted into the effects on personnel and weapons systems produced one surprising result - the lack of quantifiable results on the effects of winter conditions. A lot of qualitative research or opinions are contained in the literature. This was true for both the individual system and the combined effects during a combined arms operation. However, some basic issues must still be resolved such as whether heaters should be employed during mounted operations. The combined and synergistic of effects of cold weather on equipment and soldiers during mounted and dismounted operations is one that must be addressed to determined the true capabilities of the U.S. Army in many areas of potential conflicts.

3. Combat Simulation Analysis

3.1 General

Four experiments were conducted to measure the effects of snow cover in a widely used Army combat simulation. The reference (base case) experiment used a standard Janus terrain database. Subsequent experiments further degraded mobility on frozen ground and for 7 and 14 inches of snow. Speed predictions were provided by the U.S. Army Engineer Waterways Experiment Station (WES) using the NRMM. Measures of Effectiveness (MOE) considered were:

- Blue Force Status (attrition) by Time (all units);
- Red Force Status (attrition) by Time (all units) ;
- Red Force Status (attrition) by Time (Objective Tom only);
- Force Exchange Ratio;
- Direct Fires by Range;
- Kills by Range (Kills to Fires Ratio); and
- Time to Objective.

3.2 Scenario

The scenario was based on a standard scenario approved by the Training and Doctrine Command (TRADOC). The situation and terrain were provided by the Scenario and Wargaming Center of TRADOC's Analysis Center (TRAC) at Fort Leavenworth, Kansas. Force composition and tactics were developed in DSE's Combat Simulation Laboratory. Combat system characteristics were contained in an unclassified database developed by the National Simulation Center (NSC) at Fort Leavenworth. An assumption is made that the relative change in performance would be comparable if classified data were used. It is recommended that these experiments be reproduced in a classified environment to validate the results.

3.2.1 Force Structure

Red is a Soviet-style motorized rifle battalion (BMP) in defensive positions near the 38th parallel in northern Korea. It is composed of three motorized rifle companies, a mortar battery, and air defense and automatic grenade launcher platoons. Companies have three infantry platoons, each with three BMP-2 Infantry Fighting Vehicles. Dismounted firepower includes 16 assault rifles, 3 light machine-guns, 3 antitank grenade launchers, and a sniper rifle. BMPs fire AT-5 antitank missiles, with a maximum range of approximately 4 kilometers, and 30 millimeter armor piercing and high explosive ammunition.

Blue is a U.S.-style task force of two M1A1 and two mechanized infantry companies. Each tank company has 14 tanks armed with 120 millimeter main guns; infantry vehicles are M2 and M3 Bradleys, firing TOW missiles to approximately 4 kilometers. Bradleys also fire 25 millimeter armor piercing and high explosive ammunition. Dismounted firepower includes 11 riflemen, 6 squad automatic weapon (SAW) gunners, 3 AT-4 antitank missile gunners, and 2 M203 grenade gunners. Each company team has an Armored Vehicle Launched Bridge (AVLB), an M113 towing a trailer mounted mine clearing line charge (MICLIC), and an Armored Combat Earthmover (ACE). An M109A3 howitzer battery and an air defense platoon are in direct support of the task force.

3.2.2 Objective and Terrain

Blue's mission is to seize Objective Tom, a company position on Red's right flank. Blue then is to consolidate on the objective, prepare for a counterattack, and attack by fire adjacent Red companies. A mechanized infantry team crosses the Line of Departure/Line of Contact (LD/LC) ahead of the rest of the task force and establishes a base of fire north of the village and west of Objective Tom. Each company/team is accompanied by an AVLB which must establish a crossing point over a small stream within 2.5 kilometers of the objective. The actual crossing point is concealed from enemy view. The second company/team attacks between two small villages southwest of the objective, while the third attacks from the south (see Figure 3.1). The distance from Blue's attack position to the objective is about five kilometers. A bridgehead had been established immediately forward of the attack position.

Natural obstacles include a well-observed river on Red's extreme left flank and a hilly, wooded area on the right. The slope of this hill typically is 30 to 35 percent, although it is as much as 45 percent at the extreme. Blue forces using this approach would have to traverse this slope for nearly 500 meters.

3.2.3 Environment

Factors other than snow were kept as neutral as realistically possible and constant. The scenario takes place in a typical northern Korea January. The base case assumes frozen but clear ground. The soil is considered to be a sand- silty clay classified as SM-SC in the Unified Soil Classification System (USGS) soil classification system with a freeze depth of 99 inches and a thaw depth of 0 inches. This provides a basic soil strength of 750 Rating Cone Index (RCI), which would be virtually non-deformable under all types of vehicle traffic.

The freeze depth for snow-covered terrain was set to 99 inches, the thaw depth to 0.0 inches, and the NRMM default for snow density of 0.1 was used. The ground surface was considered to be non-ice covered. The average snowpack was set to 7 inches, and the worst-case value of 14 inches was used for the high-level experiment. Other environmental conditions were kept constant and are shown in Table 3.1.

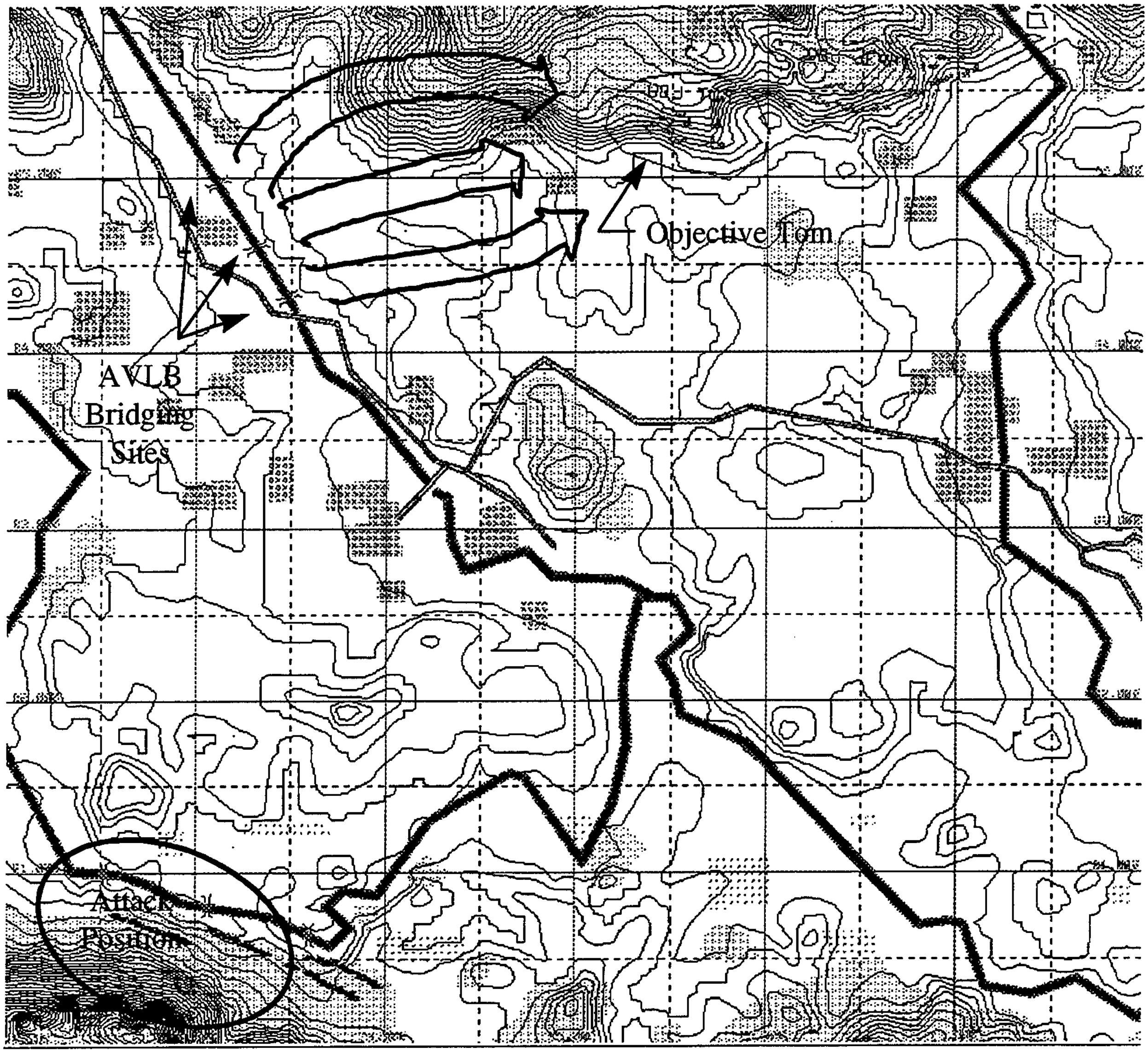

Figure 3.1 Janus terrain map

Environmental Constants						
Air Temp	Humidity	Wind Speed	Wind Direction	Angle of the Sun	Visibility	Air Mass
32° F	40%	9 Km/Hr	ESE	90°	9 Km	cP

Table 3.1 Environmental constants

3.2.4 Mobility

Vehicle speeds were simulated in two steps. Firs t, absolute maximum speed values were input into the vehicle database for each experiment. Second, the Janus terrain map was modified so that slopes would further degrade mobility by a percentage. Four scenarios (experiments) were conducted using Janus. These were designed to isolate the effects of cold weather on mobility and included

- **Experiment 1** - Normal Janus methodology for calculating speed. However, the maximum vehicle speeds were modified based upon the maximum vehicle speeds as predicted by NRMM for this type of terrain and weather (see Table 3.2).
- **Experiment 2** - Using the terrain shown in Figure 3.1, areas were identified with 10%, 20%, etc., slopes. The model was forced to use the speeds shown in Table 3.3 in lieu the methodology currently used in Janus for predicting vehicle speed. Note that Experiments 1 and 2 both represent a base case (mobility unaffected by cold weather). However, the speeds are calculated using two different approaches.
- **Experiment 3** - Using the same methodology described in Experiment 2, the speeds were further degrade using the data contained in Table 3.4 based upon NRMM predictions for 7" of snow.
- **Experiment 4** - Using the same methodology described in Experiment 2, the speeds were further degrade using the data contained in Table 3.5 based upon NRMM predictions for 14" of snow.

Note that all mobility degradation factors were based on predictions supplied by WES using NRMM II version 2.5.8b (last revised June 1996). This model provides Upslope, Downslope, Level, and Omni speeds per 1 square kilometer area. Since Janus does not differentiate between up or downslope speeds, the Omni value was used.

Base Case - Using Janus Methodology				
	Speed (mph)	10% Slope (%)	20% Slope (%)	30% Slope (%)
M1A1	39.31	No Change	No Change	No Change
M2A1	35.74	"	"	"
M113A1	27.54	"	"	"
AVLB	21.99	"	"	"
M9	31.92	"	"	"

Table 3.2 Experiment 1 speed factors

Base Case - Using NRMM Results				
	Speed (mph)	10% Slope (%)	20% Slope (%)	30% Slope (%)
M1A1	39.31	69	53	40
M2A1	35.74	70	47	39
M113A1	27.54	73*	63*	41*
AVLB	21.99	73	53	36
M9	31.92	62	46	36
Averages**		69	50	38

Table 3.3 Experiment 2 speed factors

7" Snow				
	Speed (mph)	10% Slope (%)	20% Slope (%)	30% Slope (%)
M1A1	39.65	68	50	32
M2A1	34.62	69	44	35
M113A1	22.23	81*	67*	42*
AVLB	21.16	70	48	30
M9	31.00	60	43	32
Averages**		67	46	32

Table 3.4 Experiment 3 speed factors

14" Snow				
	Speed (mph)	10% Slope (%)	20% Slope (%)	30% Slope (%)
M1A1	38.60	67	50	32
M2A1	30.64	72	47	38
M113A1	20.44	85*	65*	43*
AVLB	20.50	72	50	31
M9	30.83	58	42	30
Averages**		67	47	32

Table 3.5 Experiment 4 speed factors

Notes: *M113 factors were not included in averages to avoid skewing group speeds.
**Values applied to terrain. NRMM tables are included at Appendix A.

3.2.5 Engagement Criteria

All direct fire engagements were database driven. Criteria for a firing event includes detection, identification of the target as on the firer's target list, availability of the appropriate ammunition, target within maximum weapon range, and a Single Shot Kill Probability (SSKP) above a preset minimum.

3.3 Tools

3.3.1 Janus

Janus is a combat simulation model focusing on echelons at brigade and below. It is co-managed by the Simulation, Training, and Instrumentation Command (STRICOM), the NSC, and TRAC. Janus allows up to six separate forces to act independently on a digitized battlefield. Unit behavior may be autonomous, semi-autonomous, or completely interactive, depending upon function. Detections and direct fire events are autonomous, provided database criteria are met. Movement must be planned, but units follow planned routes unless they are stopped or diverted by the interactor. Indirect fire missions must be planned, though as many as 12 missions may be queued. Terminally-guided munitions may be fired only if the target is illuminated by a designator at an appropriate angle.

System characteristics are determined by a detailed hierarchy of database tables, which may be altered by the user. These tables describe the system's dimensions and capabilities, specify sensors, weapons, and basic loads, and determine which targets may be engaged. Tables of hit and kill probabilities establish the SSKPs for all ranges and shooter/target postures. Vulnerability to mines, artillery, heat, and chemicals also may be specified.

The terrain is built upon elevation data supplied by the Defense Mapping Agency (DMA). Nearly all Janus terrain originates from Level 1 elevation data, which maps a grid of elevation posts every 100 meters. Intermediate elevation data is interpolated. Terrain features may be input from Digital Feature Analysis Data (DFAD), digitized from 1:50,000 scale maps, or input directly using a mouse. Typical features include roads, rivers, urban areas, buildings and vegetation. Several variations of each of these may be defined and input using a terrain editor function in Janus. Each terrain feature may be coded for visibility per 25 meters and assigned a coefficient for speed degradation. Obstacles may be assigned crossing times for various types of wheeled, tracked, and dismounted units.

Janus is a stochastic model. Once an event meets all other criteria, a pseudo-random number is generated. If the event exceeds the threshold it is executed. Therefore, runs will have different outcomes and a suitable number of replications must be run to become confident with the central tendencies.

3.3.2 *JETS* - The Janus Evaluator's Tool Set

JETS is a personal computer-based database analysis tool developed in the Department of Systems Engineering at the United States Military Academy. It enables the analyst to import and query Janus output data from a large number of runs. It was the primary post-processing tool used in this study.

3.4 Simulation Results

3.4.1 Blue Force Status

Blue attrition was measured in vehicles remaining as a function of time, starting with 96 vehicles. In the base case scenario (standard Janus terrain), Blue reached the objective with an average of 72.4 (75.4 percent) remaining. Modifying terrain to reflect NRMM values for frozen ground resulted in an average of 60.6 (63.1 percent) remaining, a 12.3 percent decrease. The two snow scenarios, using NRMM values for snow depth and slope, produced similar results, 34.2 (35.6 percent) remaining in the 7-inch scenario and 37.7 (39.3 percent) in the 14-inch scenario, a difference of 1.6 percent. One-way analysis of variance (ANOVA) was used to test for significant differences in the means. Figures 3.2 through 3.5 show Blue vehicle attrition over time for the four experiments. Tabular data and analysis is contained at Appendix B.

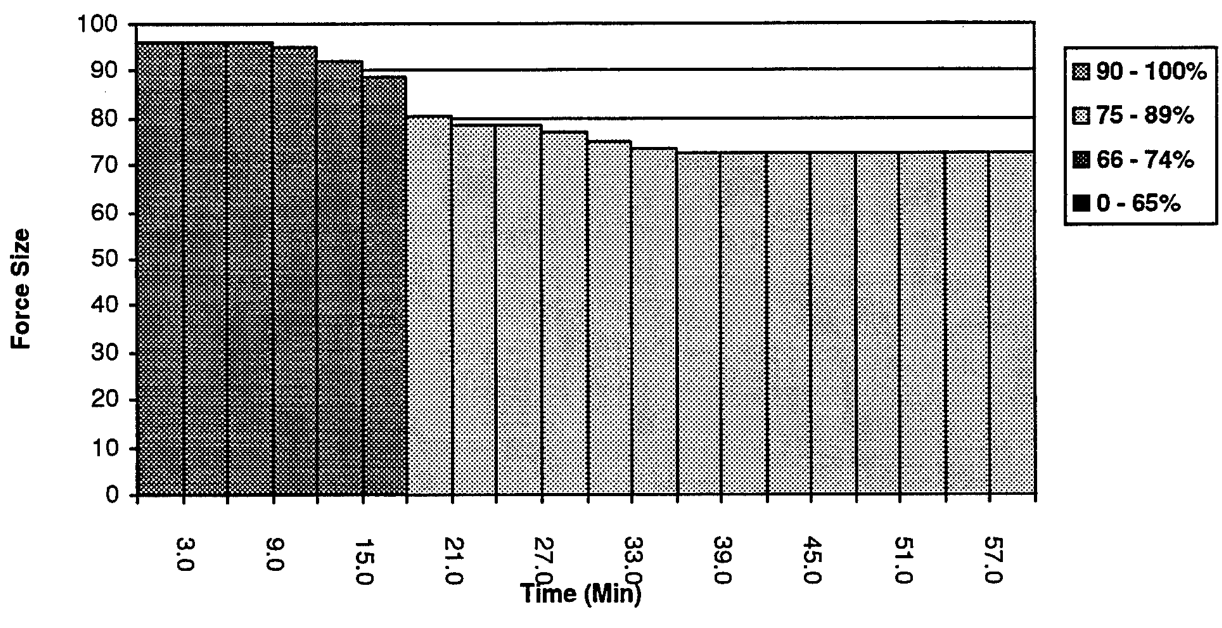

Figure 3.2 Blue vehicles, Janus base case

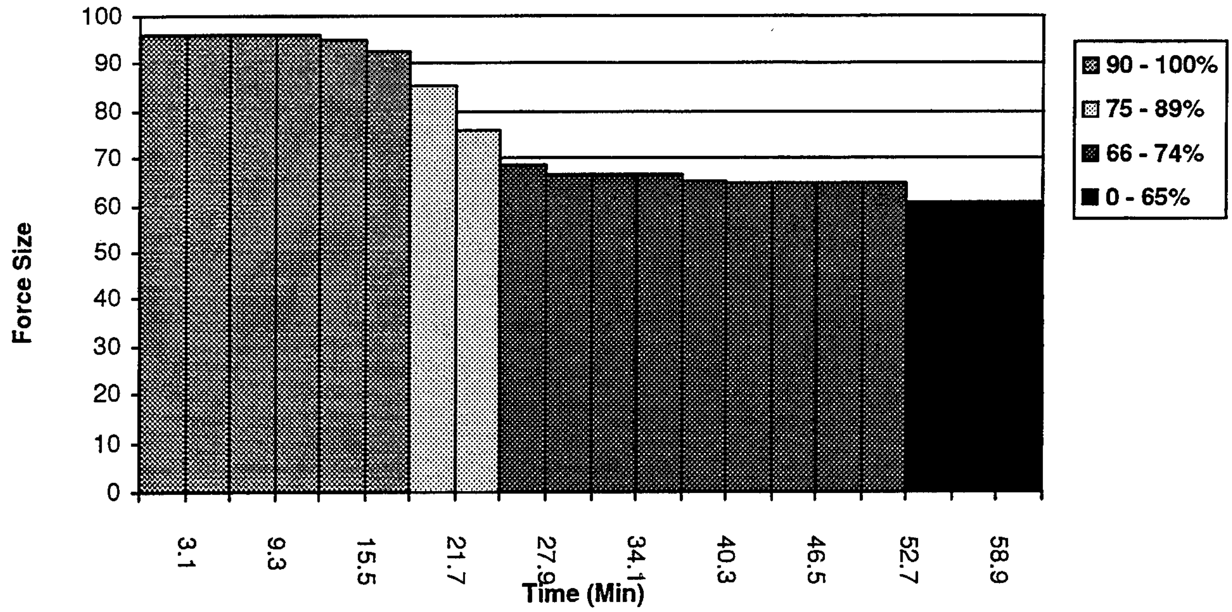

Figure 3.3 Blue vehicles, NRMM base case

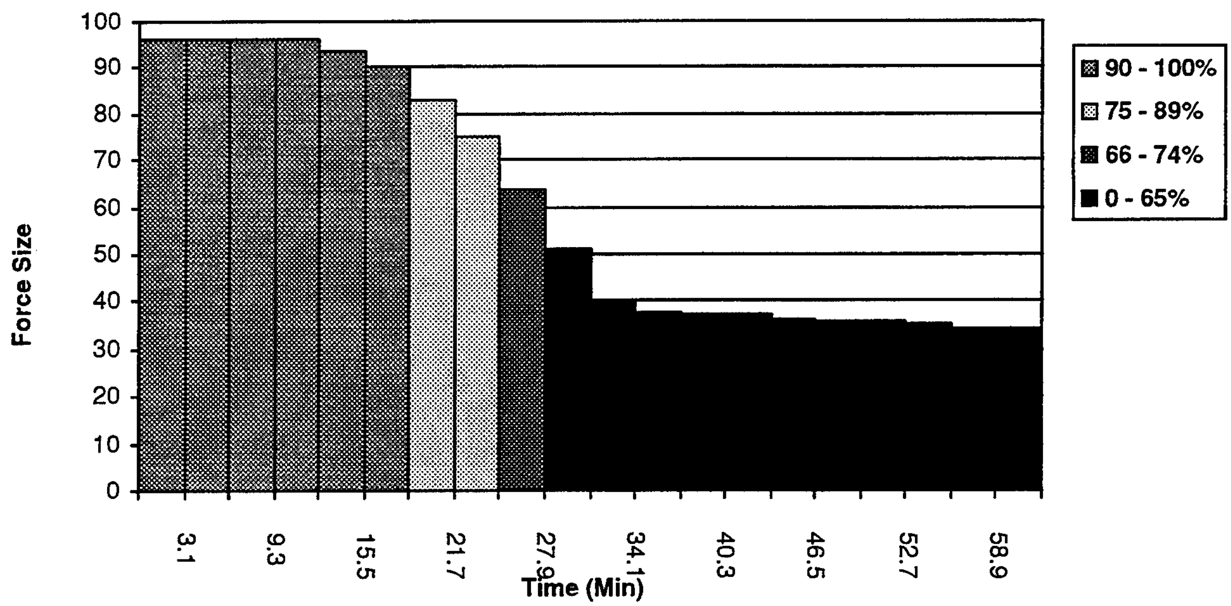

Figure 3.4 Blue vehicles, 7" snow

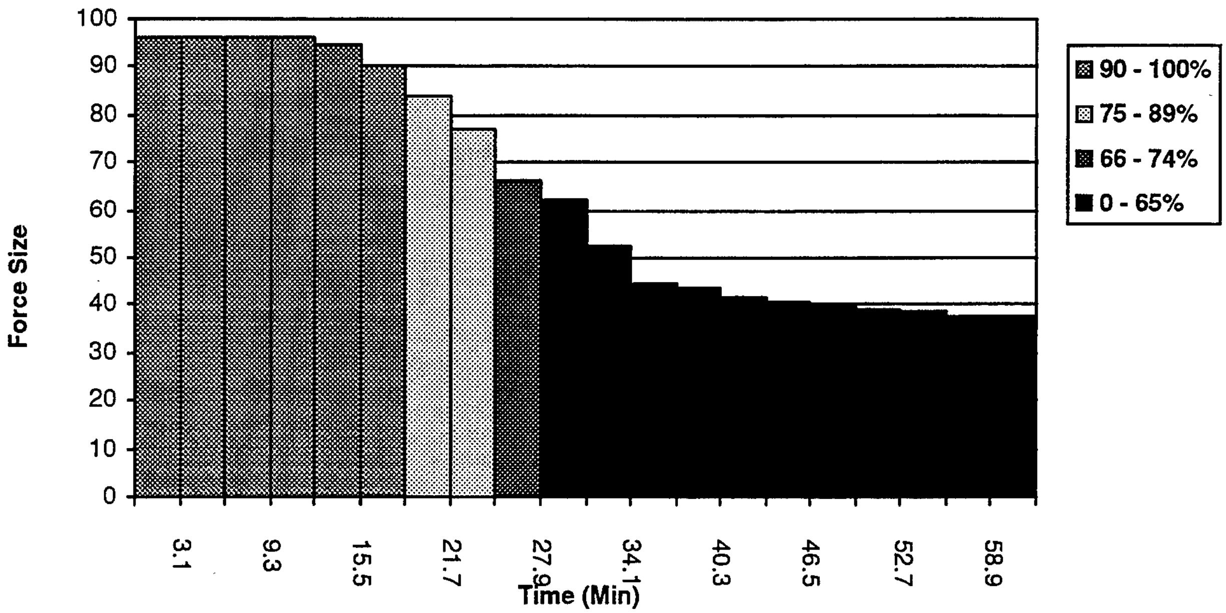

Figure 3.5 Blue vehicles, 14" snow

This ANOVA measure addressed three questions:

- Are the means of all four experiments statistically the same?
- Are the experiments using standard Janus terrain and no snow but frozen ground statistically the same?
- Are the two experiments with snow data statistically the same?

Analysis of the four experiments supports the conclusions that can be inferred from the results shown in Table 3.6, that is,

- The means of all four experiments are not statistically the same.
- There is a significant difference between the means in the experiments using standard Janus terrain and NRMM values with no snow.
- There is no significant difference between the means in the two experiments using NRMM data with snow.

Note that the values shown in Table 3.6 are the means and standard deviations remaining at the end of the scenario (time of 60 minutes). They are not the average over the duration of the simulation.

```
Individual 95% CIs For Mean
                                              Based on Pooled StDev
 Level        N       Mean      StDev   -+---------+---------+---------+-----
Base Case    10     72.400      7.891                             (--*---)
0" Snow      10     60.600      5.835                     (--*---)
7" Snow      10     34.200      8.626   (---*--)
14" Snow     10     37.700     11.026     (---*---)
                                        -+---------+---------+---------+-----
Pooled StDev =       8.548              30        45        60        75
```

Table 3.6 Means, standard deviations, and 95% CI for number of blue vehicles

3.4.2 Red Force Status

In all cases, Blue cleared Objective Tom, which consisted of a company-sized mechanized infantry unit in the defense. Based on Blue's remaining strength, additional attrition data for Red was collected as Blue consolidated on the objective and began to attack by fire the adjacent units of the Red battalion. Therefore, two measures of Red attrition were made: Objective Tom only and all Red. Red strength on Objective Tom started at 81 vehicles and dismounts; total Red strength was 294. Figures 3.6 through 3.9 show Red strength on Objective Tom only.

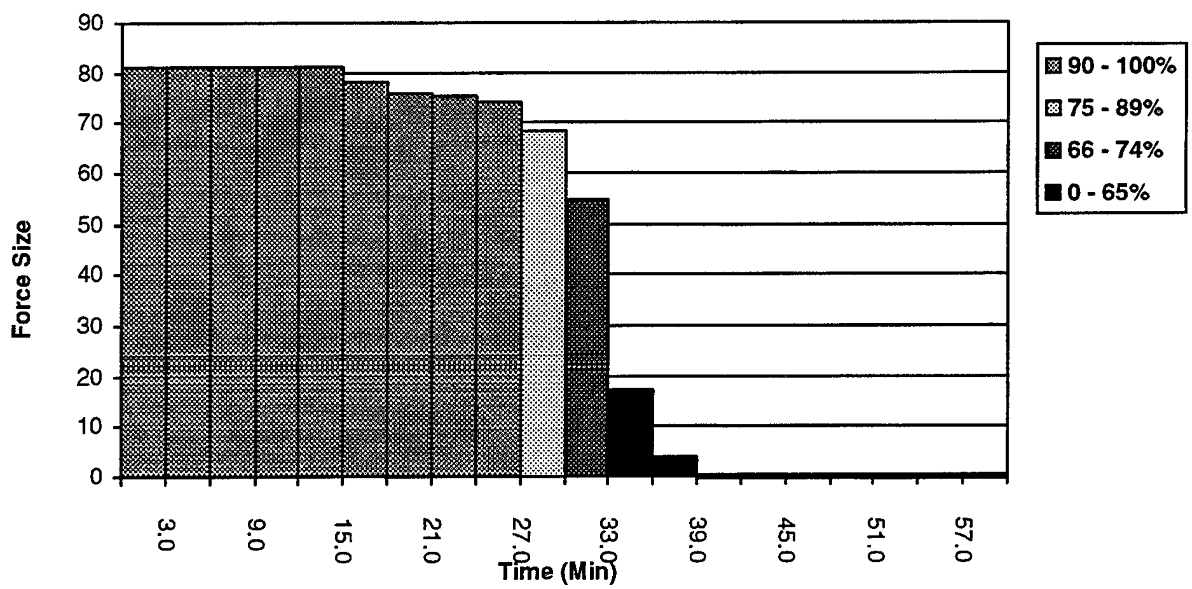

Figure 3.6 Objective Tom, Janus base case

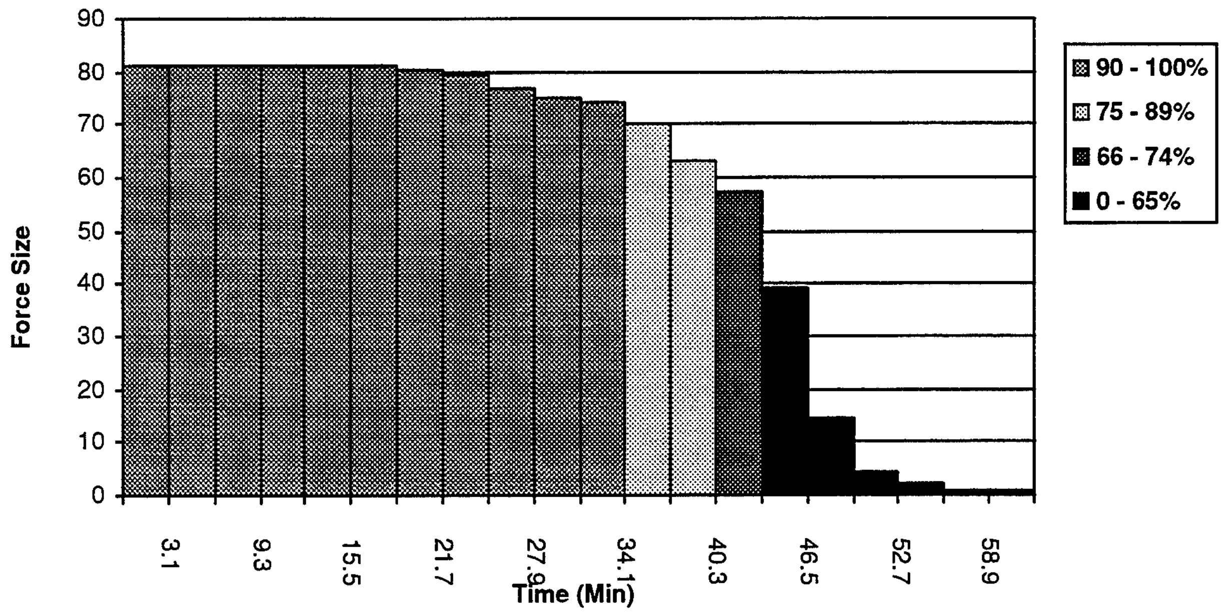

Figure 3.7 Objective Tom, NRMM base case

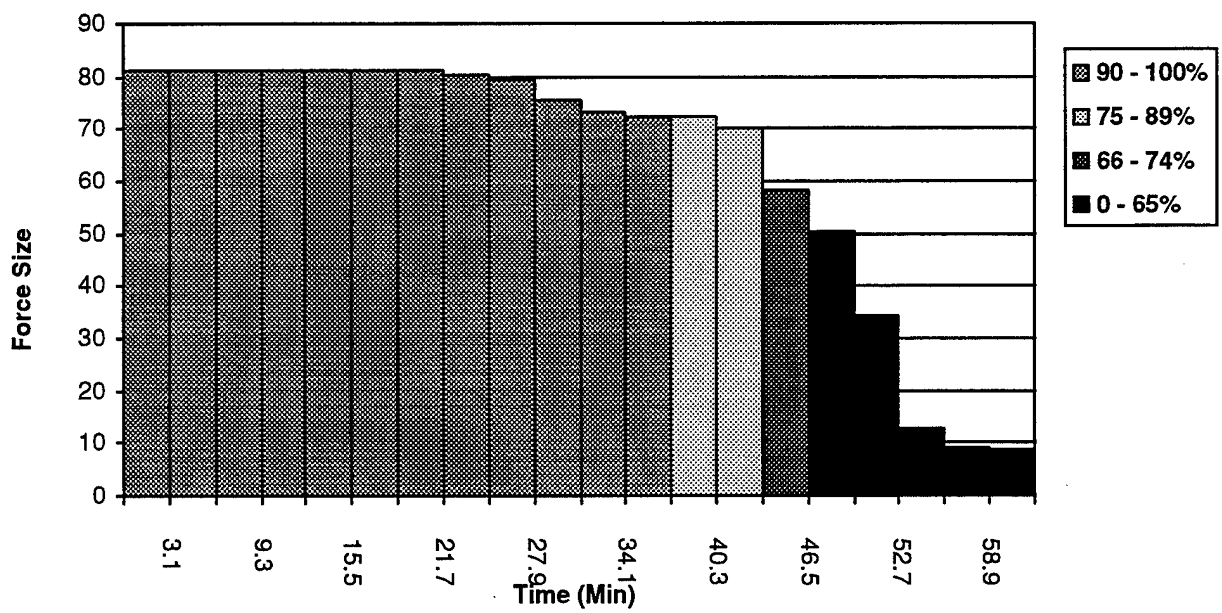

Figure 3.8 Objective Tom, 7" snow

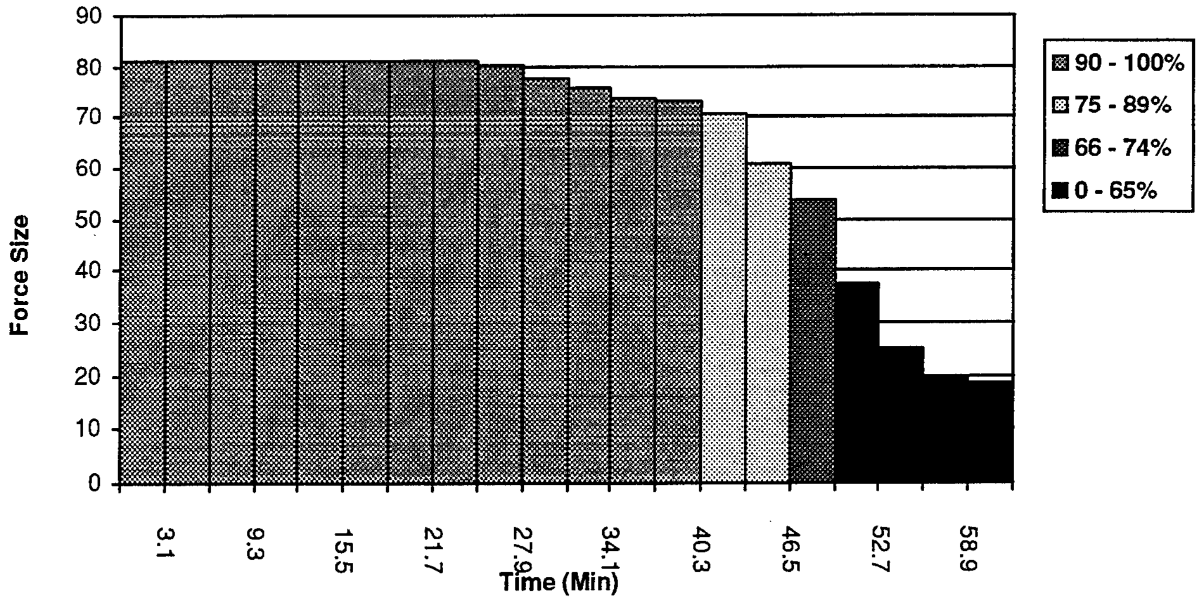

Figure 3.9 Objective Tom, 14" snow

Analysis supports the hypothesis that there is no significant difference in the attrition of Red on Objective Tom regardless of scenario (Appendix C).

Figures 3.10 through 3.13 show total Red force attrition (Appendix D).

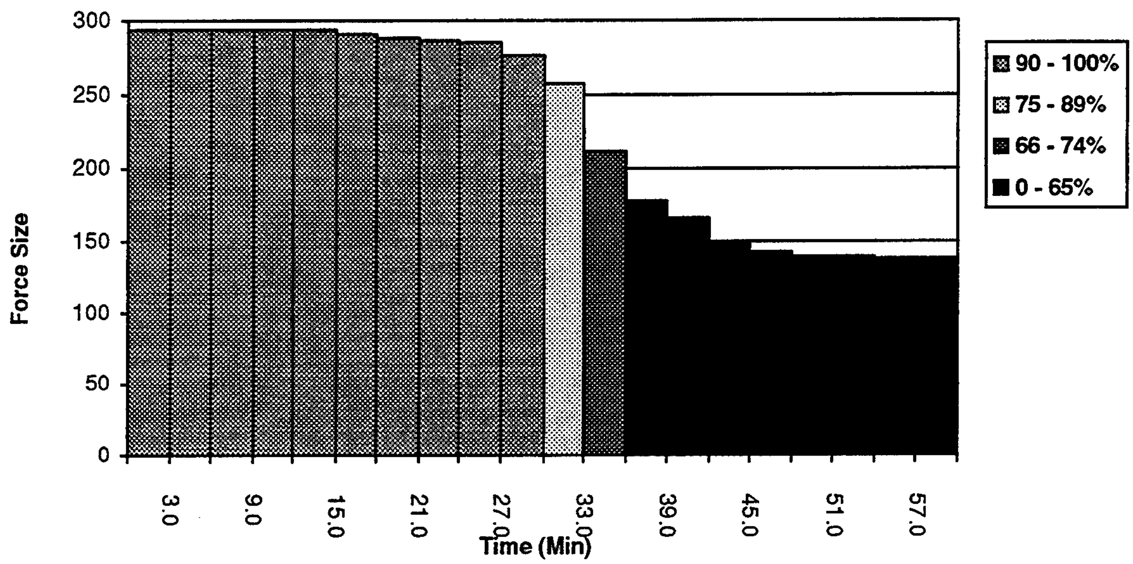

Figure 3.10 All red, Janus base case

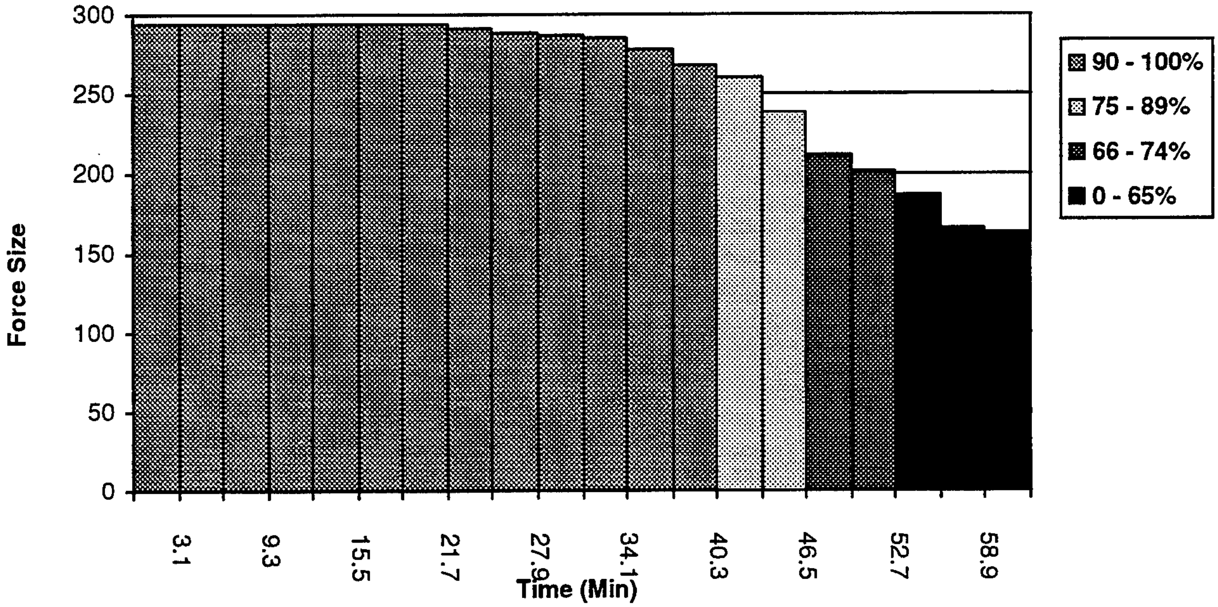

Figure 3.11 All red, NRMM base case

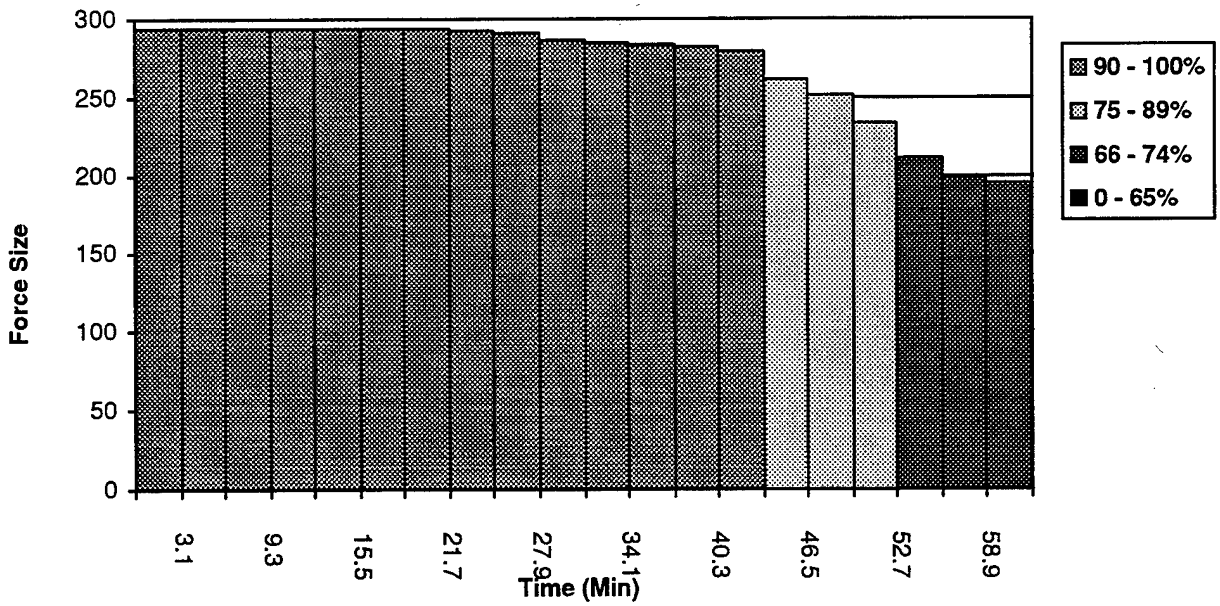

Figure 3.12 All red, 7" snow

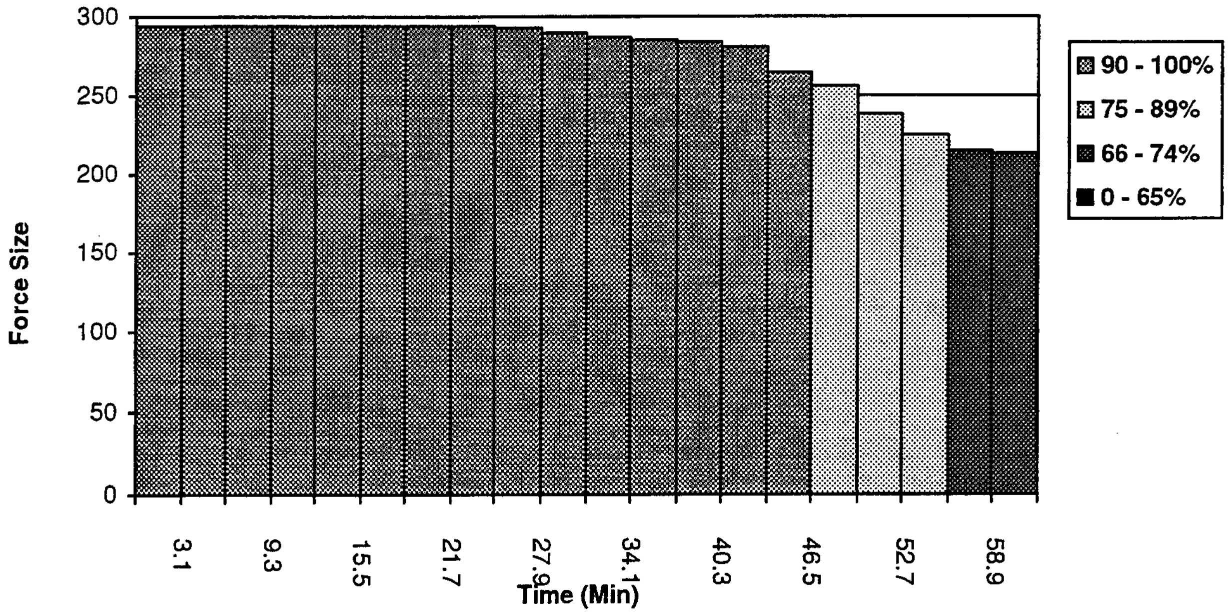

Figure 3.13 All red, 14" snow

Tables 3.7 and 3.8 shows the means, standard deviations, and individual 95 percent confidence intervals for these two MOEs at the end of the simulation for the four experiments.

```
Individual 95% CIs For Mean
                                          Based on Pooled StDev
 Level        N       Mean      StDev  -+---------+---------+---------+-----
Base Case    10       0.30       0.48   (---------*----------)
0" Snow      10       0.70       1.49   (----------*---------)
7" Snow      10       8.70      22.71          (---------*----------)
14" Snow     10      18.40      31.18                  (---------*----------)
                                       -+---------+---------+---------+-----
Pooled StDev =       19.30            -12         0        12        24
```

Table 3.7 Means, standard deviations, and 95% CI for red strength at Objective Tom

```
Individual 95% CIs For Mean
                                              Based on Pooled StDev
 Level        N        Mean      StDev   ------+---------+---------+---------+
Base Case    10      138.40      13.76   (-----*----)
0" Snow      10      163.60      11.09          (-----*----)
7" Snow      10      195.30      35.97                    (----*----)
14" Snow     10      212.70      41.66                        (-----*----)
                                         ------+---------+---------+---------+
Pooled StDev =        28.90                   140       175       210       245
```

Table 3.8 Means, standard deviations, and 95% CI for overall red force strength

This measure addressed the same three questions as the Blue attrition MOE:

- Are the means of all four experiments statistically the same?
- Are the experiments using standard Janus terrain and NRMM values with no snow statistically the same?
- Are the two experiments with snow data statistically the same?

Analysis supports the following conclusions:

- The means of all four experiments are not statistically the same.
- There is a significant difference between the means in the experiments using standard Janus terrain and NRMM values with no snow.
- There is no significant difference between the means in the two experiments using NRMM data with snow.

3.4.3 Force Exchange Ratio

Force Exchange Ratio (FER) indicates the relative rate of attrition of each force. It is the ratio of Red remaining divided by Red initial over Blue remaining divided by Blue initial. It is useful for showing if Blue is attriting Red at a rate sufficient to indicate mission achievement. An FER greater than 1 generally is considered favorable to Blue. Figures 3.14 through 3.17 show FER results for the four experiments.

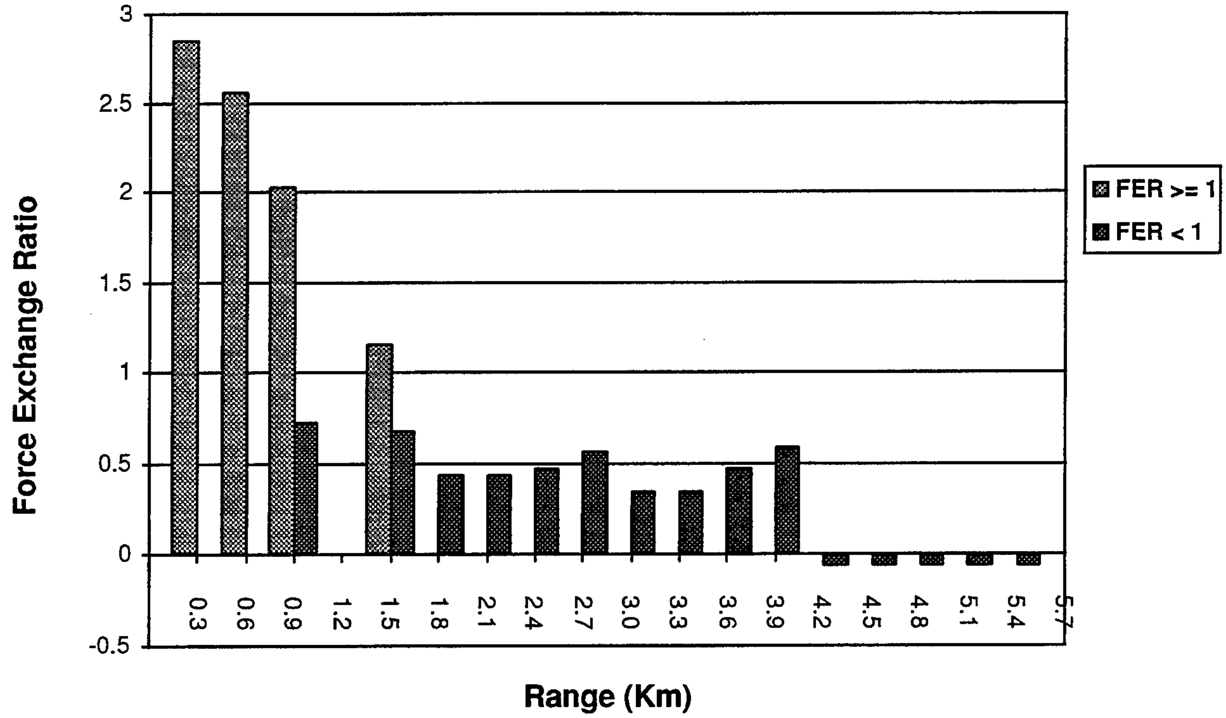

Figure 3.14 FER, Janus base case

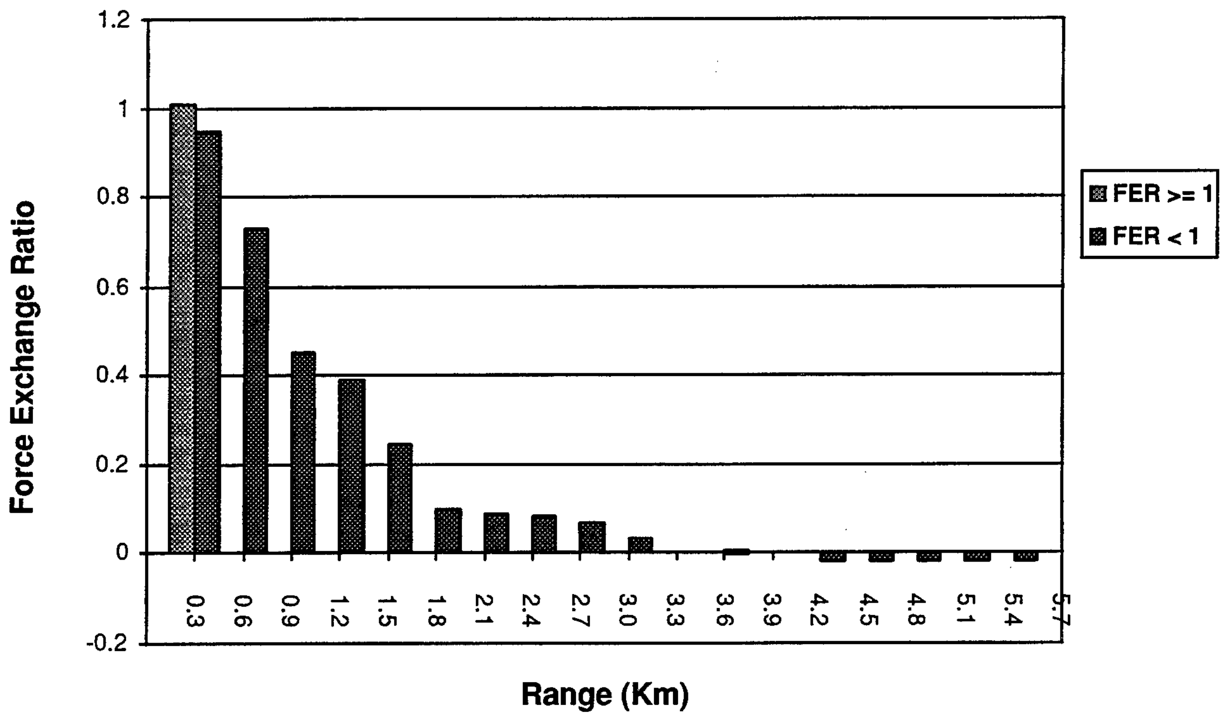

Figure 3.15 FER, NRMM base case

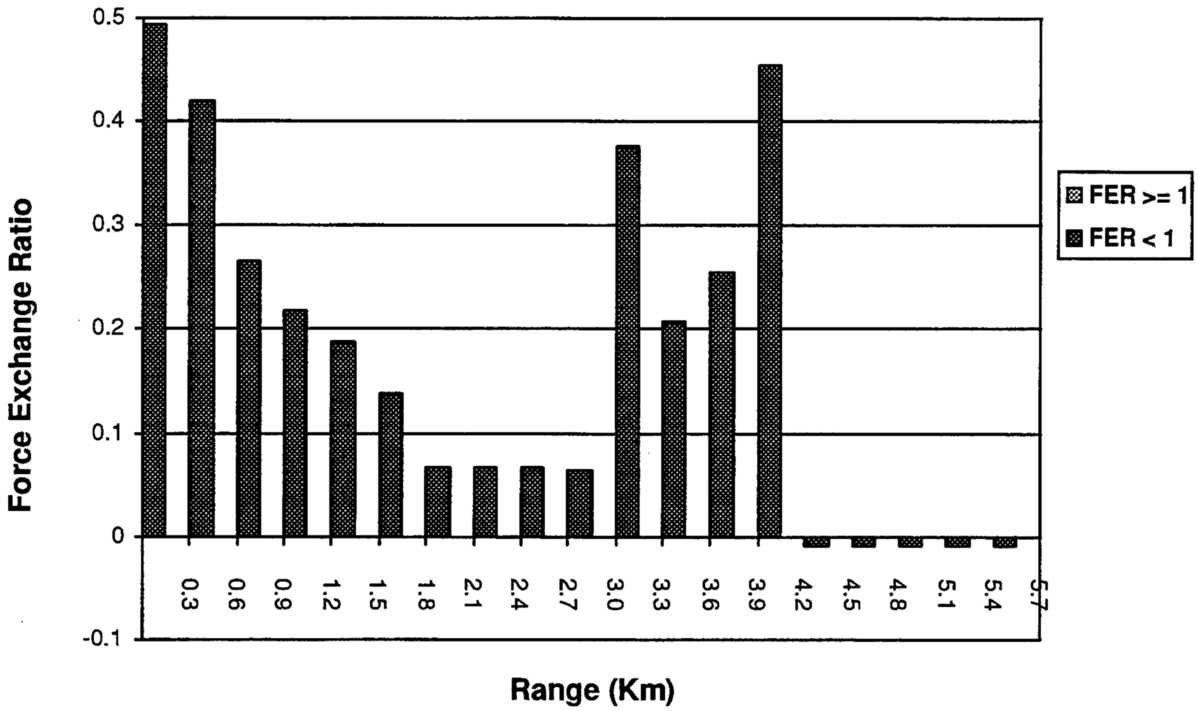

Figure 3.16 FER, 7" snow

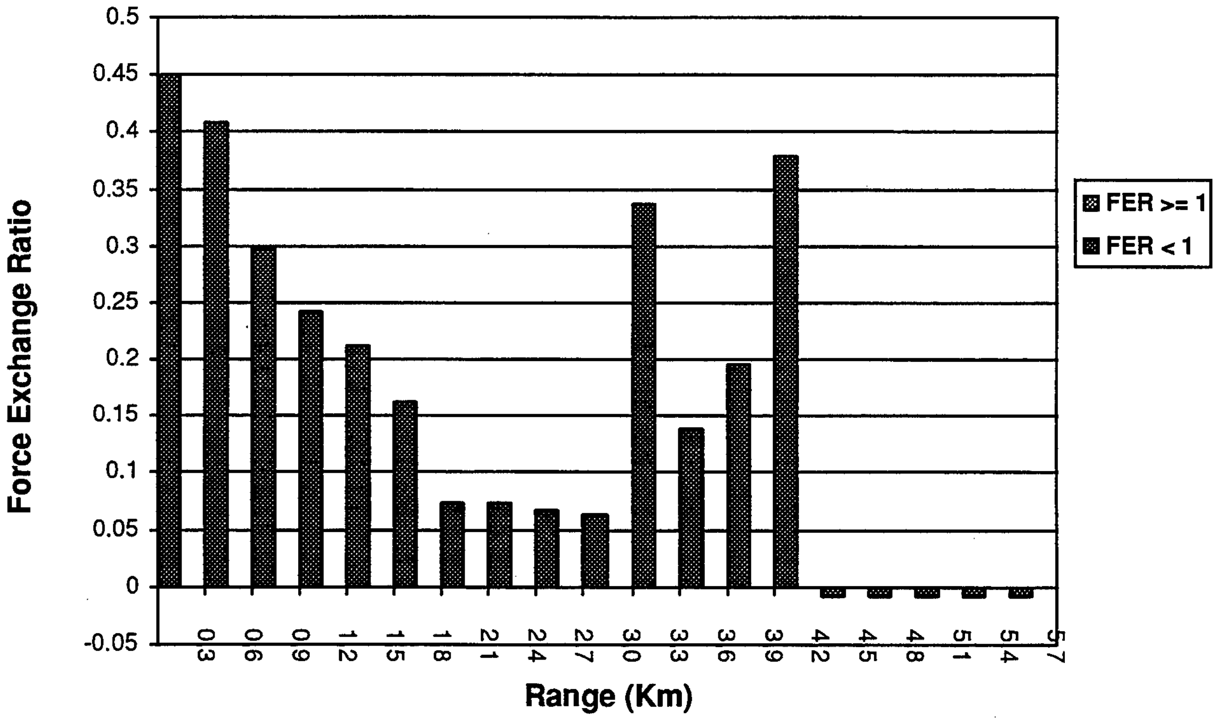

Figure 3.17 FER, 14" snow

Table 3.9 shows the means, standard deviations, and individu al 95 percent confidence intervals for this MOE in the four experiments at the end of the simulation.

```
Individual 95% CIs For Mean
                                       Based on Pooled StDev
 Level        N      Mean     StDev   ---------+---------+---------+-------
Base Case    10    3.2484    1.2268                              (---*----)
0" Snow      10    1.0455    0.2571        (---*----)
7" Snow      10    0.5532    0.3021   (----*---)
14" Snow     10    0.5320    0.3257   (---*----)
                                      ---------+---------+---------+-------
Pooled StDev =     0.6649                     1.0       2.0       3.0
```

Table 3.9 Means, standard deviations, and 95% CI for FER

Analysis (see Appendix E) supports the following conclusions:

- The means of all four experiments are not statistically the same.
- The means of the three experiments using NRMM data are not statistically the same.
- There is no significant difference between the means in the two experiments using NRMM data with snow.

3.4.4 Direct Fires by Range

Direct Fires by Range shows engagement ranges over the course of the scenario. It is useful in determining standoff ranges and engagement area effectiveness. Tables 3.10 and 3.11 show the mean number of firing events by side, range band, and experiment. Figures 3.18 through 3.21 show how Red and Blue direct fires were distributed by weapons type for each experiment. Supporting data are in Appendix F.

Blue Direct Fire Ranges				
	Base	0" Snow	7" Snow	14" Snow
0 - <1 Km	113.20	60.38	2.30	32.75
1 - <2 Km	34.72	53.92	2.24	42.66
2 - <3 Km	5.12	7.66	2.80	2.92
3 - >3 Km	15.18	15.42	22.55	26.53

Table 3.10 Blue firing events by side, range band, and experiment

Red Direct Fire Ranges				
	Base	0" Snow	7" Snow	14" Snow
0 - <1 Km	2.75	6.65	2.30	2.53
1 - <2 Km	4.04	3.62	2.24	2.04
2 - <3 Km	3.50	0.40	2.80	1.32
3 - >3 Km	6.33	13.17	22.55	22.23

Table 3.11 Red firing events by side, range band, and experiment

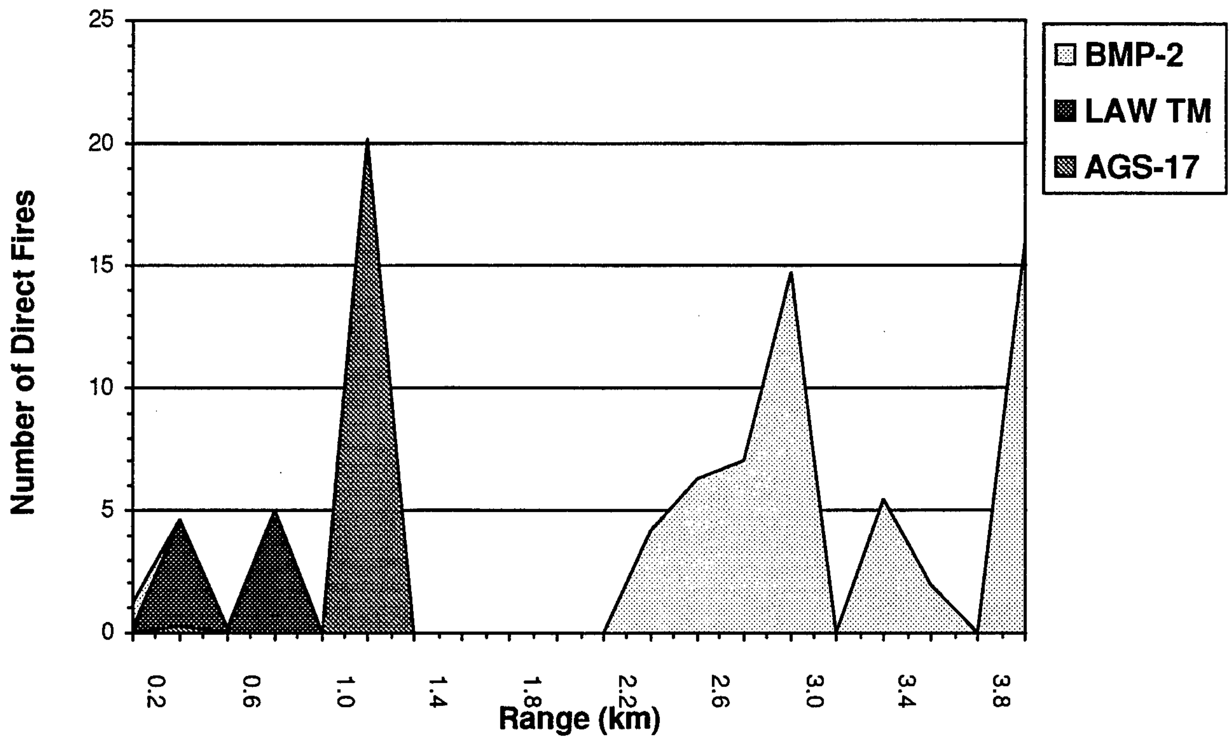

Figure 3.18a Red fires, Janus base case

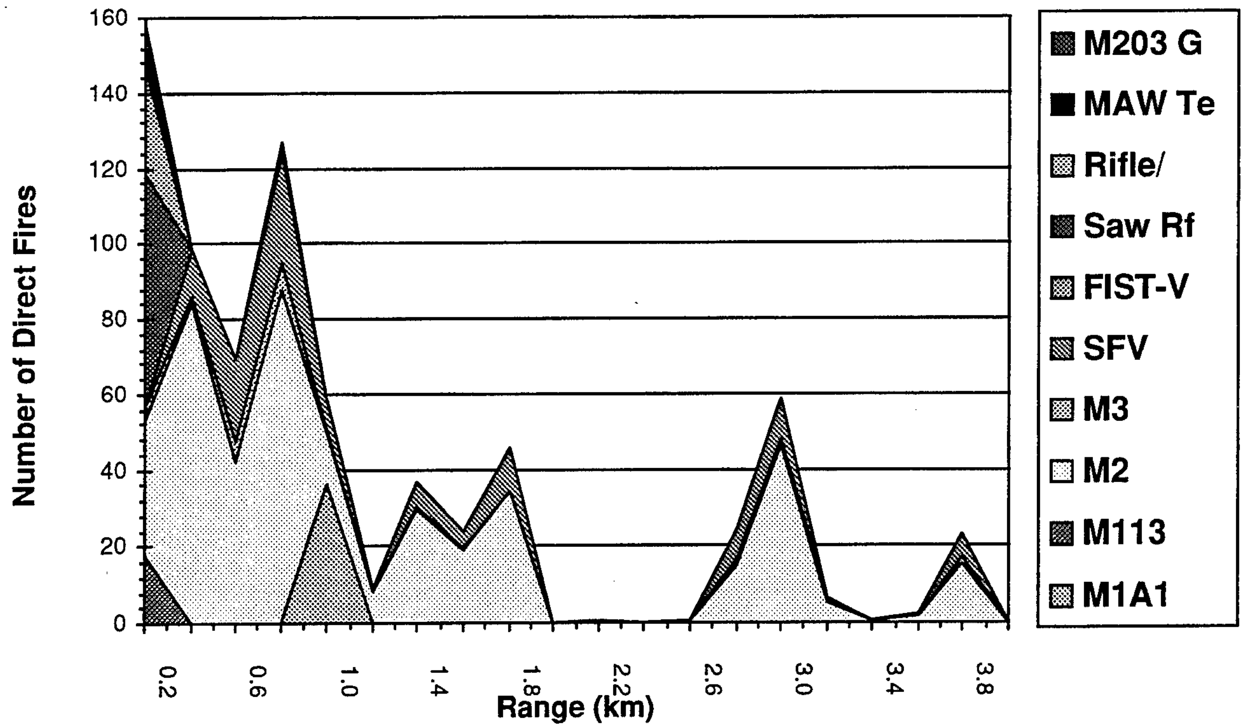

Figure 3.18b Blue fires, Janus base case

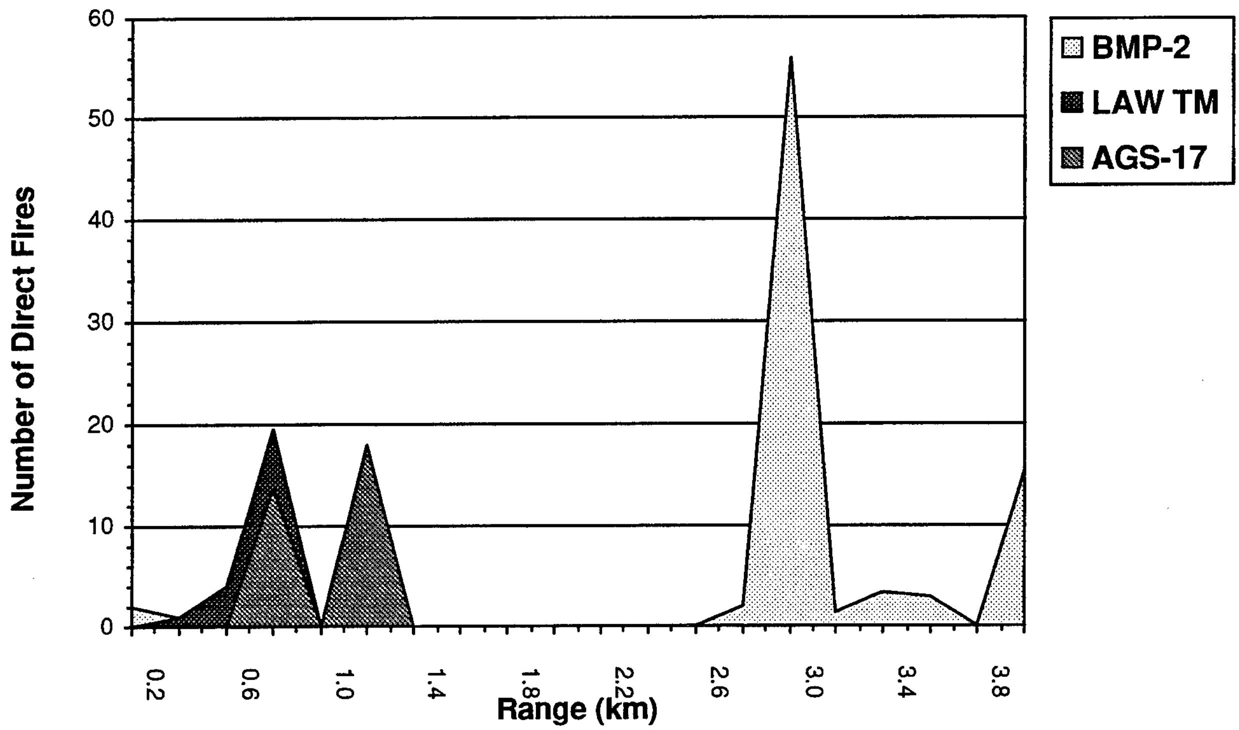

Figure 3.19a Red fires, NRMM base case

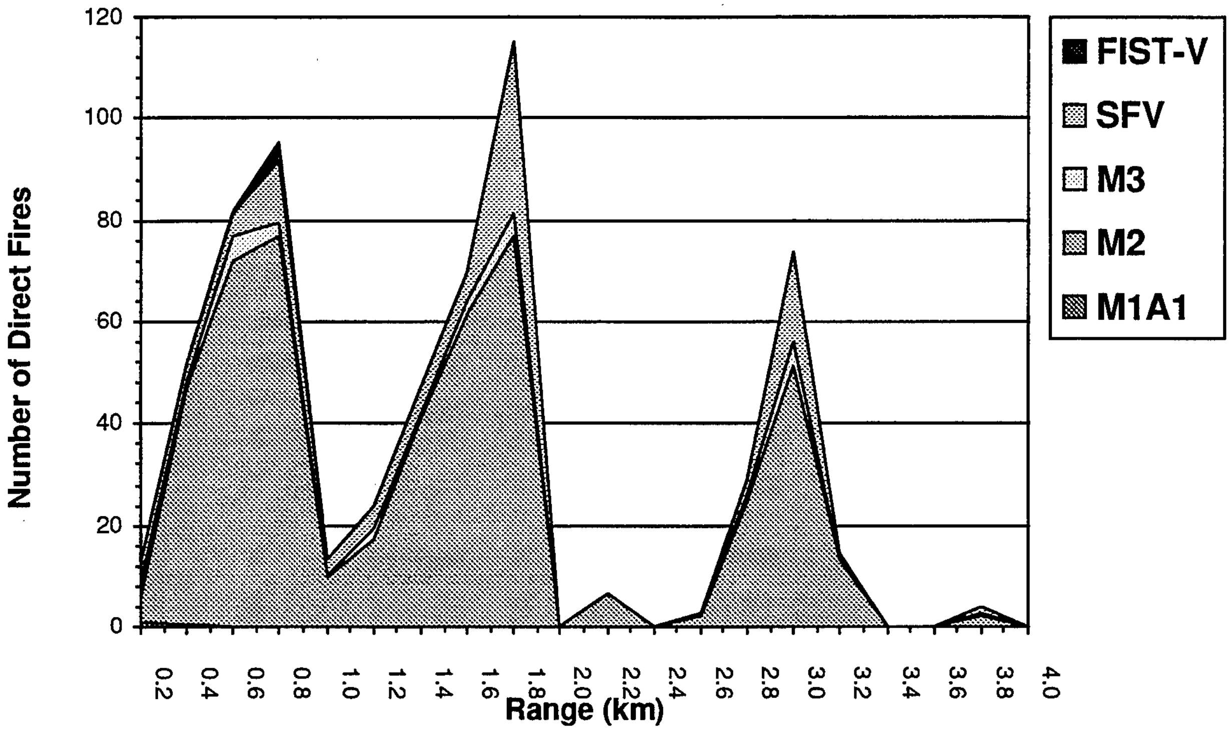

Figure 3.19b Blue fires, NRMM base case

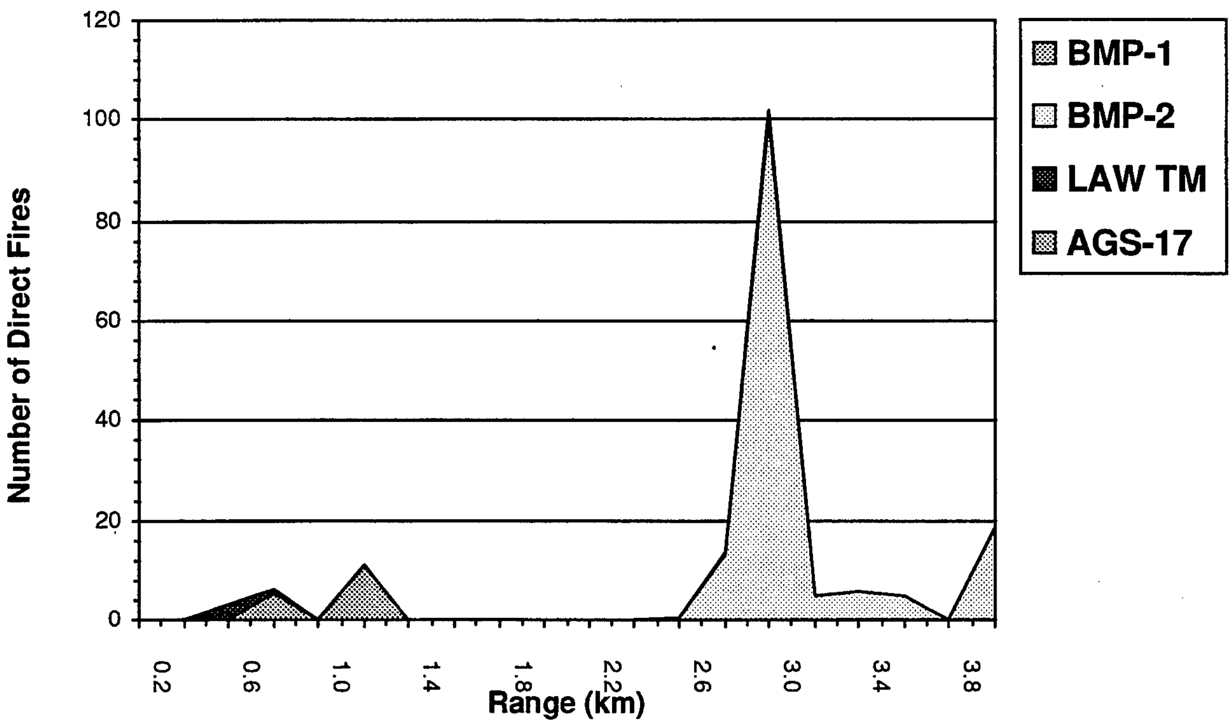

Figure 3.20a Red fires, 7" snow

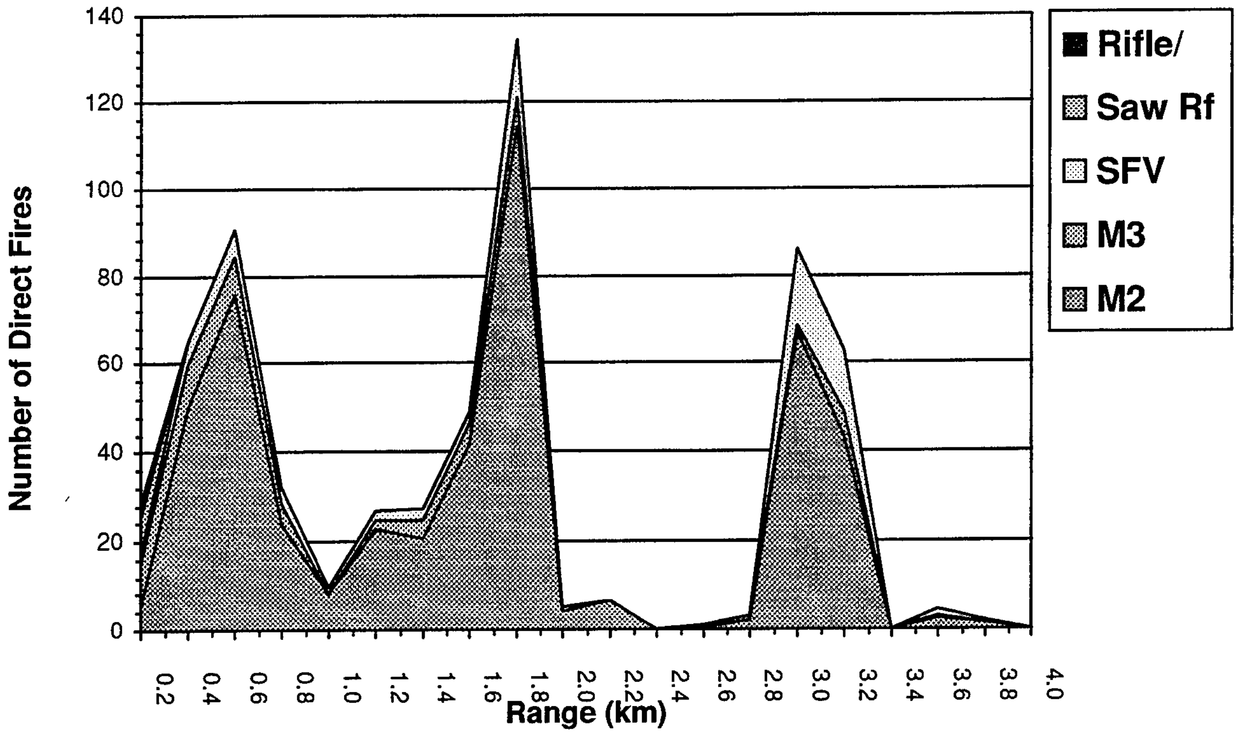

Figure 3.20b Blue fires, 7" snow

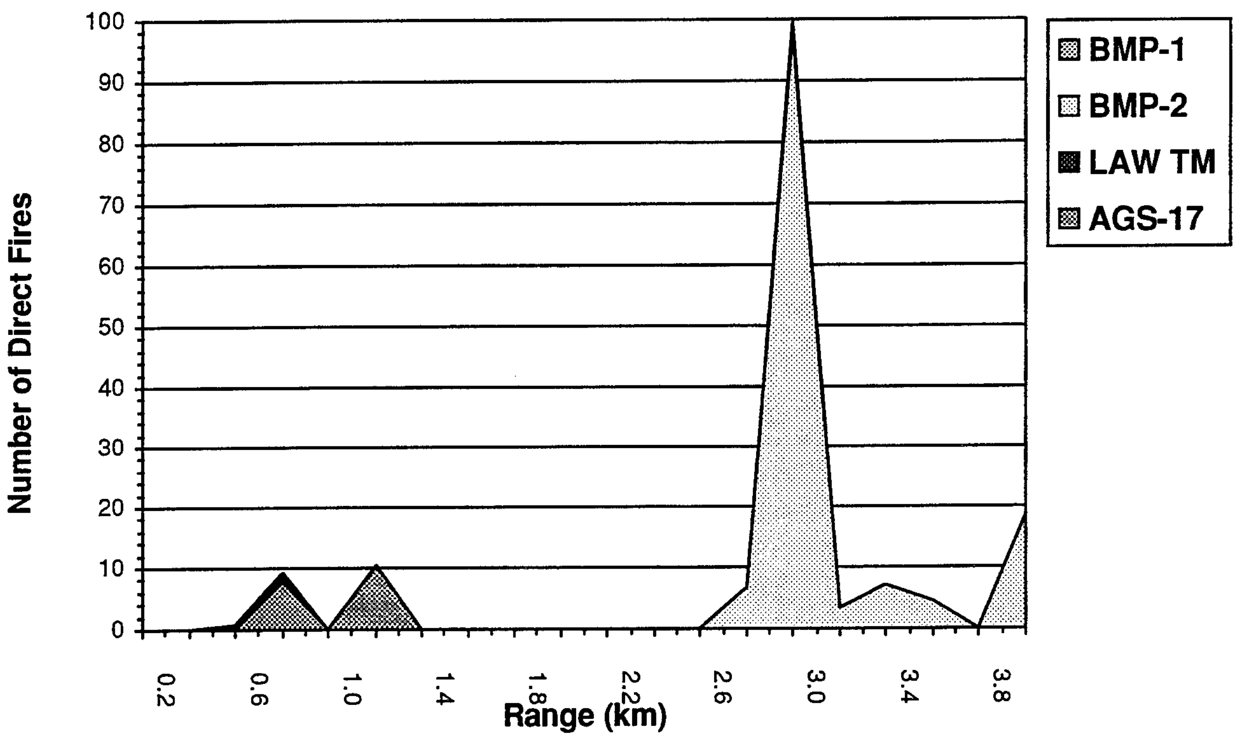

Figure 3.21a Red fires, 14" snow

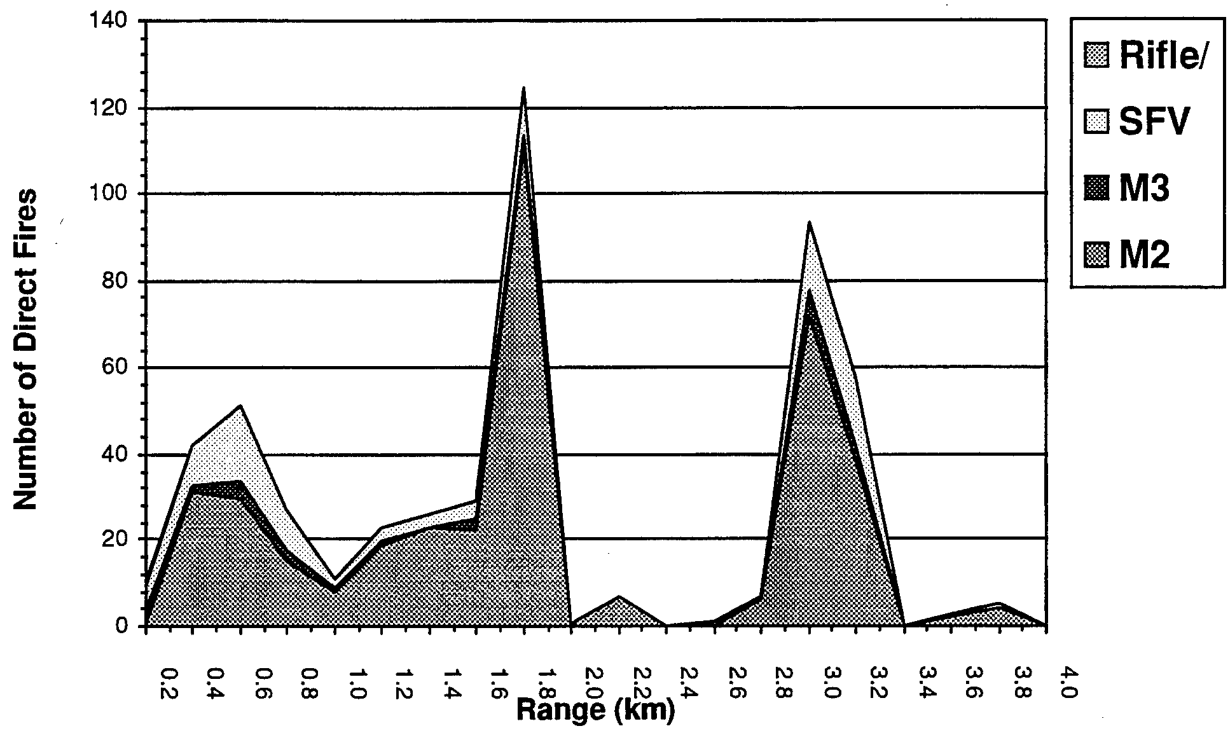

Figure 3.21b Blue fires, 14" snow

Blue consistently has three periods of intense firing: at TOW standoff range (less than 3.75 kilometers), at Bradley 25mm standoff range (less than 2 kilometers), and during the assault on the objective.

The majority of red's firing occurred at optimum missile range (3 kilometers) and jumped from 14.7 to 56.1 (282 percent) from the base case to the NRMM no snow scenario, and another 79 percent to 101.7 and 99.5 in the 7″ and 14″ snow scenarios, respectively.

3.4.5 Kills by Range

Kills by Range shows the effectiveness of fires over the course of the scenario. It is also useful in evaluating standoff ranges and engagement area effectiveness. Tables 3.12 and 3.13 show the mean number of kills by side, range band, and experiment.

Figures 3.22 through 3.25 show Red and Blue direct fires for each experiment. Supporting data are in Appendix G.

Red Kills by Range				
	Base	0" Snow	7" Snow	14" Snow
0 - < 1 Km	4.13	1.53	0.60	0.47
1 - < 2 Km	4.33	0.50	3.23	3.73
2 - < 3 Km	1.47	0.03	0.67	0.20
3 - > 3 Km	2.66	5.84	28.92	25.78

Table 3.12 Red kills by range

Blue Kills by Range				
	Base	0" Snow	7" Snow	14" Snow
0 - < 1 Km	42.50	26.10	18.47	12.80
1 - < 2 Km	6.07	13.20	10.27	10.23
2 - < 3 Km	0.17	1.00	0.17	0.57
3 - > 3 Km	1.50	1.46	1.98	1.86

Table 3.13 Blue kills by range

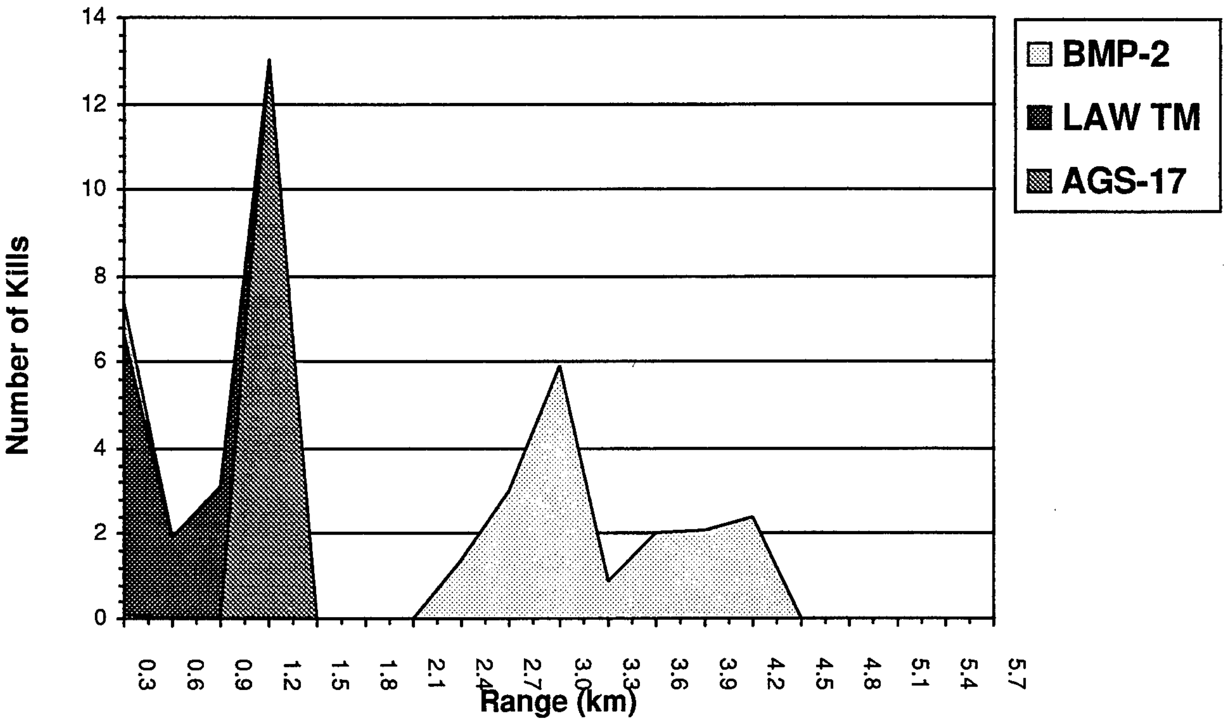

Figure 3.22a Red kills, Janus base case

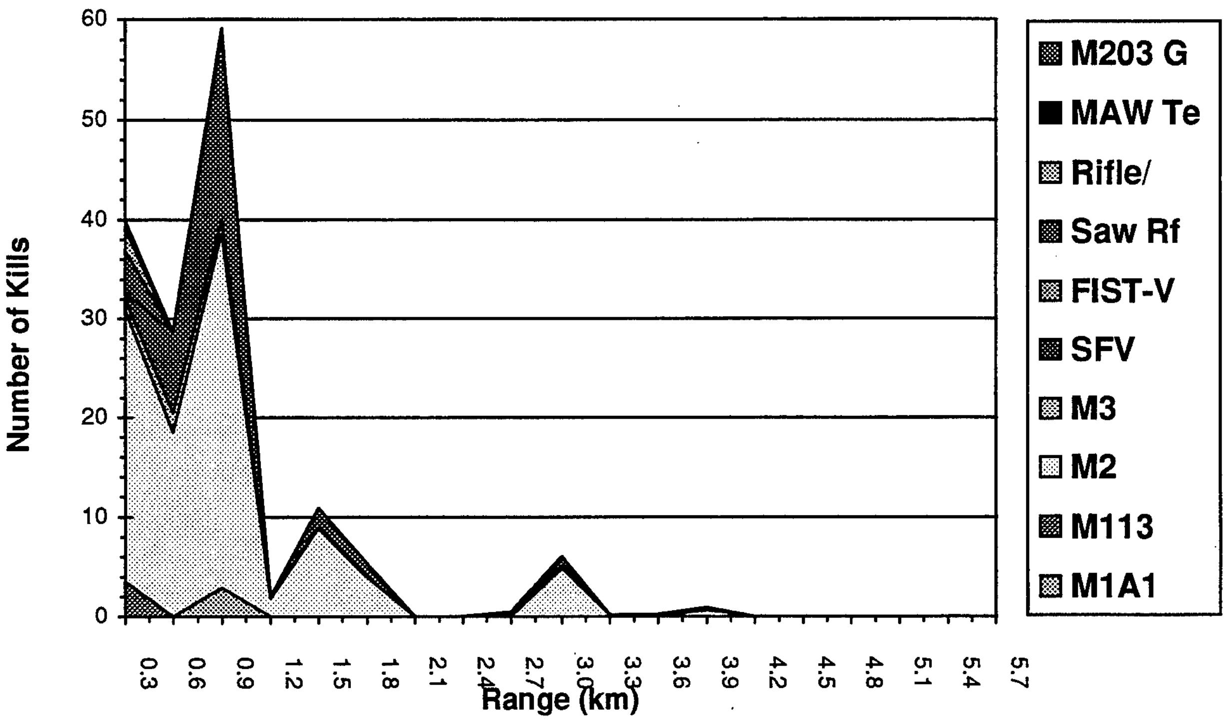

Figure 3.22b Blue kills, Janus base case

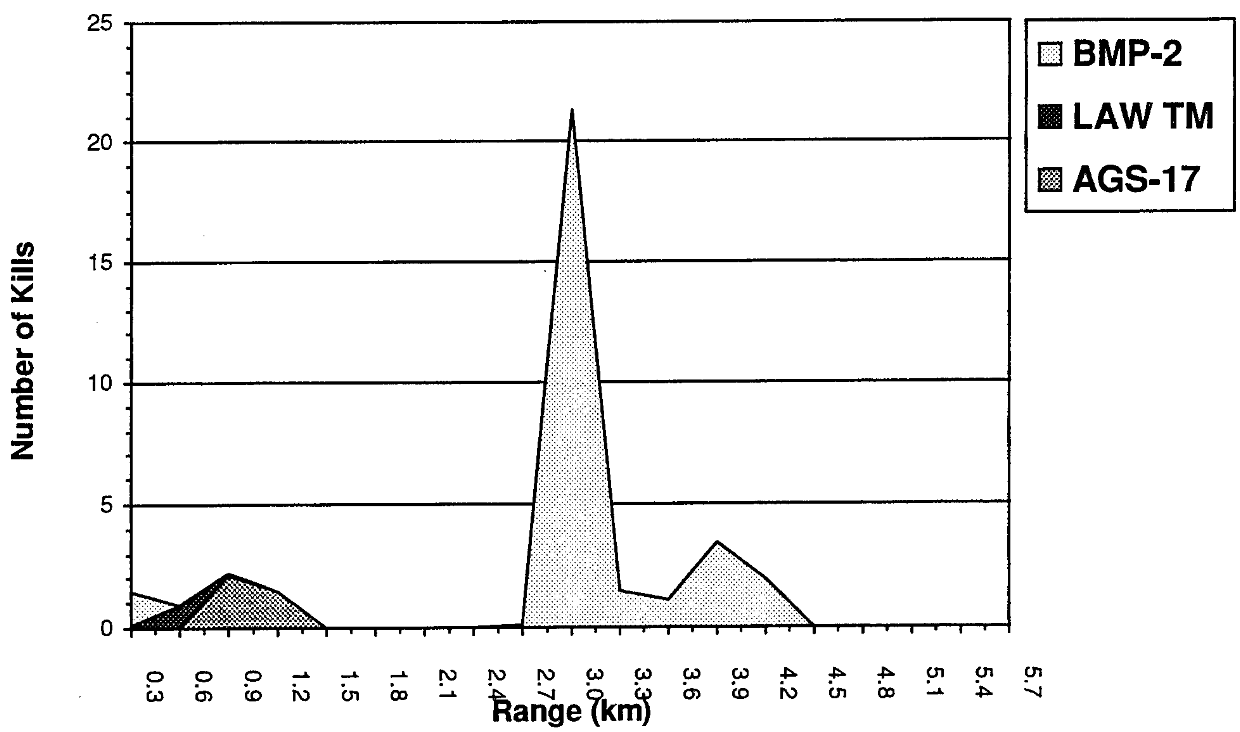

Figure 3.23a Red kills, NRMM base case

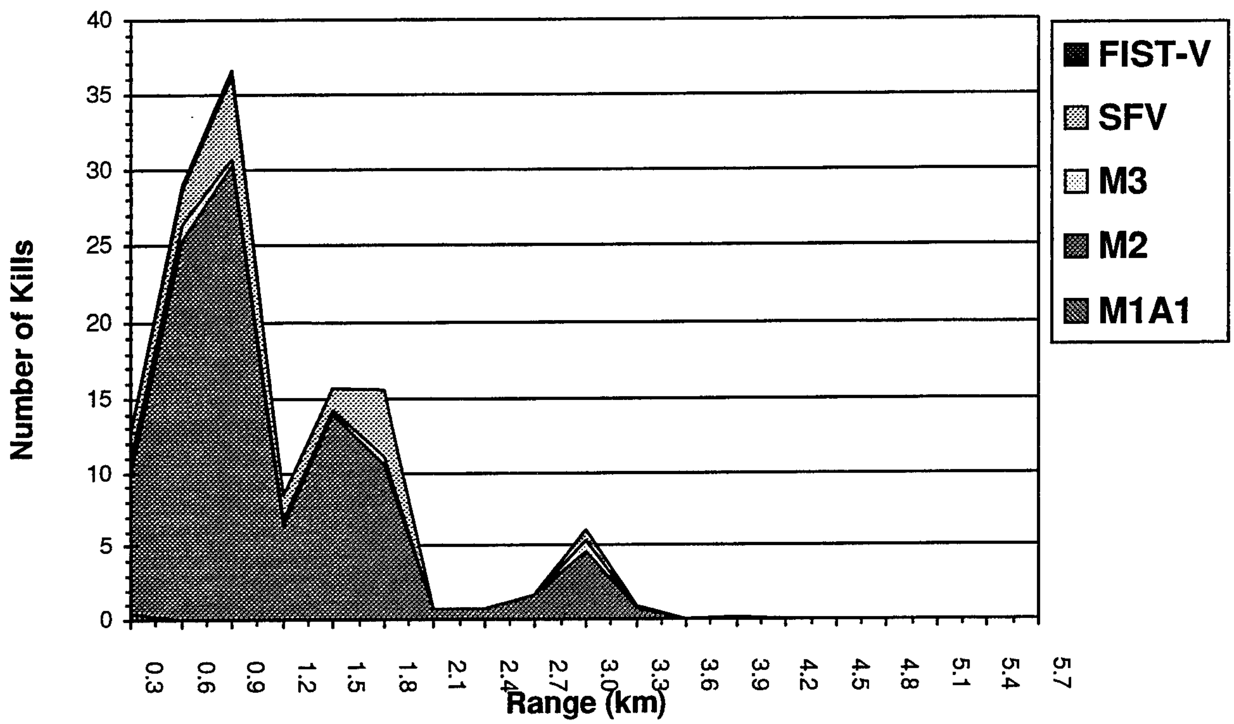

Figure 3.23b Blue kills, NRMM base case

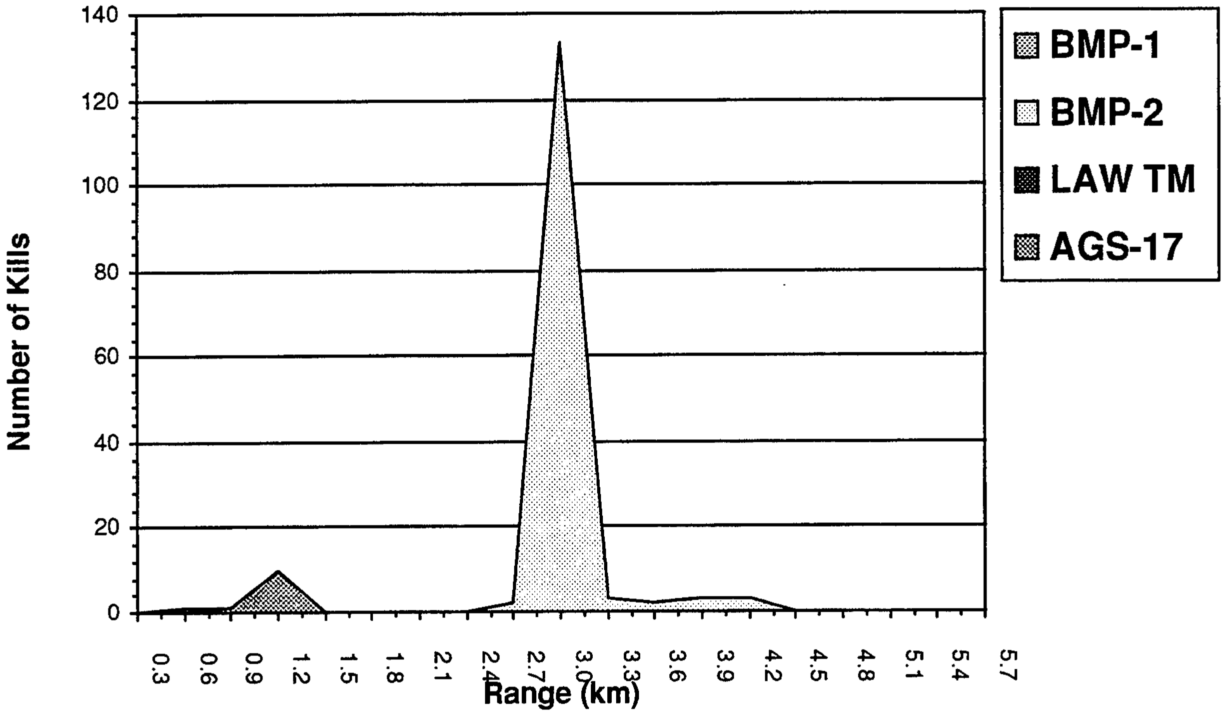

Figure 3.24a   Red kills, 7" snow

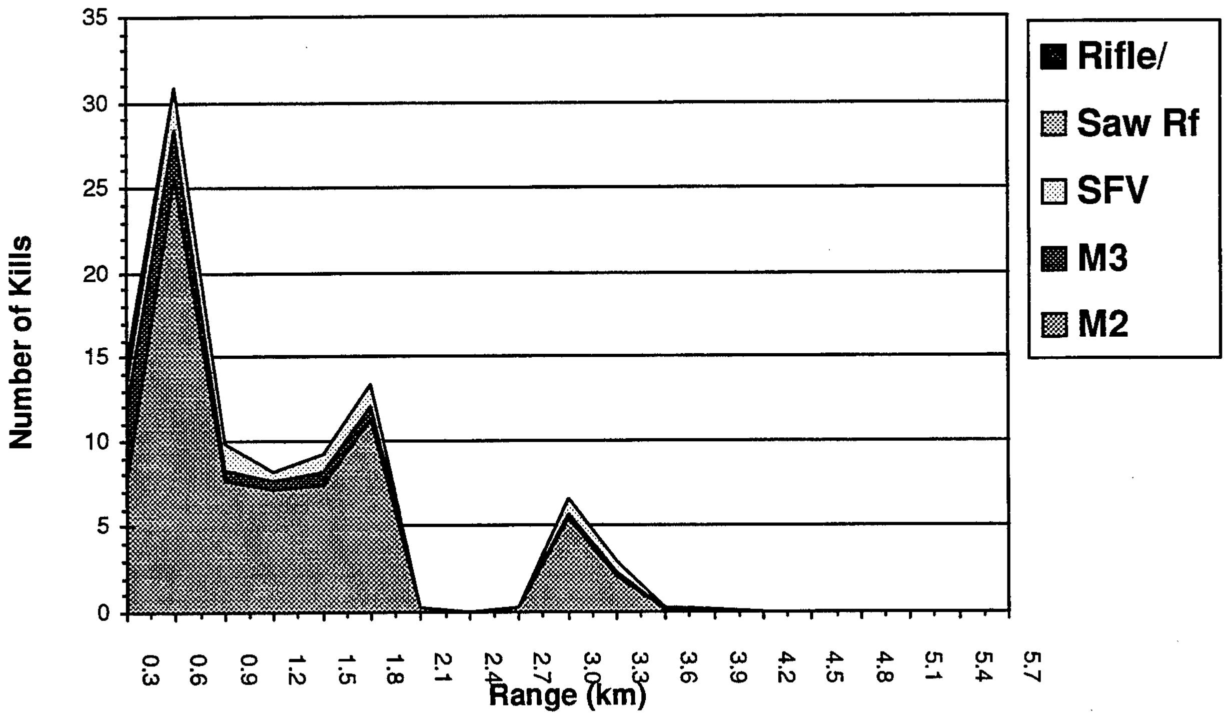

Figure 3.24b   Blue kills, 7" snow

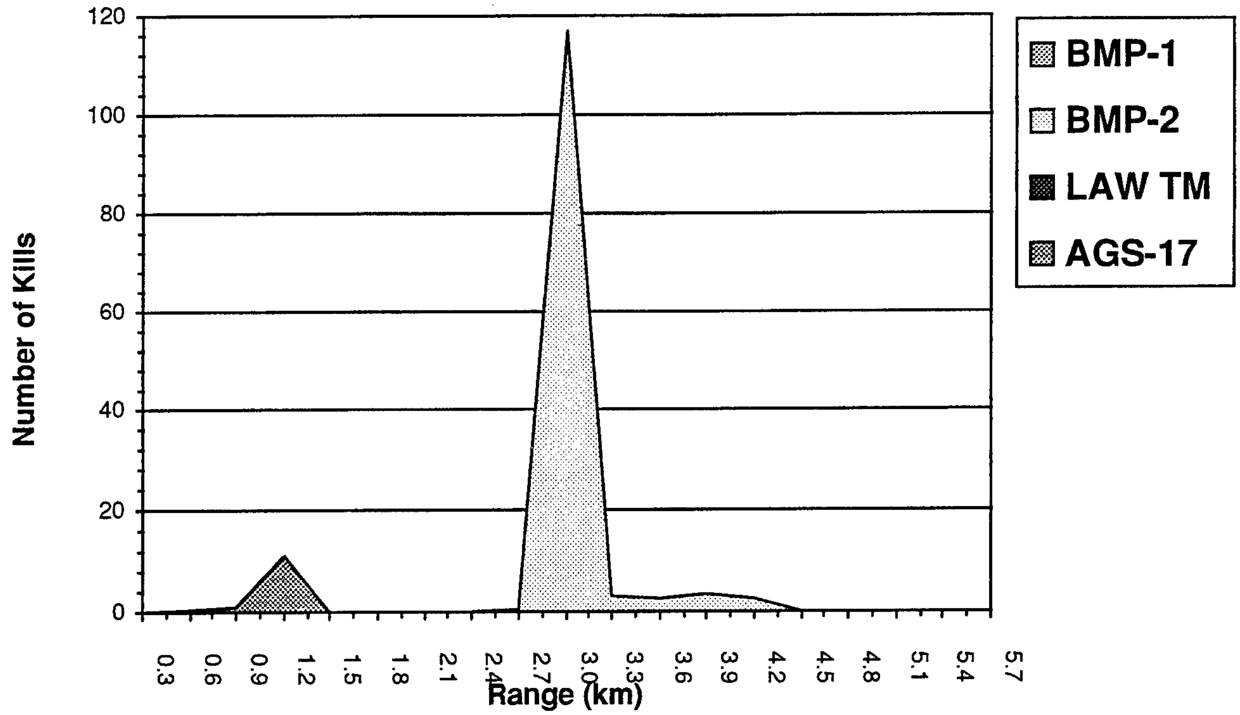

Figure 3.25a Red kills, 14" snow

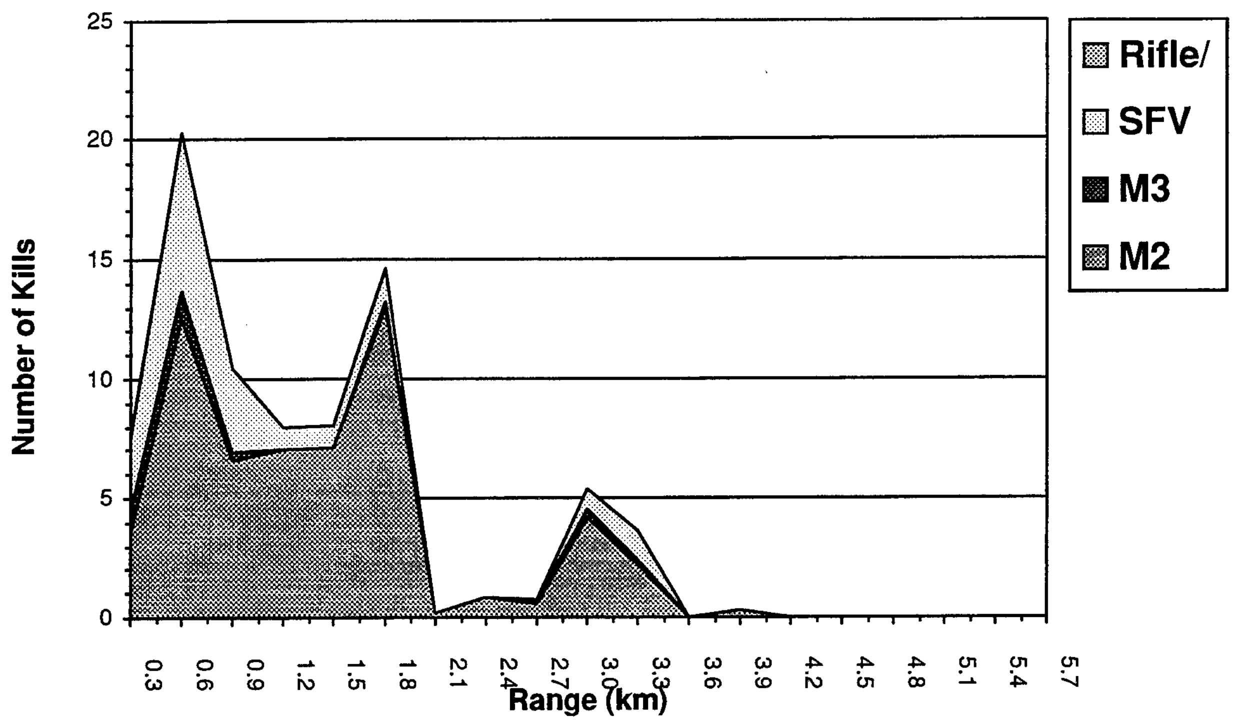

Figure 3.25b Blue kills, 14" snow

The effectiveness of Red and Blue fires can be measured by kill-to-fire ratios, shown in Tables 3.14 and 3.15. These tables show the ratio of the mean number of kills divided by the mean number of fires for each side, range band, and experiment. A number greater than one suggests that the victim was a vehicle with units mounted.

Red Kill to Fire Ratio				
	Base	0" Snow	7" Snow	14" Snow
0 - <1 Km	1.50	0.23	0.26	0.19
1 - <2 Km	1.07	0.14	1.44	1.83
2 - <3 Km	0.42	0.08	0.24	0.15
>3 Km	0.42	0.44	1.28	1.16

Table 3.14 Red kill to fire ratio

Blue Kill to Fire Ratio				
	Base	0" Snow	7" Snow	14" Snow
0 - <1 Km	0.38	0.43	8.03	0.39
1 - <2 Km	0.17	0.24	4.58	0.24
2 - <3 Km	0.03	0.13	0.06	0.20
>3 Km	0.10	0.09	0.09	0.07

Table 3.15 Blue kill to fire ratio

3.4.6 Time to Objective

Time to objective reflects the mean game time until the first Blue unit arrives on the objective. It is useful in measuring the effects of snow on operational time covering a small tactical distance (about 5 kilometers).

Table 3.16 shows the time to objective for each experiment. In run 1 of the 7″ scenario and runs 8, 9, and 12 of the 14″ scenario no Blue vehicle reached the objective within the 60 minutes of game time. In a number of cases, Blue vehicles were nearly motionless due to the environment, but still were able to fire onto the objective.

Blue Time to Objective (minutes)				
Run	Base	0	7	14
1	33	54		54
2	34	51	53	56
3	34	52	55	55
4	32	52	55	56
5	35	51	54	
6	36	53	54	
7	34	51	51	54
8	34	52	53	54
9	35	52	52	
10	35	53	54	60

Table 3.16 Blue time to objective

Analysis supports the alternate hypotheses that the mean time to objective between each of the four experiments is not the same. See Table 3.17 and Appendix H.

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level       N      Mean      StDev    ---+---------+---------+---------+---
Base Case  10    34.200      1.135     (*)
0" Snow    10    52.100      0.994                              (*-)
7" Snow     9    53.444      1.333                                (*-)
14" Snow    7    55.571      2.149                                   (*-)
                                      ---+---------+---------+---------+---
Pooled StDev =    1.397                 35.0      42.0      49.0      56.0
```

Table 3.17 Means, standard deviations, and 95% CI for time to objective

4. Summary and Conclusions

4.1 General

The study of weather effects on tactical military operations has focused almost exclusively on human factors, with the majority of those efforts addressing the effects of hot temperatures. Considerably less has been devoted to man/machine factors, and less yet to integration of known weather effects into commonly used training and analysis simulations. This study begins that integration. Through a survey of human factors studies, exploration into cold weather effects on mobility and countermobility, and analysis of cold weather effects in a combat simulation, the need is highlighted for additional research.

4.2 Effects on Mounted Operations

From a mounted operations perspective, cold weather and snow can affect many factors. This study concentrated simply on one of those factors – mobility. As shown by the results presented in Chapter 3, the mobility degredation produce a predictable affect (i.e., the enemy had more time to acquire, track, and kill the blue force). Of more interest are the effects on sensors during periods of heavy snowfall and cold weather. For North Korea, would the U.S. loose their technology advantage because of the degraded performance of thermal sights and laser targeting systems? If so how would the U.S. perform in a major regional conflict initiated by the North under such conditions? These are some of the issues that must be addressed.

4.3 Effects on Human Factors

The effects of extreme winter conditions on human factors issues such as manual dexterity and the subsequent effects on military operations is very complicated. For mounted and dismounted operations the effects could be dramatic. Though beyond the scope of this original effort (i.e., quantify the effects of cold weather operations on the traditional engineering functions such as mobility and countermobility based upon battle outcome, human/machine interaction and equipment effectiveness must be addressed simultaneously to capture the true effects.

4.4 Effects on Combat Simulations

4.4.1 Summary of MOE

Table 4.1 summarizes the results of the analyses of variance (ANOVA) for the data contained in Chapter 3. H_0 represents the null hypothesis, μ is the mean of the outcomes of the experiment noted by the subscript, where Base is the Janus base case, the NRMM base case, and 7 and 14 are snow depth experiments in inches.

Measure of Effectiveness	Hypothesis	Result
Blue Force Status	H_0: $\mu_{Base}=\mu_0=\mu_7=\mu_{14}$ H_0: $\mu_{Base}=\mu_0$ H_0: $\mu_7=\mu_{14}$	Reject Reject Fail to reject
Red Force Status Objective Tom only	H_0: $\mu_{Base}=\mu_0=\mu_7=\mu_{14}$	Fail to reject
Red Force Status All Red	H_0: $\mu_{Base}=\mu_0=\mu_7=\mu_{14}$ H_0: $\mu_{Base}=\mu_0$ H_0: $\mu_7=\mu_{14}$	Reject Reject Fail to reject
Force Exchange Ratio	H_0: $\mu_{Base}=\mu_0=\mu_7=\mu_{14}$ H_0: $\mu_0=\mu_7=\mu_{14}$ H_0: $\mu_7=\mu_{14}$	Reject Reject Fail to reject
Time to Objective	H_0: $\mu_{Base}=\mu_0=\mu_7=\mu_{14}$ H_0: $\mu_0=\mu_7=\mu_{14}$	Reject Reject

Table 4.1 ANOVA Results

An analysis of variance is a test for equality of several means. It asks the question: Can the samples represented by these means be considered to have been drawn from populations having the same mean, or does the variation within the samples reflect chance errors of the sampling process?

Accepting a 5 percent chance of rejecting the hypothesis when in fact it is true, we determine an *F ratio* of the variances between experiments and within experiments.

If that number is close to one, we do not reject the hypothesis. The acceptable divergence from one is determined by the probability distribution of the *F* random variable given the degrees of freedom of the two variations.

Citing the Blue Force Status analysis (page B-3), we conclude that the hypothesis that the means of all four experiments are the same must be rejected because the F ratio (46.03) exceeds the critical value (2.86) allowable given our 5 percent tolerance.

The hypothesis that the means between the two snow experiments are equal is not rejected, however, since the F ratio (0.63) does not exceed the F statistic (4.41).

Tables 4.2 and 4.3 show the relationships between direct fires and the base case (standard Janus terrain) and the NRMM-adjusted frozen ground experiments.

Blue Direct Fire Comparisons				
		0" Snow	7" Snow	14" Snow
0 - < 1 Km	% of Base Case	53.33%	2.03%	28.93%
	% of 0" (NRMM)		3.81%	54.24%
1 - < 2 Km	% of Base Case	155.30%	6.45%	122.87%
	% of 0" (NRMM)		4.27%	79.12%
2 - < 3 Km	% of Base Case	149.61%	54.69%	57.03%
	% of 0" (NRMM)		36.55%	38.12%
3 - > 3 Km	% of Base Case	101.54%	148.52%	174.75%
			146.27%	172.11%

Table 4.2 Blue direct fire comparisons

Red Direct Fire Comparisons				
		0″ Snow	7″ Snow	14″ Snow
0 - < 1 Km	% of Base Case	241.82%	83.64%	91.82%
	% of 0" (NRMM)		34.59%	37.97%
1 - < 2 Km	% of Base Case	89.60%	55.45%	50.50%
	% of 0" (NRMM)		61.88%	56.35%
2 - < 3 Km	% of Base Case	11.43%	80.00%	37.71%
	% of 0" (NRMM)		700.00%	330.00%
3 - > 3 Km	% of Base Case	207.89%	356.05%	351.05%
			171.27%	168.86%

Table 4.3 Red direct fire comparisons

Tables 4.4 and 4.5 show the relationships between kills and the base case (standard Janus terrain) and the NRMM-adjusted frozen ground experiments.

Blue Kill Comparisons				
		0″ Snow	7″ Snow	14″ Snow
0 - < 1 Km	% of Base Case	61.41%	43.46%	30.12%
	% of 0" (NRMM)		70.77%	49.04%
1 - < 2 Km	% of Base Case	217.46%	169.19%	168.53%
	% of 0" (NRMM)		77.80%	77.50%
2 - < 3 Km	% of Base Case	588.24%	100.00%	335.29%
	% of 0" (NRMM)		17.00%	57.00%
3 - > 3 Km	% of Base Case	97.33%	132.00%	124.00%
	% of 0" (NRMM)		135.62%	127.40%

Table 4.4 Blue kill comparisons

Red Kill Comparisons				
		0″ Snow	7″ Snow	14″ Snow
0 - < 1 Km	% of Base Case	37.05%	14.53%	11.38%
	% of 0" (NRMM)		37.05%	14.53%
1 - < 2 Km	% of Base Case	11.55%	74.60%	86.14%
	% of 0" (NRMM)		11.55%	74.60%
2 - < 3 Km	% of Base Case	2.04%	45.58%	13.61%
	% of 0" (NRMM)		2.04%	45.58%
3 - > 3 Km	% of Base Case	219.55%	1087.22%	969.17%
	% of 0" (NRMM)		219.55%	1087.22%

Table 4.5 Red kill comparisons

4.4.2 Conclusions

4.4.2.a Standard Janus Versus NRMM Enhanced Scenarios

Results strongly suggest that there is a significant difference in simulation outcomes between the standard Janus and enhanced (NRMM base case) scenarios. Examination of Blue vehicles remaining in the base case shows a 75.42 percent mean survival rate, whereas the rate in the enhanced terrain scenario was 63.13 percent. Mean Red survival jumped from 47.08 percent in the base case to 55.65 percent.

Fires and kills also show marked differences between the experiments. Blue fired about the same number of shots (101.54 percent) in the enhanced experiment at ranges of three kilometers and greater with about the same lethality (97.33 percent). Red fired more than twice as often (207.89 percent) in the enhanced terrain experiment and more than doubled its lethality (219.55 percent).

Blue effectiveness increased at medium ranges in the enhanced experiment, with the greatest increase in the 2 - 3 kilometer range band. Blue fires in this band increased by nearly half (149.61 percent of base case). Kills nearly five times greater in the enhanced experiment (588.24 percent of base case) suggest greater effectiveness against vehicles with mounted units. This also may be the result of increased detections by

Blue because of the earlier Red fire times. Detection data were not analyzed in these experiments.

Action on the objective (less than 1 kilometer) reflect the effects of Red's greater effectiveness at longer ranges. Red's kills in that band are 37.05 percent of the base case and Blue's are 61.41 percent.

The one measure that did not show a significant difference between any of the four experiments was mean Red force on the objective. In all cases the Red motorized rifle company was completely or almost completely destroyed. Blue's attrition prior to then points back to the total Red survival rate mentioned earlier.

4.4.2.b Seven-Inch Versus Fourteen-Inch Snow Scenario

Results strongly suggest that there is no significant difference in outcomes between the two snow experiments. Only in the time to objective MOE could the difference not be attributed to chance, using a 95 percent confidence interval.

Blue forces remaining were 35.6 and 39.3 percent respectively for the two experiments. Total Red forces remaining were 66.43 and 72.35 percent respectively.

4.4.2.c Frozen Ground/No Snow Versus Snow

Results suggest that there is a significant difference between the no-snow and snow experiments using NRMM data. Contrasting the mean Blue force remaining in the no-snow experiment (63.13 percent) with the mean of the two snow levels (37.45 percent) shows a 25.68 percent drop in survivability when attacking under the experimental conditions.

A limitation of Janus is that there is no withdrawal criteria -- units will follow assigned routes regardless of attrition, fear, or fatigue. In the no-snow experiment, Blue lost a third of its vehicles within 53 minutes. This coincided with the mean time of first unit on the objective, so it is reasonable to assume that momentum may keep a unit moving onto the objective.

In the two snow experiments, however, a third was lost within the first 28 minutes, approximately half the time until the first unit reached the objective. That number dropped to half within 34 minutes. At this point the prudence and efficacy to fight through is in question.

4.4.2.d Tactics, Techniques and Procedures (TTP)

Army TTPs such as FM 71-123, *"Tactics and Techniques for Combined Arms Heavy Forces: Armored Brigade, Battalion/Task Force, and Company/Team,"* suggest attacking defending company-sized units with at least battalion strength. Army doctrine, including FM 100-5, *"Operations,"* further stress synchronization of all the Battlefield Operating Systems (BOS) to achieve success. These experiments did not employ fire support, either through coordinated indirect fire or close air support (CAS) from rotary or fixed wing aircraft.

Prospects for success of an attack under any but the base case conditions is marginal. As Blue mobility decreased, prolonged exposure to enemy missile fire caused significant battle damage. Indirect fires, including suppression and CAS, may reduce vulnerability during crossings of exposed areas. Failure to maintain offensive mass in snow conditions further degraded Blue's effectiveness and enabled Red to attrit Blue more piecemeal.

4.5 Future Work

4.5.1 Combat Simulation

This study suggests there is sharp decrease in offensive effectiveness as mechanized units move from a no-snow to a snow environment. However there is no significant difference in effectiveness between the 7-inch and 14-inch levels. This suggests that there is point at which a steep decline in effectiveness levels out, beyond which additional combat multipliers need to be used to ensure success. Given the diverse environments in which the Army may be called, it is useful to further explore where that threshold may be.

This study examined only one factor, mobility due to snow conditions. Integration of human factors and man/machine effects of cold weather also could be expected to generate significant results. Atmospheric conditions unique to cold weather also warrant attention. Detections and laser effectiveness are two areas that may be studied.

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Appendix A: NRMM Vehicle Speed Predictions

NRMM Vehicle Speed Predictions

VEHICLE 1 FILE=M1A1.STD ID= M1A1 ABRAMS TANK (WES STANDARD)					
Slope	Predicted Speed (mph)				
(%)	Omni	Up	Level	Down	% delta
0	39.31	39.31	39.31	39.31	
0	39.65	39.65	39.65	39.65	
0	38.6	38.6	38.6	38.6	
10	27.14	16.48	39.31	40.95	69.04%
10	26.98	16.34	39.65	40.35	68.05%
10	26.02	15.48	38.6	40.35	67.41%
20	21	10.75	39.31	40.95	53.42%
20	19.79	9.99	37.5	40.35	49.91%
20	19.22	9.56	37.5	40.35	49.79%
30	15.63	7.04	39.31	40.95	39.76%
30	12.69	5.85	24.52	40.35	32.01%
30	12.46	5.71	24.52	40.35	32.28%

VEHICLE 2 FILE=M2A1.DAT ID= M2A1 BRADLEY					
Slope	Predicted Speed (mph)				
(%)	Omni	Up	Level	Down	% delta
0	35.74	35.74	35.74	35.74	
0	34.62	34.62	34.62	34.62	
0	30.64	30.64	30.64	30.64	
10	25.09	15.65	35.74	36.12	70.20%
10	23.98	14.57	34.62	36.23	69.27%
10	22.14	13.29	30.64	36.23	72.26%
20	16.65	8.03	35.74	36.12	46.59%
20	15.3	7.16	34.62	36.23	44.19%
20	14.25	6.65	30.64	36.23	46.51%
30	13.77	6.17	35.74	36.12	38.53%
30	12.02	5.18	34.62	36.23	34.72%
30	11.48	4.98	30.64	36.23	37.47%

VEHICLE 3 FILE=M113A1.DAT ID= M113A1 APC					
Slope	Predicted Speed (mph)				
(%)	Omni	Up	Level	Down	% delta
0	27.54	27.54	27.54	27.54	
0	22.23	22.23	22.23	22.23	
0	20.44	20.44	20.44	20.44	
10	19.98	11.09	27.54	42.19	72.55%
10	18.09	10.31	22.23	42	81.38%
10	17.36	9.99	20.44	42	84.93%
20	17.33	8.84	27.54	42.19	62.93%
20	14.81	7.47	22.23	42	66.62%
20	13.29	6.53	20.44	42	65.02%
30	11.32	4.88	27.54	42.19	41.10%
30	9.37	3.98	22.23	42	42.15%
30	8.71	3.68	20.44	42	42.61%

VEHICLE 4 FILE=AVLB.DAT ID= AVLB (M60A1 CHASSIS)					
Slope	Predicted Speed (mph)				
(%)	Omni	Up	Level	Down	% delta
0	21.16	21.16	21.16	21.16	
0	21.99	21.99	21.99	21.99	
0	20.5	20.5	20.5	20.5	
10	15.48	8.87	21.16	29.55	73.16%
10	15.34	8.63	21.99	29.21	69.76%
10	14.72	8.28	20.5	29.21	71.80%
20	11.16	5.33	21.16	29.55	52.74%
20	10.57	4.9	21.99	29.21	48.07%
20	10.16	4.71	20.5	29.21	49.56%
30	7.58	3.18	21.16	29.54	35.82%
30	6.59	2.66	21.99	29.21	29.97%
30	6.35	2.57	20.5	29.21	30.98%

VEHICLE 5 FILE=M9.DAT ID= M9 (ACE)					
Slope	Predicted Speed (mph)				
(%)	Omni	Up	Level	Down	% delta
0	31.92	31.92	31.92	31.92	
0	31	31	31	31	
0	30.83	30.83	30.83	30.83	
10	19.84	11.29	31.92	31.92	62.16%
10	18.66	10.39	31	31	60.19%
10	17.94	9.75	30.83	31	58.19%
20	14.67	7.05	31.92	31.92	45.96%
20	13.31	6.21	31	31	42.94%
20	12.8	5.9	30.83	31	41.52%
30	11.65	5.13	31.92	31.91	36.50%
30	9.85	4.16	31	31	31.77%
30	9.25	3.85	30.83	31	30.00%

Notes

Constant at all levels:

TT = 1
UC = 4
JP = 1
TR = 1
IR = 1

Freeze Depth = 99"
Thaw Depth = 0"
Soil Type = SM-SC

Values applied to 1 sq. km. areas

Appendix B: Blue Force Status By Time

Blue Force Status by Time

Janus Base Case

Minutes	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
3	96	96	96	96	96	96	96	96	96	96
6	96	96	96	96	96	96	96	96	96	96
9	96	96	96	96	96	96	96	96	96	96
12	95	95	95	95	95	95	95	95	95	95
15	92	95	89	93	92	91	93	94	90	91
18	87	91	86	91	90	87	90	90	86	88
21	81	85	84	72	77	86	90	83	67	78
24	78	81	84	71	73	86	90	79	63	78
27	78	81	84	71	73	86	90	79	63	78
30	77	79	83	71	71	83	88	78	62	77
33	77	77	81	71	68	82	84	78	58	73
36	75	75	80	71	66	81	82	77	56	71
39	74	74	79	70	65	79	82	76	55	71
42	73	74	79	70	65	79	82	76	55	71
45	73	74	79	70	65	79	82	76	55	71
48	73	74	79	70	65	79	82	76	55	71
51	73	74	79	70	65	79	82	76	55	71
54	73	74	79	70	65	79	82	76	55	71
57	73	74	79	70	65	79	82	76	55	71
60	73	74	79	70	65	79	82	76	55	71

NRMM Base Case

3.1	96	96	96	96	96	96	96	96	96	96
6.2	96	96	96	96	96	96	96	96	96	96
9.3	96	96	96	96	96	96	96	96	96	96
12.4	96	96	96	96	96	96	96	96	96	96
15.5	95	95	95	95	94	94	96	95	95	95
18.6	93	91	91	92	93	93	94	94	93	91
21.7	85	85	83	84	87	85	86	86	86	84
24.8	75	76	75	75	77	75	78	75	75	77
27.9	66	66	66	69	66	74	67	73	66	73
31	65	60	62	69	65	74	64	73	62	73
34.1	65	60	62	69	65	74	64	73	62	73
37.2	64	60	62	69	65	74	64	73	62	73
40.3	63	57	61	69	64	73	62	70	62	71
43.4	63	57	61	69	64	73	62	70	58	71
46.5	63	57	61	69	64	73	62	70	57	71
49.6	63	57	61	69	64	73	62	70	57	71
52.7	63	57	60	69	64	73	62	70	57	71
55.8	58	55	57	68	61	67	58	65	53	68
58.9	58	55	57	68	59	67	57	65	53	68
62	58	54	57	68	59	67	57	65	53	68

7" Snow

Minutes	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
3.1	96	96	96	96	96	96	96	96	96	96
6.2	96	96	96	96	96	96	96	96	96	96
9.3	96	96	96	96	96	96	96	96	96	96
12.4	96	96	96	96	96	96	96	96	96	96
15.5	94	95	95	92	94	93	93	92	96	94
18.6	92	91	92	89	90	90	89	87	93	90
21.7	85	80	83	83	86	84	84	79	83	82
24.8	74	76	75	74	77	74	75	75	73	76
27.9	61	64	64	64	66	64	64	65	60	66
31	41	50	53	56	52	54	52	47	55	50
34.1	30	39	40	39	43	48	46	39	39	35
37.2	27	39	40	33	43	48	46	39	35	29
40.3	22	39	40	32	43	48	46	39	35	29
43.4	22	39	40	32	43	48	46	39	35	29
46.5	22	37	40	30	41	48	46	37	34	29
49.6	22	37	36	30	40	48	46	37	34	26
52.7	22	37	36	30	40	48	46	37	34	26
55.8	20	37	36	30	40	48	46	37	33	26
58.9	19	32	35	30	39	48	45	37	32	26
62	19	31	35	30	39	48	45	37	32	26

14" Snow

3.1	96	96	96	96	96	96	96	96	96	96
6.2	96	96	96	96	96	96	96	96	96	96
9.3	96	96	96	96	96	96	96	96	96	96
12.4	96	96	96	96	96	96	96	96	96	96
15.5	93	95	96	94	94	95	94	95	95	93
18.6	88	90	92	91	91	91	89	90	90	88
21.7	85	84	82	85	85	85	83	82	84	82
24.8	77	77	77	77	77	77	77	77	77	77
27.9	63	66	67	66	67	66	67	66	67	66
31	56	64	62	64	61	65	61	64	61	65
34.1	53	50	57	57	48	57	54	53	44	52
37.2	42	47	57	44	45	37	47	44	33	51
40.3	38	47	57	42	45	31	47	44	32	51
43.4	38	47	57	42	45	24	47	44	23	51
46.5	38	46	56	42	45	22	46	43	21	48
49.6	37	46	56	41	44	20	46	43	20	45
52.7	37	46	56	41	40	19	46	43	18	45
55.8	37	45	52	41	40	19	46	42	18	45
58.9	36	42	52	38	40	19	45	42	18	45
62	36	42	52	38	40	19	45	42	18	45

Analysis of Variance - Blue Force Status

run	Base	0" Snow	7" Snow	14" Snow
1	73	58	19	36
2	74	54	31	42
3	79	57	35	52
4	70	68	30	38
5	65	59	39	40
6	79	67	48	19
7	82	57	45	45
8	76	65	37	42
9	55	53	32	18
10	71	68	26	45

```
                                             Individual 95% CIs For Mean
                                             Based on Pooled StDev
 Level        N       Mean      StDev    -+---------+---------+---------+-----
Base Case    10     72.400      7.891                              (--*---)
NRMM         10     60.600      5.835                      (--*---)
7" Snow      10     34.200      8.626    (---*--)
14" Snow     10     37.700     11.026      (---*---)
                                         -+---------+---------+---------+-----
Pooled StDev =       8.548               30        45        60        75
```

Hypothesis: $H_0: \mu_{Base} = \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	3	10090.5	3363.5	46.03	0.000
Error	36	2630.5	73.1		
Total	39	12721.0			

$F(3, 36) = 46.03$; $F_{0.05}(3, 36) = 2.86$
$46.03 > 2.86$
Reject null hypothesis

Hypothesis: $H_0: \mu_{Base} = \mu_0$

Source	DF	SS	MS	F	p
Factor	1	696.2	696.2	14.46	0.001
Error	18	866.8	48.2		
Total	19	1563.0			

$F(1, 18) = 14.46$; $F_{0.05}(1, 18) = 4.41$
$14.46 > 4.41$
Reject null hypothesis

Hypothesis: $H_0: \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	1	61.2	61.2	0.63	0.439
Error	18	1763.7	98.0		
Total	19	1824.9			

$F(1, 18) = 0.63$; $F_{0.05}(1, 18) = 4.41$; $F_{0.01}(1, 18) = 8.28$
$0.63 < 4.41$
Do not reject null hypothesis

Appendix C: Red Force Status By Time - Objective Tom

Red Force Status by Time

Objective Tom

Janus Base Case

Minutes	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
3	81	81	81	81	81	81	81	81	81	81
6	81	81	81	81	81	81	81	81	81	81
9	81	81	81	81	81	81	81	81	81	81
12	81	81	81	81	81	81	81	81	81	81
15	81	81	81	81	81	81	81	81	81	81
18	78	79	79	78	78	77	76	79	79	79
21	76	76	75	76	77	75	75	76	77	75
24	75	75	75	75	76	75	75	76	76	75
27	75	75	75	75	74	75	67	75	75	75
30	72	66	65	66	70	66	62	72	74	73
33	67	60	62	22	62	62	20	62	65	63
36	48	17	11	13	25	14	3	11	18	11
39	4	4	3	4	4	3	3	5	5	4
42	0	0	0	1	0	0	0	1	1	0
45	0	0	0	1	0	0	0	1	1	0
48	0	0	0	1	0	0	0	1	1	0
51	0	0	0	1	0	0	0	1	1	0
54	0	0	0	1	0	0	0	1	1	0
57	0	0	0	1	0	0	0	1	1	0
60	0	0	0	1	0	0	0	1	1	0

NRMM Base Case

3.1	81	81	81	81	81	81	81	81	81	81
6.2	81	81	81	81	81	81	81	81	81	81
9.3	81	81	81	81	81	81	81	81	81	81
12.4	81	81	81	81	81	81	81	81	81	81
15.5	81	81	81	81	81	81	81	81	81	81
18.6	81	81	81	81	81	81	81	81	81	81
21.7	80	80	81	81	80	81	80	80	81	81
24.8	80	77	80	79	80	79	80	79	80	78
27.9	78	77	77	75	79	75	80	75	78	75
31	75	75	75	75	75	75	76	75	76	75
34.1	74	75	75	75	75	75	75	75	69	75
37.2	71	67	75	67	75	69	70	72	65	69
40.3	67	65	67	65	64	59	66	64	59	57
43.4	62	62	62	62	60	53	55	59	45	54
46.5	50	55	51	21	45	20	46	45	27	31
49.6	17	19	19	20	9	10	7	17	21	5
52.7	8	4	3	4	4	4	4	7	4	4
55.8	3	4	3	0	4	1	1	1	3	0
58.9	0	4	3	0	2	0	0	0	0	0
62	0	4	3	0	0	0	0	0	0	0

7" Snow

Minutes	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
3.1	81	81	81	81	81	81	81	81	81	81
6.2	81	81	81	81	81	81	81	81	81	81
9.3	81	81	81	81	81	81	81	81	81	81
12.4	81	81	81	81	81	81	81	81	81	81
15.5	81	81	81	81	81	81	81	81	81	81
18.6	81	81	81	81	81	81	81	81	81	81
21.7	81	81	81	81	81	81	81	81	81	81
24.8	80	80	81	81	79	81	80	81	81	81
27.9	79	78	79	80	78	80	77	81	81	80
31	77	75	74	75	74	74	74	77	77	76
34.1	76	73	73	74	73	72	71	73	75	74
37.2	74	72	72	73	72	72	71	73	72	74
40.3	73	71	72	73	72	72	71	73	72	74
43.4	73	68	72	73	70	70	57	73	71	74
46.5	73	59	64	54	63	48	50	59	47	66
49.6	73	55	49	51	50	34	44	48	39	62
52.7	73	50	43	22	44	1	18	22	17	56
55.8	73	1	4	4	2	1	6	1	1	35
58.9	73	1	2	4	1	0	0	1	0	10
62	73	0	1	4	1	0	0	1	0	7

14" Snow

3.1	81	81	81	81	81	81	81	81	81	81
6.2	81	81	81	81	81	81	81	81	81	81
9.3	81	81	81	81	81	81	81	81	81	81
12.4	81	81	81	81	81	81	81	81	81	81
15.5	81	81	81	81	81	81	81	81	81	81
18.6	81	81	81	81	81	81	81	81	81	81
21.7	81	81	81	81	81	81	81	81	81	81
24.8	81	81	81	81	81	81	81	81	81	81
27.9	80	80	80	81	79	81	79	81	81	81
31	78	77	75	79	75	79	75	81	81	77
34.1	76	75	72	75	75	79	74	77	80	74
37.2	74	72	72	73	74	77	72	72	77	72
40.3	72	71	72	72	74	77	72	72	77	72
43.4	72	69	65	71	73	77	65	65	76	72
46.5	55	56	49	50	72	77	53	56	76	63
49.6	47	41	41	44	61	77	49	50	76	53
52.7	42	3	5	32	40	77	30	19	76	51
55.8	7	1	0	1	37	77	13	3	76	36
58.9	2	1	0	1	11	77	5	1	76	20
62	0	1	0	1	8	77	1	1	76	19

Analysis of Variance - Red Force Remaining

Objective Only				
run	Base	0	7	14
1	0	0	73	0
2	0	4	0	1
3	0	3	1	0
4	1	0	4	1
5	0	0	1	8
6	0	0	0	77
7	0	0	0	1
8	1	0	1	1
9	1	0	0	76
10	0	0	7	19

```
                                               Individual 95% CIs For Mean
                                               Based on Pooled StDev
 Level        N        Mean       StDev   -+---------+---------+---------+-----
Base Case    10        0.30        0.48    (---------*----------)
NRMM         10        0.70        1.49    (----------*---------)
7" Snow      10        8.70       22.71           (---------*----------)
14" Snow     10       18.40       31.18                   (---------*----------)
                                          -+---------+---------+---------+-----
Pooled StDev =        19.30              -12         0        12        24
```

Hypothesis: $H_0: \mu_{Base} = \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	3	2174	725	1.95	0.140
Error	36	13411	373		
Total	39	15585			

$F(3, 36) = 1.95$; $F_{0.05}(3, 36) = 2.86$

$1.95 < 2.86$

Do not reject null hypothesis

Appendix D: Red Force Status By Time - All Red

Red Force Status by Time
All Red

Janus Base Case

Minutes	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
3	294	294	294	294	294	294	294	294	294	294
6	294	294	294	294	294	294	294	294	294	294
9	294	294	294	294	294	294	294	294	294	294
12	294	294	294	294	294	294	294	294	294	294
15	294	294	294	294	294	294	294	294	294	294
18	291	291	292	290	290	289	288	292	291	291
21	288	287	287	288	289	287	287	288	289	287
24	286	285	287	287	288	287	287	288	288	287
27	285	284	287	285	286	286	275	285	287	287
30	282	272	274	273	279	272	267	282	283	284
33	268	261	268	221	265	266	220	266	274	269
36	246	215	209	187	222	214	181	208	222	212
39	192	183	164	166	175	180	180	179	184	182
42	158	177	155	163	158	169	176	161	167	172
45	150	156	139	158	148	142	155	154	156	137
48	149	141	132	152	148	135	148	149	155	124
51	149	120	131	152	148	133	144	149	155	118
54	147	120	130	152	148	133	144	149	155	118
57	145	120	127	152	148	132	142	149	155	118
60	145	120	125	152	148	131	141	149	155	118

NRMM Base Case

3.1	294	294	294	294	294	294	294	294	294	294
6.2	294	294	294	294	294	294	294	294	294	294
9.3	294	294	294	294	294	294	294	294	294	294
12.4	294	294	294	294	294	294	294	294	294	294
15.5	294	294	294	294	294	294	294	294	294	294
18.6	294	294	294	294	294	294	294	294	294	294
21.7	293	293	294	294	293	294	293	293	294	294
24.8	293	290	292	291	293	291	292	292	292	290
27.9	290	289	289	287	291	287	292	287	290	287
31	287	287	287	287	287	287	288	286	288	287
34.1	285	287	286	287	286	285	287	284	276	285
37.2	279	276	286	277	286	273	279	275	269	279
40.3	273	268	275	270	269	261	272	267	261	263
43.4	266	265	267	265	263	255	256	262	247	259
46.5	249	255	252	218	245	218	247	242	225	227
49.6	215	217	216	217	208	207	205	211	218	199
52.7	206	202	200	201	202	199	202	201	200	198
55.8	199	198	200	160	197	167	191	185	197	167
58.9	174	180	179	152	175	158	158	165	177	148
62	161	180	173	152	173	158	158	162	174	145

7" Snow

Minutes	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
3.1	294	294	294	294	294	294	294	294	294	294
6.2	294	294	294	294	294	294	294	294	294	294
9.3	294	294	294	294	294	294	294	294	294	294
12.4	294	294	294	294	294	294	294	294	294	294
15.5	294	294	294	294	294	294	294	294	294	294
18.6	294	294	294	294	294	294	294	294	294	294
21.7	294	294	294	294	294	294	294	294	294	294
24.8	293	293	294	294	291	293	293	294	294	293
27.9	291	290	291	292	290	292	289	293	293	292
31	289	287	286	287	286	286	286	289	288	288
34.1	288	284	285	285	285	284	282	284	286	286
37.2	286	283	284	284	284	284	282	284	283	286
40.3	285	280	284	284	283	281	280	283	283	286
43.4	285	276	284	284	281	279	258	282	281	286
46.5	285	259	271	256	265	245	247	260	250	274
49.6	285	250	250	251	247	231	241	249	238	268
52.7	285	245	244	221	241	198	215	221	216	257
55.8	285	196	205	203	199	198	203	200	198	234
58.9	285	188	203	203	198	168	189	200	164	209
62	285	176	202	203	190	162	172	198	159	206

14" Snow

3.1	294	294	294	294	294	294	294	294	294	294
6.2	294	294	294	294	294	294	294	294	294	294
9.3	294	294	294	294	294	294	294	294	294	294
12.4	294	294	294	294	294	294	294	294	294	294
15.5	294	294	294	294	294	294	294	294	294	294
18.6	294	294	294	294	294	294	294	294	294	294
21.7	294	294	294	294	294	294	294	294	294	294
24.8	294	294	294	294	294	294	294	294	294	294
27.9	293	292	292	293	291	294	291	293	293	294
31	290	289	287	291	287	291	287	293	293	289
34.1	286	287	281	287	287	291	286	289	292	286
37.2	284	284	278	285	286	289	283	284	289	284
40.3	282	283	278	284	286	289	283	284	289	284
43.4	282	281	270	282	285	288	275	276	288	283
46.5	260	257	243	252	283	288	255	261	288	267
49.6	250	242	235	244	265	288	249	247	287	256
52.7	240	200	199	232	240	288	229	216	287	252
55.8	204	195	192	201	235	288	212	199	287	233
58.9	188	194	170	199	209	288	204	197	287	217
62	175	194	170	199	206	288	200	192	287	216

Analysis of Variance - Red Force Status

All Units				
run	Base	0	7	14
1	145	161	285	175
2	120	180	176	194
3	125	173	202	170
4	152	152	203	199
5	148	173	190	206
6	131	158	162	288
7	141	158	172	200
8	149	162	198	192
9	155	174	159	287
10	118	145	206	216

```
                                           Individual 95% CIs For Mean
                                           Based on Pooled StDev
 Level       N      Mean      StDev    ------+---------+---------+---------+
Base Case   10    138.40      13.76    (-----*----)
NRMM        10    163.60      11.09           (-----*----)
7" Snow     10    195.30      35.97                     (----*----)
14" Snow    10    212.70      41.66                         (-----*----)
                                       ------+---------+---------+---------+
Pooled StDev =    28.90                     140       175       210       245
```

Hypothesis: $H_0: \mu_{Base} = \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	3	32779	10926	13.08	0.000
Error	36	30071	835		
Total	39	62850			

$F(3, 36) = 13.08$; $F_{0.05}(3, 36) = 2.86$
13.08 > 2.86
Reject null hypothesis

Hypothesis: $H_0: \mu_{Base} = \mu_0$

Source	DF	SS	MS	F	p
Factor	1	3175	3175	20.33	0.000
Error	18	2811	156		
Total	19	5986			

$F(1, 18) = 20.33$; $F_{0.05}(1, 18) = 4.41$
20.33 > 4.41
Reject null hypothesis

Hypothesis: $H_0: \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	1	1514	1514	1.00	0.331
Error	18	27260	1514		
Total	19	28774			

$F(1, 18) = 1.00$; $F_{0.05}(1, 18) = 4.41$; $F_{0.01}(1, 18) = 8.28$
1.00 < 4.41
Do not reject null hypothesis

Appendix E: Force Exchange Ratio

Force Exchange Ratio

Janus Base Case

Range	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
5.7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.2	0.789	1.578	0.395	0	3.156	0	0.395	2.367	0.263	0.395
3.9	0.789	3.156	0.225	0.526	0.789	0.132	0.197	1.973	0.099	0.316
3.6	0.592	0.631	0.175	0.395	0.631	0.099	0.158	1.184	0.088	0.197
3.3	0.526	0.947	0.158	0.316	0.658	0.088	0.263	0.789	0.079	0.197
3	0.789	1.085	0.526	0.418	0.579	0.631	0.921	0.947	0.212	0.418
2.7	0.592	0.789	0.592	0.309	0.434	0.631	1.052	0.728	0.191	0.395
2.4	0.526	0.684	0.592	0.284	0.377	0.631	1.052	0.557	0.191	0.395
2.1	0.526	0.684	0.592	0.284	0.377	0.631	1.052	0.557	0.191	0.395
1.8	1.008	0.789	0.921	0.347	0.446	1.105	2.63	0.743	0.359	0.482
1.5	1.754	1.526	1.644	0.537	0.72	2.052	3.683	1.393	0.502	1.008
1.2	1.744	0.842	0.731	0.663	0.512	0.715	1.105	1.315	0.346	0.47
0.9	2.806	2.393	3.069	2.304	1.642	1.914	2.142	3.814	0.839	1.86
0.6	3.293	3.131	3.916	2.841	1.806	2.297	3.183	4.527	1.102	2.514
0.3	3.919	3.121	3.704	4.31	1.92	2.796	2.808	5.721	1.462	2.723

NRMM Base Case

5.7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.2	0	0	0	0	0	0	0	0	0	0
3.9	0	0	0	0	0	0	0	0.07	0	0
3.6	0	0	0	0	0	0	0	0.07	0	0
3.3	0.07	0	0	0.031	0	0.035	0.167	0.093	0	0.031
3	0.063	0.056	0.057	0.083	0.054	0.076	0.052	0.121	0.057	0.085
2.7	0.09	0.062	0.074	0.103	0.081	0.089	0.061	0.121	0.066	0.109
2.4	0.09	0.07	0.074	0.103	0.09	0.127	0.061	0.133	0.066	0.121
2.1	0.09	0.077	0.082	0.103	0.09	0.127	0.087	0.133	0.082	0.121
1.8	0.288	0.147	0.18	0.248	0.252	0.355	0.227	0.376	0.172	0.303
1.5	0.396	0.287	0.32	0.455	0.423	0.583	0.349	0.485	0.353	0.4
1.2	0.456	0.315	0.367	0.455	0.471	0.631	0.418	0.493	0.509	0.491
0.9	0.693	0.516	0.58	0.916	0.717	0.987	0.663	0.781	0.604	1.083
0.6	0.899	0.697	0.792	1.265	0.885	1.24	0.925	0.954	0.788	1.322
0.3	0.969	0.737	0.858	1.405	0.905	1.279	0.965	1.134	0.759	1.444

Notes: -1 indicates a divide by zero, meaning that there had been no Blue losses at that point.
0 indicates the numerator (Red losses) is zero, but at least one Blue loss had occurred.

7" Snow

Range	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
5.7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.2	0	0.789	0	0.395	0.197	0.789	0.789	0.395	1.578	0.789
3.9	0	0.395	0	0.197	0.132	0.451	0.451	0.158	0.526	0.263
3.6	0.158	0.263	0	0.143	0.132	0.351	0.395	0.113	0.395	0.197
3.3	0.316	0.43	0.215	0.21	0.351	0.552	0.71	0.232	0.701	0.287
3	0.034	0.077	0.057	0.059	0.083	0.126	0.102	0.059	0.065	0.045
2.7	0.034	0.076	0.055	0.057	0.104	0.124	0.102	0.059	0.063	0.045
2.4	0.034	0.076	0.055	0.057	0.104	0.124	0.102	0.059	0.063	0.045
2.1	0.034	0.076	0.055	0.062	0.104	0.124	0.102	0.059	0.063	0.049
1.8	0.034	0.156	0.11	0.156	0.208	0.328	0.252	0.135	0.102	0.085
1.5	0.034	0.213	0.203	0.177	0.305	0.426	0.313	0.173	0.165	0.111
1.2	0.034	0.224	0.214	0.206	0.318	0.541	0.374	0.217	0.24	0.111
0.9	0.034	0.272	0.245	0.235	0.395	0.674	0.465	0.256	0.335	0.127
0.6	0.034	0.421	0.337	0.397	0.598	1.153	0.715	0.404	0.525	0.226
0.3	0.034	0.512	0.425	0.446	0.684	1.17	0.823	0.473	0.616	0.349

14" Snow

5.7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5.1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.8	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
4.2	0.316	0	1.578	0.395	0	0.395	0.789	0.395	0.395	0.263
3.9	0.197	0	1.381	0.158	0	0.158	0.113	0.132	0.132	0.099
3.6	0.143	0	0.69	0.099	0	0.099	0.099	0.079	0.113	0.079
3.3	0.329	0.263	0.933	0.287	0.237	0.143	0.329	0.304	0.243	0.338
3	0.057	0.075	0.168	0.069	0.064	0.023	0.093	0.074	0.026	0.117
2.7	0.067	0.089	0.168	0.066	0.08	0.023	0.093	0.074	0.026	0.128
2.4	0.067	0.096	0.168	0.066	0.096	0.023	0.093	0.094	0.026	0.149
2.1	0.067	0.096	0.168	0.066	0.104	0.023	0.102	0.094	0.026	0.149
1.8	0.158	0.178	0.375	0.203	0.223	0.023	0.314	0.221	0.026	0.277
1.5	0.182	0.295	0.473	0.251	0.351	0.023	0.348	0.281	0.026	0.405
1.2	0.228	0.353	0.565	0.259	0.352	0.023	0.383	0.313	0.026	0.346
0.9	0.319	0.395	0.789	0.358	0.413	0.023	0.41	0.401	0.026	0.374
0.6	0.444	0.621	1.105	0.491	0.498	0.023	0.611	0.559	0.026	0.464
0.3	0.54	0.621	1.151	0.524	0.534	0.023	0.727	0.634	0.026	0.54

Analysis of Variance - Force Exchange Ratio

run	base	0	7	14
1	3.919	0.969	0.034	0.54
2	3.121	0.737	0.512	0.621
3	3.704	0.858	0.425	1.151
4	4.31	1.405	0.446	0.524
5	1.92	0.905	0.684	0.534
6	2.796	1.279	1.17	0.023
7	2.808	0.965	0.823	0.727
8	5.721	1.134	0.473	0.634
9	1.462	0.759	0.616	0.026
10	2.723	1.444	0.349	0.54

```
                                          Individual 95% CIs For Mean
                                          Based on Pooled StDev
Level        N      Mean     StDev   ---------+---------+---------+-------
Base Case   10    3.2484    1.2268                              (---*----)
NRMM        10    1.0455    0.2571       (---*----)
7" Snow     10    0.5532    0.3021   (----*---)
14" Snow    10    0.5320    0.3257   (---*----)
                                     ---------+---------+---------+-------
Pooled StDev =    0.6649                    1.0       2.0       3.0
```

Hypothesis: $H_0: \mu_{Base} = \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	3	50.005	16.668	37.70	0.000
Error	36	15.916	0.442		
Total	39	65.922			

$F(3, 36) = 37.70$; $F_{0.05}(3, 36) = 2.86$
$37.70 > 2.86$
Reject null hypothesis

Hypothesis: $H_0: \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	2	1.6883	0.8442	9.61	0.001
Error	27	2.3713	0.0878		
Total	29	4.0596			

$F(2, 27) = 9.61$; $F_{0.05}(2, 27) = 3.35$
$9.61 > 3.35$
Reject null hypothesis

Hypothesis: $H_0: \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	1	0.0022	0.0022	0.02	0.882
Error	18	1.7764	0.0987		
Total	19	1.7787			

$F(1, 18) = 0.02$; $F_{0.05}(1, 18) = 4.41$; $F_{0.01}(1, 18) = 8.28$
$0.02 < 4.41$
Do Not reject null hypothesis

Appendix F: Direct Fires By Range

Direct Fires by Range

Janus Base Case - Red

Range	AGS-17	LAW TM	BMP-2	Tot All
0.2	0.000	0.200	1.000	1.200
0.4	0.300	4.300	0.000	4.600
0.6	0.000	0.200	0.000	0.200
0.8	0.000	5.000	0.000	5.000
1	0.000	0.000	0.000	0.000
1.2	20.200	0.000	0.000	20.200
1.4	0.000	0.000	0.000	0.000
1.6	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
2.2	0.000	0.000	0.000	0.000
2.4	0.000	0.000	4.200	4.200
2.6	0.000	0.000	6.300	6.300
2.8	0.000	0.000	7.000	7.000
3	0.000	0.000	14.700	14.700
3.2	0.000	0.000	0.000	0.000
3.4	0.000	0.000	5.500	5.500
3.6	0.000	0.000	1.900	1.900
3.8	0.000	0.000	0.000	0.000
4	0.000	0.000	15.900	15.900

Janus Base Case - Blue

Range	M1A1	M113	M2	M3	SFV	FIST-V	Saw Rf	Rifle/	MAW Te	M203 G	Tot All
0.2	0.100	17.500	35.000	3.500	0.000	0.000	62.400	28.500	8.900	2.300	158.200
0.4	0.000	0.000	84.000	1.800	12.300	0.000	0.000	0.000	0.000	0.000	98.100
0.6	0.000	0.000	42.300	5.200	22.000	0.000	0.000	0.000	0.000	0.000	69.500
0.8	0.000	0.000	87.900	7.000	29.100	1.500	0.000	0.000	1.500	0.000	127.000
1	35.900	0.000	14.100	0.300	8.500	0.000	0.000	0.000	0.100	0.000	58.900
1.2	0.000	0.000	8.200	0.300	0.100	0.000	0.000	0.000	0.000	0.000	8.600
1.4	0.000	0.000	29.600	0.400	6.900	0.000	0.000	0.000	0.000	0.000	36.900
1.6	0.000	0.000	19.000	0.600	4.000	0.000	0.000	0.000	0.000	0.000	23.600
1.8	0.000	0.000	34.400	0.000	11.200	0.000	0.000	0.000	0.000	0.000	45.600
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.2	0.000	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.300
2.4	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200
2.6	0.000	0.000	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.600
2.8	0.000	0.000	14.900	1.600	8.000	0.000	0.000	0.000	0.000	0.000	24.500
3	0.000	0.000	46.400	1.700	10.700	0.000	0.000	0.000	0.000	0.000	58.800
3.2	0.000	0.000	5.100	1.200	0.000	0.000	0.000	0.000	0.000	0.000	6.300
3.4	0.000	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.300
3.6	0.000	0.000	1.700	0.100	0.600	0.000	0.000	0.000	0.000	0.000	2.400
3.8	0.000	0.000	15.400	1.900	6.000	0.000	0.000	0.000	0.000	0.000	23.300
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

NRMM Base Case - Red

Range	AGS-17	LAW TM	BMP-2	Tot All
0.2	0.000	0.000	2.100	2.100
0.4	0.000	1.000	0.000	1.000
0.6	0.000	3.900	0.000	3.900
0.8	13.700	5.900	0.000	19.600
1	0.000	0.000	0.000	0.000
1.2	18.100	0.000	0.000	18.100
1.4	0.000	0.000	0.000	0.000
1.6	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
2.2	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.000	0.000
2.6	0.000	0.000	0.000	0.000
2.8	0.000	0.000	2.000	2.000
3	0.000	0.000	56.100	56.100
3.2	0.000	0.000	1.400	1.400
3.4	0.000	0.000	3.300	3.300
3.6	0.000	0.000	2.800	2.800
3.8	0.000	0.000	0.000	0.000
4	0.000	0.000	15.400	15.400

NRMM Base Case - Blue

Range	M1A1	M2	M3	SFV	FIST-V	Tot All
0.2	1.100	4.500	3.400	4.000	0.000	13.000
0.4	0.600	46.100	1.600	3.400	0.000	51.700
0.6	0.000	71.800	4.900	4.400	0.500	81.600
0.8	0.100	76.800	2.700	12.000	3.600	95.200
1	0.000	9.800	0.200	3.400	0.000	13.400
1.2	0.000	17.400	2.000	4.400	0.000	23.800
1.4	0.000	41.200	0.800	5.200	0.000	47.200
1.6	0.000	61.200	2.800	5.900	0.000	69.900
1.8	0.000	76.600	4.700	34.000	0.000	115.300
2	0.000	0.000	0.000	0.000	0.000	0.000
2.2	0.000	6.600	0.000	0.000	0.000	6.600
2.4	0.000	0.000	0.000	0.000	0.000	0.000
2.6	0.000	2.300	0.400	0.000	0.000	2.700
2.8	0.000	24.700	1.400	2.900	0.000	29.000
3	0.000	51.200	4.900	17.600	0.000	73.700
3.2	0.000	13.200	0.100	1.400	0.000	14.700
3.4	0.000	0.100	0.000	0.000	0.000	0.100
3.6	0.000	0.000	0.000	0.000	0.000	0.000
3.8	0.000	2.200	0.300	1.500	0.000	4.000
4	0.000	0.000	0.000	0.000	0.000	0.000

7" Snow - Red

Range	AGS-17	LAW TM	BMP-2	BMP-1	Tot All
0.2	0.000	0.000	0.000	0.000	0.000
0.4	0.000	0.100	0.000	0.000	0.100
0.6	0.000	2.900	0.000	0.000	2.900
0.8	5.300	0.900	0.000	0.000	6.200
1	0.000	0.000	0.000	0.000	0.000
1.2	11.200	0.000	0.000	0.000	11.200
1.4	0.000	0.000	0.000	0.000	0.000
1.6	0.000	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000
2.2	0.000	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.000	0.000	0.000
2.6	0.000	0.000	0.500	0.000	0.500
2.8	0.000	0.000	13.300	0.200	13.500
3	0.000	0.000	100.200	1.500	101.700
3.2	0.000	0.000	4.700	0.000	4.700
3.4	0.000	0.000	5.700	0.000	5.700
3.6	0.000	0.000	4.800	0.000	4.800
3.8	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	18.400	0.000	18.400

7" Snow - Blue

Range	M2	M3	SFV	Saw Rf	Rifle/	Tot All
0.2	4.900	10.100	1.900	8.200	3.000	28.100
0.4	49.900	9.900	5.300	0.000	0.000	65.100
0.6	75.700	8.700	6.300	0.000	0.000	90.700
0.8	23.900	4.600	3.600	0.000	0.000	32.100
1	8.400	0.000	1.600	0.000	0.000	10.000
1.2	22.600	2.000	2.400	0.000	0.000	27.000
1.4	20.800	3.700	2.800	0.000	0.000	27.300
1.6	41.700	4.700	2.500	0.000	0.000	48.900
1.8	114.400	6.400	13.600	0.000	0.000	134.400
2	4.000	0.000	1.200	0.000	0.000	5.200
2.2	6.700	0.000	0.000	0.000	0.000	6.700
2.4	0.000	0.000	0.000	0.000	0.000	0.000
2.6	0.700	0.100	0.000	0.000	0.000	0.800
2.8	2.000	1.200	0.000	0.000	0.000	3.200
3	66.700	1.900	17.500	0.000	0.000	86.100
3.2	43.000	5.800	14.200	0.000	0.000	63.000
3.4	0.000	0.000	0.000	0.000	0.000	0.000
3.6	2.700	0.200	1.800	0.000	0.000	4.700
3.8	1.500	0.200	0.200	0.000	0.000	1.900
4	0.000	0.000	0.000	0.000	0.000	0.000

14" Snow - Red

Range	AGS-17	LAW TM	BMP-2	BMP-1	Tot All
0.2	0.000	0.000	0.000	0.000	0.000
0.4	0.000	0.000	0.000	0.000	0.000
0.6	0.000	0.900	0.000	0.000	0.900
0.8	7.800	1.400	0.000	0.000	9.200
1	0.000	0.000	0.000	0.000	0.000
1.2	10.200	0.000	0.000	0.000	10.200
1.4	0.000	0.000	0.000	0.000	0.000
1.6	0.000	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000
2.2	0.000	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.000	0.000	0.000
2.6	0.000	0.000	0.000	0.000	0.000
2.8	0.000	0.000	6.500	0.100	6.600
3	0.000	0.000	97.900	1.600	99.500
3.2	0.000	0.000	3.500	0.000	3.500
3.4	0.000	0.000	7.200	0.000	7.200
3.6	0.000	0.000	4.600	0.000	4.600
3.8	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	18.600	0.000	18.600

14" Snow - Blue

Range	M2	M3	SFV	Rifle/	Tot All
0.2	0.400	3.200	5.700	1.200	10.500
0.4	31.100	1.500	9.500	0.000	42.100
0.6	29.600	4.200	17.500	0.000	51.300
0.8	14.900	2.700	9.500	0.000	27.100
1	8.000	0.700	2.400	0.000	11.100
1.2	18.500	1.000	3.100	0.000	22.600
1.4	22.800	0.000	3.200	0.000	26.000
1.6	22.500	2.500	4.000	0.000	29.000
1.8	110.600	3.000	11.000	0.000	124.600
2	0.400	0.000	0.000	0.000	0.400
2.2	6.900	0.000	0.000	0.000	6.900
2.4	0.000	0.000	0.000	0.000	0.000
2.6	0.000	0.800	0.000	0.000	0.800
2.8	6.300	0.000	0.200	0.000	6.500
3	71.600	6.300	15.400	0.000	93.300
3.2	38.500	3.700	15.500	0.000	57.700
3.4	0.000	0.000	0.000	0.000	0.000
3.6	2.000	0.200	0.600	0.000	2.800
3.8	4.000	0.200	1.200	0.000	5.400
4	0.000	0.000	0.000	0.000	0.000

Appendix G: Kills By Range

Kills by Range

Janus Base Case - Red

Range	AGS-17	LAW TM	BMP-2	Tot All
0.3	0.100	6.600	0.700	7.400
0.6	0.000	1.900	0.000	1.900
0.9	0.000	3.100	0.000	3.100
1.2	13.000	0.000	0.000	13.000
1.5	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000
2.1	0.000	0.000	0.000	0.000
2.4	0.000	0.000	1.400	1.400
2.7	0.000	0.000	3.000	3.000
3	0.000	0.000	5.900	5.900
3.3	0.000	0.000	0.900	0.900
3.6	0.000	0.000	2.000	2.000
3.9	0.000	0.000	2.100	2.100
4.2	0.000	0.000	2.400	2.400
4.5	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000

Janus Base Case - Blue

Range	M1A1	M113	M2	M3	SFV	FIST-V	Saw Rf	Rifle/	MAW Te	M203 G	Tot All
0.3	0.100	3.400	27.300	1.300	0.500	0.000	4.200	2.200	0.600	0.300	39.900
0.6	0.000	0.000	18.400	2.100	8.100	0.000	0.000	0.000	0.000	0.000	28.600
0.9	2.900	0.000	35.700	1.400	18.700	0.100	0.000	0.000	0.200	0.000	59.000
1.2	0.000	0.000	1.800	0.100	0.200	0.000	0.000	0.000	0.000	0.000	2.100
1.5	0.000	0.000	8.800	0.100	1.900	0.000	0.000	0.000	0.000	0.000	10.800
1.8	0.000	0.000	4.000	0.000	1.300	0.000	0.000	0.000	0.000	0.000	5.300
2.1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100
2.7	0.000	0.000	0.100	0.100	0.200	0.000	0.000	0.000	0.000	0.000	0.400
3	0.000	0.000	4.900	0.300	0.900	0.000	0.000	0.000	0.000	0.000	6.100
3.3	0.000	0.000	0.200	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.300
3.6	0.000	0.000	0.100	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.200
3.9	0.000	0.000	0.600	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.900
4.2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

NRMM Base Case - Red

Range	AGS-17	LAW TM	BMP-2	Tot All
0.3	0.000	0.100	1.400	1.500
0.6	0.000	0.900	0.000	0.900
0.9	2.100	0.100	0.000	2.200
1.2	1.500	0.000	0.000	1.500
1.5	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000
2.1	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.000	0.000
2.7	0.000	0.000	0.100	0.100
3	0.000	0.000	21.300	21.300
3.3	0.000	0.000	1.500	1.500
3.6	0.000	0.000	1.100	1.100
3.9	0.000	0.000	3.400	3.400
4.2	0.000	0.000	1.900	1.900
4.5	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000

NRMM Base Case - Blue

Range	M1A1	M2	M3	SFV	FIST-V	Tot All
0.3	0.400	9.600	0.800	2.000	0.000	12.800
0.6	0.000	25.300	1.000	2.300	0.300	28.900
0.9	0.000	30.200	0.400	5.600	0.400	36.600
1.2	0.000	6.400	0.400	1.600	0.000	8.400
1.5	0.000	14.000	0.200	1.500	0.000	15.700
1.8	0.000	10.500	0.600	4.400	0.000	15.500
2.1	0.000	0.700	0.000	0.000	0.000	0.700
2.4	0.000	0.700	0.000	0.000	0.000	0.700
2.7	0.000	1.600	0.000	0.000	0.000	1.600
3	0.000	4.600	0.700	0.800	0.000	6.100
3.3	0.000	0.800	0.000	0.100	0.000	0.900
3.6	0.000	0.000	0.000	0.000	0.000	0.000
3.9	0.000	0.100	0.000	0.000	0.000	0.100
4.2	0.000	0.000	0.000	0.000	0.000	0.200
4.5	0.000	0.000	0.000	0.000	0.000	0.400
4.8	0.000	0.000	0.000	0.000	0.000	0.100
5.1	0.000	0.000	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000	0.000	0.400
5.7	0.000	0.000	0.000	0.000	0.000	0.600

7" Snow - Red

Range	AGS-17	LAW TM	BMP-2	BMP-1	Tot All
0.3	0.000	0.000	0.000	0.000	0.000
0.6	0.000	0.900	0.000	0.000	0.900
0.9	0.900	0.000	0.000	0.000	0.900
1.2	9.700	0.000	0.000	0.000	9.700
1.5	0.000	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000	0.000
2.1	0.000	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.000	0.000	0.000
2.7	0.000	0.000	2.000	0.000	2.000
3	0.000	0.000	133.100	0.200	133.300
3.3	0.000	0.000	2.900	0.000	2.900
3.6	0.000	0.000	2.200	0.000	2.200
3.9	0.000	0.000	2.900	0.000	2.900
4.2	0.000	0.000	3.300	0.000	3.300
4.5	0.000	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000	0.000

7" Snow - Blue

Range	M2	M3	SFV	Saw Rf	Rifle/	Tot All
0.3	7.500	4.500	1.400	0.700	0.500	14.600
0.6	25.600	2.800	2.500	0.000	0.000	30.900
0.9	7.700	0.600	1.600	0.000	0.000	9.900
1.2	7.100	0.500	0.600	0.000	0.000	8.200
1.5	7.400	0.800	1.000	0.000	0.000	9.200
1.8	11.300	0.800	1.300	0.000	0.000	13.400
2.1	0.200	0.000	0.000	0.000	0.000	0.200
2.4	0.000	0.000	0.000	0.000	0.000	0.000
2.7	0.300	0.000	0.000	0.000	0.000	0.300
3	5.500	0.200	0.900	0.000	0.000	6.600
3.3	2.100	0.200	0.700	0.000	0.000	3.000
3.6	0.100	0.000	0.100	0.000	0.000	0.200
3.9	0.100	0.000	0.000	0.000	0.000	0.100
4.2	0.000	0.000	0.000	0.000	0.000	0.000
4.5	0.000	0.000	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000	0.000	0.000

14" Snow - Red

Range	AGS-17	LAW TM	BMP-2	BMP-1	Tot All
0.3	0.000	0.000	0.000	0.000	0.000
0.6	0.000	0.500	0.000	0.000	0.500
0.9	0.900	0.000	0.000	0.000	0.900
1.2	11.200	0.000	0.000	0.000	11.200
1.5	0.000	0.000	0.000	0.000	0.000
1.8	0.000	0.000	0.000	0.000	0.000
2.1	0.000	0.000	0.000	0.000	0.000
2.4	0.000	0.000	0.000	0.000	0.000
2.7	0.000	0.000	0.600	0.000	0.600
3	0.000	0.000	116.600	0.400	117.000
3.3	0.000	0.000	3.300	0.000	3.300
3.6	0.000	0.000	2.600	0.000	2.600
3.9	0.000	0.000	3.500	0.000	3.500
4.2	0.000	0.000	2.500	0.000	2.500
4.5	0.000	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000	0.000

14" Snow - Blue

Range	M2	M3	SFV	Rifle/	Tot All
0.3	3.500	0.900	3.100	0.100	7.600
0.6	12.500	1.200	6.600	0.000	20.300
0.9	6.600	0.300	3.600	0.000	10.500
1.2	7.000	0.000	1.000	0.000	8.000
1.5	7.100	0.000	1.000	0.000	8.100
1.8	13.000	0.200	1.400	0.000	14.600
2.1	0.200	0.000	0.000	0.000	0.200
2.4	0.800	0.000	0.000	0.000	0.800
2.7	0.600	0.100	0.000	0.000	0.700
3	4.200	0.300	0.900	0.000	5.400
3.3	2.200	0.200	1.200	0.000	3.600
3.6	0.000	0.000	0.000	0.000	0.000
3.9	0.300	0.000	0.000	0.000	0.300
4.2	0.000	0.000	0.000	0.000	0.000
4.5	0.000	0.000	0.000	0.000	0.000
4.8	0.000	0.000	0.000	0.000	0.000
5.1	0.000	0.000	0.000	0.000	0.000
5.4	0.000	0.000	0.000	0.000	0.000
5.7	0.000	0.000	0.000	0.000	0.000

Appendix H: Analysis Of Variance - Time To Objective

Analysis of Variance - Time to Objective

Blue Time to Objective (minutes)				
Run	Base	0	7	14
1	33	54		54
2	34	51	53	56
3	34	52	55	55
4	32	52	55	56
5	35	51	54	
6	36	53	54	
7	34	51	51	54
8	34	52	53	54
9	35	52	52	
10	35	53	54	60

```
Individual 95% CIs For Mean
                                            Based on Pooled StDev
 Level        N      Mean      StDev    ---+---------+---------+---------+---
Base Case    10    34.200      1.135     (*)
NRMM         10    52.100      0.994                               (*-)
7" Snow       9    53.444      1.333                                 (*-)
14" Snow      7    55.571      2.149                                    (*-)
                                        ---+---------+---------+---------+---
Pooled StDev =     1.397                35.0      42.0      49.0      56.0
```

Hypothesis: $H_0: \mu_{Base} = \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	3	2739.87	913.29	468.08	0.000
Error	32	62.44	1.95		
Total	35	2802.31			

$F(3, 32) = 468.08$; $F_{0.05}(3, 32) = 2.9$
$468.08 > 2.9$
Reject null hypothesis

Hypothesis: $H_0: \mu_0 = \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	2	49.66	24.83	11.23	0.000
Error	23	50.84	2.21		
Total	25	100.50			

$F(2, 23) = 11.23$; $F_{0.05}(2, 23) = 3.42$
$11.23 > 3.42$
Reject null hypothesis

Hypothesis: $H_0: \mu_7 = \mu_{14}$

Source	DF	SS	MS	F	p
Factor	1	17.81	17.81	5.95	0.029
Error	14	41.94	3.00		
Total	15	59.75			

$F(1, 14) = 5.95$; $F_{0.05}(1, 14) = 4.60$
$5.95 > 4.60$
Reject null hypothesis

Hypothesis: $H_0: \mu_0 = \mu_7$

Source	DF	SS	MS	F	p
Factor	1	8.56	8.56	6.29	0.023
Error	17	23.12	1.36		
Total	18	31.68			

$F(1, 17) = 6.69$; $F_{0.05}(1, 17) = 4.45$
$6.69 > 4.45$
Reject null hypothesis