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A comparison study of JANUS and HLA Warrior

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THESIS

A COMPARISON STUDY OF JANUS AND HLA WARRIOR

by

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June 2000

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The Training & Doctrine Command (TRADOC) Analysis Center (TRAC) – Monterey, California re-engineered the Janus simulation as a technology demonstration. The completed simulation, HLA Warrior, applied modern technologies including an object-oriented design and state-of-art user interfaces. The project also re-wrote the Janus source code in C++. The purpose of this thesis was to assess HLA Warrior's fidelity, defined as its ability to replicate Janus results, by conducting a statistical comparison of Janus and HLA Warrior. Given that Janus has high "face-validity," Janus results acted as the baseline from which HLA Warrior results were compared. The comparison involved executing identical scenarios in Janus and HLA Warrior, gathering results, and conducting a rigorous statistical comparison of Janus and HLA Warrior results. Statistical tests included the paired *t*-test and non-parametric Wilcoxon Signed Ranks Test.

Results from the tests showed differences between Janus and HLA Warrior. Investigation into the causes of the differences found two source code errors in HLA Warrior. Re-evaluation of HLA Warrior following correction of the errors resulted in a reduction in magnitude of the differences. Probable causes due to algorithm implementation differences were also identified. While differences exist, HLA Warrior appears to have face-validity and generally produces outcomes similar to Janus.

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A COMPARISON STUDY OF JANUS AND HLA WARRIOR

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ABSTRACT

The Training & Doctrine Command (TRADOC) Analysis Center (TRAC) – Monterey, California re-engineered the Janus simulation as a technology demonstration. The completed simulation, HLA Warrior, applied modern technologies including an object-oriented design and state-of-art user interfaces. The project also re-wrote Janus source code in C++. The purpose of this thesis was to assess HLA Warrior's fidelity, defined as its ability to replicate Janus results, by conducting a statistical comparison of Janus and HLA Warrior. Given that Janus has high "face-validity," Janus results acted as the baseline from which HLA Warrior results were compared. The comparison involved executing identical scenarios in Janus and HLA Warrior, gathering results, and conducting a rigorous statistical comparison of Janus and HLA Warrior results. Statistical tests included the paired *t*-test and non-parametric Wilcoxon Signed Ranks Test.

Results from the tests showed differences between Janus and HLA Warrior. Investigation into the causes of the differences found two source code errors in HLA Warrior. Re-evaluation of HLA Warrior following correction of the errors resulted in a reduction in magnitude of the differences. Probable causes due to algorithm implementation differences were also identified. While differences exist, HLA Warrior appears to have face-validity and generally produces outcomes similar to Janus.

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EXECUTIVE SUMMARY

The United States Army's Training and Doctrine Command Analysis Center-Monterey (TRAC-Monterey) recently re-engineered the Janus simulation as a technology demonstration. Technologies included an innovative architecture, state-of-art user interfaces, and built-in High-Level Architecture (HLA) tools. The project ported Janus to a personal computer (PC) running the Windows NT (WinNT) operating system and rewrote Janus source code in C++ while maintaining the integrity of the Janus algorithms. The resulting simulation is known as HLA Warrior.

The purpose of this thesis was to assess HLA Warrior's fidelity, defined as the simulation's ability to replicate Janus results, by conducting a statistical comparison of Janus and HLA Warrior scenarios. The research determined whether results from Janus and HLA Warrior scenarios were statistically similar. Since Janus has high "face-validity," it acted as the baseline to compare HLA Warrior's results. A model with high face validity is defined as a model that, on the surface, seems reasonable to people who are knowledgeable about the system under study [Ref. 1:p. 308].

Janus is a high-resolution, ground combat simulation focusing on maneuver and artillery units. Janus represents entities down to individual systems or soldiers. Janus stochastically adjudicates all detections and engagements between individual systems. Janus contains a post-processor that permits the analyst to gather comprehensive statistics on the simulation run, including reports on the number of rounds fired, detection ranges, kill ranges, Force Exchange Ratio (FER), and Loss Exchange Ratios (LER).

To assess whether HLA Warrior can replicate Janus scenario results, the research analyzed measures of performance (MOPs) that quantified the engagement process. The fundamental steps of an engagement sequence include detecting then shooting an entity. Selected MOPs included detection range, kill range, and number of rounds fired. The research also analyzed force exchange ratio (FER) as a quantitative measure of overall battle outcome.

Two scenarios were developed to analyze results from varying weapons systems: a mechanized scenario and a light infantry scenario. Each scenario was then executed in two environments, Fort Hunter-Liggett, California and Southwest Asia. These distinctly different environments support the analysis as to whether HLA Warrior successfully models the engagement process under varying line-of-sight conditions.

Each of the two scenarios (mechanized, light) was executed in two environments (Southwest Asia, Fort Hunter-Liggett) and run in two different modes (Janus, HLA Warrior). The two scenarios, two environments, and two modes resulted in a total of eight combinations for the experiment. Each of the combinations was executed 10 times. In total, 80 runs were performed to provide a reasonable data sample to analyze each MOP.

The method of analysis was to compare the MOPs resulting from a specific number of Janus runs to the MOPs resulting from the same number of HLA Warrior runs. Since Janus produces exactly the same results when the same random number seed is used (likewise for HLA Warrior), all Janus runs were executed using different, randomly selected seeds. The same random number seeds were then used in the corresponding HLA Warrior runs. The combination of the same scenario, same environment, and same random number seed executed in opposing modes (Janus and HLA Warrior) support paired output from the two simulations.

After completing all runs and gathering required data, MOPs were analyzed using the Wilcoxon Signed Ranks Test. Then those MOPs that satisfied the paired *t*-test's normality assumption as determined by observation of normal probability plots were analyzed using the more powerful paired *t*-test.

The results of the analysis showed a disparity between HLA Warrior and Janus. Further investigation into the causes of the disparity led to two possible explanations. First, two errors in the HLA Warrior source code were found. Re-evaluation of HLA Warrior following correction of the source code errors resulted in a reduction in the magnitude of the differences between Janus and HLA Warrior. A second possible cause of the differences between the simulations was a difference in the algorithm implementation methodology between Janus and HLA Warrior. While the integrity of the Janus algorithms were maintained in HLA Warrior, developers implemented algorithms differently in HLA Warrior to improve efficiency. The implementation differences could lead to a disparity in the results of the investigated MOPs.

While the two simulations are different with regards to selected MOPs, HLA Warrior generally produces similar outcomes to Janus. In general, the flow of the battles executed in HLA Warrior progressed as a subject matter expert might expect, lending a degree of face-validity to HLA Warrior.

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I. INTRODUCTION

The United States Army's Training and Doctrine Command (TRADOC) Analysis Center-Monterey, California (TRAC-Monterey) recently re-engineered the Janus simulation with modern technologies, including an innovative architecture, state-of-art user interfaces, and built-in High-Level Architecture (HLA) tools. The project ported Janus to a personal computer (PC) running the Windows NT (WinNT) operating system and rewrote Janus source code in C++. The resulting simulation is known as HLA Warrior. HLA Warrior's primary objective was to serve as a technology demonstration, providing lessons learned and reusable products to developers of future simulations.

The purpose of this thesis was to assess HLA Warrior's fidelity, defined as the simulation's ability to replicate Janus results, by conducting a statistical comparison of Janus and HLA Warrior scenarios. The research determined whether results from Janus and HLA Warrior scenarios were statistically similar. Since Janus has high "face-validity," it acted as a baseline to compare HLA Warrior's results. A model with high face validity is defined as a model that, on the surface, seems reasonable to people who are knowledgeable about the system under study [Ref. 1:p. 308]. Subject matter experts (infantry officers, armor officers, and so on) have examined the execution of various Janus scenarios and determined that the way in which the battles progressed and the outcomes of the battles were plausible and likely replicated real-world phenomena.

In order to test for similarity between Janus and HLA Warrior, measures of performance (MOPs) were developed. Where the simulation results were statistically similar, the findings aided in the validation of HLA Warrior. The thesis also identified factors that may account for any significant differences between the two simulations.

A. JANUS

Lawrence Livermore National Laboratory originally developed Janus in the 1970s, with the current version developed by TRAC-White Sands Missile Range, New Mexico. Most Janus systems use a UNIX operating system and execute on Hewlett-Packard workstations.

Janus is a ground combat simulation primarily focusing on maneuver and artillery units. Janus also models engineer support, minefield employment and breaching, rotary and fixed-wing aircraft, chemical environments, limited weather effects, and day and night visibility. Janus is a high-resolution simulation, representing entities down to individual systems or soldiers. The user may aggregate entities when appropriate. [Ref. 2:p. 21]

Analysts use Janus to conduct in-depth studies of tactics, techniques, and procedures. Analysts can also use Janus to evaluate new weapon systems in various environments, weather conditions, and mission profiles. Janus is also used to train brigade and battalion staffs.

Janus is interactive in that interplay between operators during simulated combat is possible. Users may influence scenario results by altering movement routes, planning and firing artillery missions, and mounting/dismounting entities on vehicles. User interaction is not necessary for pre-planned scenarios. For purposes of this thesis, all scenarios were pre-planned and included no user interaction during execution.

Janus stochastically adjudicates all detections and engagements between individual systems. Prior to the Janus run, the user may specify a random number seed up to seven digits, allow the system to randomly specify a seed, or use the default random number seed hard-coded into the program [Ref. 2:p. 42]. When the same random number seed is used in the same scenario without human interaction, the exact same results occur.

Janus possesses a robust database that permits the user to define a weapon system extensively and capture detailed factors required for scenario development. Individual fighting systems have distinct properties: dimensions, weight, carrying capacity, and speed. Users can also modify weapons system parameters such as range, ordnance type, and ammunition basic load (supply of ammunition each entity carries into a battle) [Ref. 2:p. 4].

Janus' post-processor permits analysts to gather comprehensive statistics on the simulation run, including reports on the detection ranges, kill ranges, chemical casualties, Force Exchange Ratio (FER), number of rounds fired, and Loss Exchange Ratios (LER).

B. HLA WARRIOR

TRAC-Monterey re-engineered the Janus simulation with several modern technologies, including an innovative architecture, windows-like user interfaces, and HLA tools. The project ported Janus to a PC running the WinNT operating system and rewrote Janus source code in C++ while maintaining the integrity of the Janus algorithms. HLA Warrior implements new graphical user interfaces (GUIs) using Vision XXI management tools that comply with Distributed Interactive Simulation (DIS) and HLA requirements. The U.S. Army National Simulation Center (NSC) will also expand

HLA Warrior capability by integrating Operations Other Than War (OOTW) algorithms from the Spectrum simulation. [Ref. 3:p. 1].

HLA Warrior possesses all of the modeling and analytical capabilities of Janus. HLA Warrior also has the capability to read and execute scenarios developed in Janus including entity locations and movement routes. This function proved useful in the design of the experiment because once a scenario is developed in Janus, its initial settings can be duplicated in HLA Warrior prior to the run.

II. PROBLEM DESCRIPTION

The purpose of this thesis was to assess HLA Warrior's fidelity, defined as the simulation's ability to replicate Janus results, by conducting a statistical comparison of Janus and HLA Warrior scenarios. To answer this question, the thesis tested HLA Warrior's ability to accurately replicate specific combat functions under varying conditions. Of primary concern is the ability of HLA Warrior to replicate the basic engagement process, detecting and killing a target.

A primary element of detecting and subsequent killing of a target in ground combat is line of sight. The target must be in the line of sight of the shooter in order to be detected. Further, the target must remain within line of sight of a direct fire weapon throughout the engagement process to be killed. Therefore, HLA Warrior must accurately replicate Janus' line-of-sight calculations.

Provided the line-of-sight calculations are accurate, HLA Warrior must replicate Janus' detection and kill algorithms accurately in order for HLA Warrior to be similar to Janus. Both Janus and HLA Warrior use a stochastic process to adjudicate detections and kills. This implies that both the random number generators and the algorithms that assess the probabilities of hit and kill in the two simulations need to be similar.

This thesis therefore provided a method to assess HLA Warrior's line-of-sight algorithms, random number generators, detection algorithms, and kill algorithms for comparison to Janus.

The following chapter describes the design of the experiment to determine whether Janus and HLA Warrior are statistically similar and address the experimental issues raised above.

III. DESIGN OF EXPERIMENT

The goal of the experiment was to provide a means to obtain data from identical scenarios executed in both Janus and HLA Warrior for the purpose of analysis. Design issues included selecting appropriate and sufficient data to be analyzed, determining the nature of the scenarios, and conducting the experiment.

A. MEASURES OF PERFORMANCE

The first issue in the design of the experiment was to identify and select data to be analyzed. The Measures of Performance (MOPs) were limited to information available from the simulations' post-processors. The MOPs also had to support the analysis of the issues raised in the Problem Description. To assess whether HLA Warrior can replicate Janus scenario results, the research analyzed MOPs that quantified the engagement process. The fundamental steps of an engagement sequence include detecting then shooting an entity. Selected MOPs included detection range, kill range, and number of rounds fired. The research also analyzed force exchange ratio (FER) as a quantitative measure of overall battle outcome.

1. Detection Range

Detecting a target is the first basic element of a battle. Before a combat system can engage and subsequently kill a target, the target must first be detected. Comparing the detection ranges produced by Janus and HLA Warrior is a quantitative method of assessing the line-of-sight calculations as well as the detection algorithms in HLA Warrior.

2. Kill Range

The second basic element in a battle is killing a target once detected. Analyzing the kill ranges of Janus and HLA Warrior provides evaluation of the line-of-sight algorithms and a quantitative method for evaluating HLA Warrior's engagement process.

3. Force Exchange Ratio

Generally, a combat simulation's overall objective is to accurately determine the victor in a given engagement. The force exchange ratio, defined by the equation below,

$$(Red_{losses} / Blue_{losses}) / (Red_{initial} / Blue_{initial})$$

is a quantitative measure of the scenario outcome. In words, the FER is the quantity of the loss exchange ratio divided by the initial force ratio. The FER is a more accurate indicator of the outcome than the loss exchange ratio (total red side losses divided by total blue side losses) because it takes initial force levels into account and standardizes losses. That is, if two opposing forces lose an equal number of systems, losses to the smaller force are more damaging than losses to the larger force.

4. Rounds Fired

Not all shots result in kills. Therefore, analysis of the total number of rounds fired in both models is useful to assess the engagement process. Comparing the total number of rounds fired in both simulations can also support analysis of Janus' kill algorithms and probability of kill processes being replicated in HLA Warrior.

B. SCENARIOS

The scenarios were developed based on the requirements posed in the Problem Description. It is important to analyze results from varied scenarios to model varying weapons systems and their capabilities. Therefore the experiment included scenarios using dissimilar systems, an armored/mechanized scenario and a light infantry scenario.

1. Mechanized Forces

The first scenario was an armored/mechanized force scenario. The scenario consisted of a tank company reinforced with armored personnel carriers defending and a similarly equipped battalion attacking. Both sides were armed with M1A1 Abrams main battle tanks and M2 Bradley armored personnel carriers (APCs). The defenders had 14 tanks and four APCs. The attacking force consisted of 39 tanks and eight APCs. The initial force ratio of attacker to defender was approximately 3:1 for armored vehicles. Additionally, both sides were equipped with two AH-64 Apache helicopters as well as air defense systems.

2. Light Forces

The second scenario was a light infantry scenario consisting of a rifle company defending and a rifle battalion attacking. The defending company consisted of 103 entities comprised of four system types including riflemen, light machine guns, machine guns, and light anti-tank weapons (LAW). The attacking battalion was similarly equipped with a total of 285 entities, resulting in an initial force ratio of approximately 3:1.

C. ENVIRONMENTS

In order to assess HLA Warrior's detection and kill algorithms, the selected scenarios were executed in contrasting environments. A hilly, wooded environment and a flat, desert environment were selected for the experiment. These distinct environments support the analysis as to whether HLA Warrior accurately models the detection and kill algorithms under varying line-of-sight conditions.

1. Fort Hunter-Liggett (HL), California

The Fort Hunter-Liggett terrain file provided a hilly, wooded environment. The hills and trees test the line-of-sight calculations and, consequently, the detection and kill algorithms in a constrained visual environment. The hills, when combined with the effects of the trees, serve to limit line of sight and adversely effect the detection and kill process.

2. Southwest Asia (SWA)

The Southwest Asia terrain file provided a relatively flat, featureless, desert environment. The terrain is less restrictive to line-of-sight than Hunter-Liggett terrain. Therefore the detection and kill ranges should approach maximum effective range of individual sensors and weapon systems.

D. MODELS

After determining the scenarios and environments, four separate models were developed: one mechanized and one light scenario in Southwest Asia and one mechanized and one light infantry scenario at Fort Hunter-Liggett. Modification of the Janus weapons system database ensured that each weapon system on one side of the battle could engage each type of system on the opposing side.

In each scenario, the blue force (the defending force) was positioned on easily defendable terrain. The fields of view vary from entity to entity to adequately test the line-of-sight calculations. All blue force ground entities (tanks, APCs, infantrymen, etc.) remained stationary throughout the battle. The blue AH-64s in the mechanized scenarios traveled along pre-planned routes. Both AH-64s began movement as the simulation commenced.

Each entity in the red force (the attacking force) traveled along a pre-planned movement route toward an objective occupied by the blue force. Additionally, the red force AH-64s in the mechanized scenarios traveled along a route that took them over the blue force. All red force movement commenced as the simulation began.

Although one of the purposes behind the development of HLA Warrior was to ease the scenario building process, no scenarios were constructed in HLA Warrior. Rather, HLA Warrior's ability to read and convert Janus scenario files was utilized. This served to ensure that the four models executed in HLA Warrior had starting positions, routes, and pre-planned missions identical to the four models executed in Janus.

E. EXPERIMENT

1. Conduct of Experiment

Each of the two scenarios (mechanized, light) was executed in two environments (Southwest Asia, Fort Hunter-Liggett) and run in two different modes (Janus, HLA Warrior). The two scenarios, two environments, and two modes resulted in a total of eight combinations for the experiment. Each of the combinations was executed 10 times. In total, 80 runs were performed to provide a reasonable data sample to analyze each MOP.

The method of analysis was to compare the MOPs resulting from a specific number of Janus runs to the MOPs resulting from the same number of HLA Warrior runs. Since Janus produces exactly the same results when the same random number seed is used (likewise for HLA Warrior), all Janus runs were executed using different randomly selected seeds. The same random number seeds were then used in the corresponding HLA Warrior runs. While the random number generator in HLA Warrior is intended to be identical to the random number generator in Janus, the implementation of the algorithms (discussed in chapter 4, Statistical Analysis), caused the random number draws in the two simulations to lose synchronization rapidly. Despite the differences in the random number utilization, the design of the experiment supports paired output from the two simulations.

2. Experimental Design Issues

Determining sample size is fundamental to the design of every experiment. An experiment is conducted a number of times so that the data produces good estimators of the true population parameters. Several techniques are available to arrive at a satisfactory sample size.

First, experimenters may apply a practical approach. Based on experience and recommendations from senior Janus analysts, a sample size of n = 10 generally produces results with "acceptable variance" for the defined MOPs. That is, the experiment is run until an estimate of the variance for the mean is reduced to a pre-determined, acceptable level. The acceptable level will be different for each MOP.

The issue of normality of data was also considered when determining sample size. Normality of the data set is one assumption required prior to applying the paired *t*-test (described below). Normal probability plots were used to test for approximate normality. As the sample size increases, one would expect the sample averages to become more normal, based on the Central Limit Theorem [Ref. 4:p. 232]. Based on observations of normal probability plots for each MOP, a sample size of n = 10 was generally considered large enough to produce normally distributed averages.

F. DATA COLLECTION

Data was collected following the 10 runs of each of the eight experimental designs described above. Summary statistics for each MOP were computed based on the raw data for each run (see Appendix A). Each cell entry for detection and kill range in Appendix A represent an average of all detection ranges and kill ranges for the specific scenario, environment and mode for a specific scenario run. The entries for Force Exchange Ratio and Rounds Fired are the final force exchange ratios and the actual number of rounds fired for each specific scenario run respectively. Tables 1-3 below present the summary statistics used in the analysis of each MOP.

Scenario	Summary Statistic	Detection Range Blue		Detection Range Red	
		Warrior	Janus	Warrior	Janus
HL Light	Average	1304.230	1082.181	1359.080	1157.988
	Standard Deviation	8.882	28.961	20.415	9.096
HL Mech	Average	3527.878	4106.420	3071.678	3445.311
	Standard Deviation	47.519	221.948	91.092	200.412
SWA Light	Average	1480.730	1070.850	1796.850	1095.394
	Standard Deviation	47.685	45.207	36.954	26.454
SWA Mech	Average	3620.313	4469.942	2675.033	3721.506
	Standard Deviation	314.325	116.839	201.431	228.863

Table 1. Detection Range Summary Statistics

Scenario	Summary Statistic	Kill Range Blue		Kill Range Red	
		Warrior	Janus	Warrior	Janus
HL Light	Average	1037.063	891.740	1126.839	1044.613
	Standard Deviation	43.028	47.663	36.116	25.195
HL Mech	Average	2922.519	2920.349	2719.824	3153.435
	Standard Deviation	126.787	286.633	109.508	258.894
SWA Light	Average	979.520	658.122	987.069	806.023
	Standard Deviation	190.953	32.414	70.824	41.741
SWA Mech	Average	3448.491	3018.577	2258.870	2854.760
	Standard Deviation	290.446	194.556	212.336	286.861

Table 2. Kill Range Summary Statistics

Scenario	Summary Statistic	FER		Rounds Fired	
		Warrior	Janus	Warrior	Janus
HL Light	Average	0.187	0.171	6690.200	71883.100
	Standard Deviation	0.031	0.056	425.022	4316.057
HL Mech	Average	0.793	1.082	323.800	511.500
	Standard Deviation	0.143	0.480	33.963	180.981
SWA Light	Average	0.746	0.326	18373.900	27723.300
	Standard Deviation	0.225	0.089	1518.918	4126.873
SWA Mech	Average	0.128	1.770	46.700	291.900
	Standard Deviation	0.025	0.413	11.615	49.983

Table 3. FER and Rounds Fired Summary Statistics

IV. STATISTICAL ANALYSIS

This chapter discusses the methodology for analyzing the results and the statistical tests used in the analysis.

A. ANALYSIS METHODOLOGY

After completing all runs and gathering required data, rigorous statistical tests were applied to determine whether HLA Warrior results were statistically similar to Janus results. For each simulation, the same random number seed was used in both Janus and the corresponding HLA Warrior run. The only difference in the scenarios was the mode (Janus or HLA Warrior) on which it was executed. Since identical scenarios were executed in identical environments on opposing simulations, the data from the two simulations is paired. Given the data was paired between Janus and HLA Warrior, two applicable statistical tests were used to determine similarity: the Wilcoxon Signed Ranks Test and the paired *t*-test. Initially, all MOPs were analyzed using the Wilcoxon Signed Ranks test, then the MOPs that satisfied the paired *t*-test normality assumption were analyzed using the more powerful paired *t*-test.

B. TOOLS FOR ANALYSIS

1. Wilcoxon Signed Ranks Test

As the actual distributions of the MOPs are not known, all MOPs were first analyzed using a pair-wise comparison by means of the non-parametric Wilcoxon Signed Ranks Test. The Wilcoxon Signed Ranks Test begins by taking the data consisting of n observed pairs (X_1,Y_1), (X_2,Y_2), …, (X_n,Y_n), and computing the absolute difference ($|D_i|$) between each of the n pairs.

$$|D_i| = |Y_i - X_i| \qquad i = 1,2,\ldots,n$$

Cases where the differences are zero (X_i equals Y_i) are omitted. The number of remaining pairs is then denoted by n', $n' \leq n$. Ranks from 1 to n' are then assigned to the n' pairs according to the relative size of their absolute differences as follows. Rank 1 is given to the pair (X_i, Y_i) with the smallest absolute difference $|D_i|$; rank 2 is given to the pair with the second smallest difference, and so on. In cases of a tie, the average of the ranks that would have been otherwise assigned is assigned to each of the pairs in the tie. [Ref. 5:p. 206-207]

First, the Wilcoxon Signed Ranks Test relies on several assumptions with regard to the D_i's. D_i's are assumed to be continuous and independent. These assumptions are justified by the construction of the D_i's; each D_i is the difference of two real numbers and each originates as a result of independently selected random number seeds. Another assumption is the distribution of the D_i's is assumed to be symmetric. If the two simulations are the same (as they are under the null hypothesis that the HLA Warrior and Janus populations are identical) the average amount by which Janus MOPs exceeds HLA Warrior MOPs should be identical to the average amount by which HLA Warrior MOPs exceeds Janus MOPs. The final assumption is the mean of the distribution of the D_i's is some hypothesized value (given the null hypothesis, the value of the mean is zero). [Ref. 5:p. 207]

The test statistic, T, equals the sum of the ranks (R_i) assigned to those pairs where Y_i exceeds X_i.

$$R_i = 0 \text{ if } X_i > Y_i \text{ } (D_i \text{ negative}).$$

$$R_i = \text{the rank assigned to } (X_i, Y_i), \text{ if } X_i < Y_i \text{ } (D_i \text{ positive}).$$

Therefore, the test statistic is given by:

$$T = \Sigma R_i.$$

For this thesis, the null hypothesis, H_o, is that the mean value of the population of X_i's (HLA Warrior results from all possible random number seeds) is equal to the value of the Y_i's (Janus results). The alternate hypothesis is that the HLA Warrior results and the Janus results are not equal. The null hypothesis is rejected in favor of the alternate hypothesis at the level of significance $\alpha = 0.05$ if:

$$T \leq w_{\alpha/2} \text{ or } T \geq w_{1-\alpha/2}.$$

Critical lower and upper values of w_p, the p^{th} quantile [Ref.6:p.208], with $\alpha = 0.05$ and n=10, are 9 and 46, respectively [Ref. 5:p. 383]. The p-values (the smallest level of significance at which the null hypothesis would be rejected when a specified test procedure is used [Ref. 4:p. 334]) for the test statistic for each MOP was then determined using the S-Plus statistical software package [Ref. 6:p. 82].

2. Paired *t*-Test

The paired *t*-test relies on the assumption that both data sets to be compared come from normal distributions. Visual observation of normal probability plots of each of the MOPs was used to determine if the data was plausibly normal. For those cases determined to be normal, the paired *t*-test was applied. As discussed previously in chapter three, the only difference in each run was the mode in which the scenario was run; therefore the results of corresponding HLA Warrior and Janus runs are paired and utilization of the paired *t*-test is appropriate.

The paired t-test takes the data that consist of n observed pairs (X_1, Y_1), (X_2, Y_2), …, (X_n, Y_n), and computes the difference (d_i) between each of the n pairs. For this thesis, the X_i's are HLA Warrior MOP results and the Y_i's are Janus MOP results. The mean of the n differences is then computed. Under the null hypothesis, the mean of the differences for each of the MOPs is zero in the population, and under the alternative hypothesis, the mean of the differences is not zero.

Null Hypothesis: $H_o: \mu_D = 0$

Alternative Hypothesis: $H_a: \mu_D \neq 0$

The test statistic, t, for the analysis is defined as:

$$t = \frac{\bar{d} - \Delta_0}{S_D / \sqrt{n}}$$

where

$$\bar{d} = \frac{\Sigma d_i}{n}$$

and the sample standard deviation is

$$S_D = \sqrt{\frac{\Sigma d_i^2 - (\Sigma d_i)^2 / n}{n-1}}.$$

The rejection region for the null hypothesis is:

$$t \geq t_{\alpha/2, n-1} \quad \text{or} \quad t \leq -t_{\alpha/2, n-1}$$

with confidence level α and $n - 1$ degrees of freedom. If t falls in the rejection region, the null hypothesis is rejected and the conclusion is that HLA Warrior and Janus are not statistically similar. [Ref. 4:p. 367-368] For this thesis, $\alpha = 0.05$.

C. RESULTS

1. Wilcoxon Signed Ranks Test

The Wilcoxon Signed Ranks Test indicates that HLA Warrior and Janus produce similar results in only a few instances. Appendix B lists the results of the Wilcoxon Signed Ranks Test. Table 4 summarizes the results for each MOP. Only three of the 24 possible outcomes showed that HLA Warrior and Janus are statistically similar.

		Measure Of Performance					
Environment	Scenario	Blue Detection Range	Red Detection Range	Blue Kill Range	Red Kill Range	Force Exchange Ratio	Rounds Fired
Hunter-Liggett	Light	Not Similar	Not Similar	Not Similar	Not Similar	Similar	Not Similar
Hunter-Liggett	Mech	Not Similar	Not Similar	Similar	Not Similar	Similar	Not Similar
Southwest Asia	Light	Not Similar	Not Similar	Not Similar	Not Similar	Not Similar	Not Similar
Southwest Asia	Mech	Not Similar	Not Similar	Not Similar	Not Similar	Not Similar	Not Similar

Table 4. Wilcoxon Signed Ranks Test Results

a. Detection Range

In all environments and scenarios, the null hypothesis that HLA Warrior and Janus produced similar results was rejected with p-values less then 0.00195 in every case. Interestingly, the results depended heavily on the scenario. In the light scenarios, HLA Warrior always produced detection ranges exceeding Janus detection ranges. Conversely, in the mechanized scenarios, Janus always produced detection ranges exceeding HLA Warrior detection ranges.

b. Kill Range

In one of the eight combinations of scenario and environment, the test leads to a failure to reject the null hypothesis that the population mean kill ranges produced by HLA Warrior and Janus are identical. The blue kill ranges in the Hunter-Liggett, mechanized scenario were found to be statistically indistinguishable with a p-value of 0.375. In all other combinations the null hypothesis was rejected with p-values less then 0.0058 in each case.

c. Force Exchange Ratio

Only the Fort Hunter-Liggett scenarios led to a failure to reject the null hypothesis that the force exchange ratios produced by HLA Warrior and Janus are similar. The p-value for the light infantry scenario was 0.492 and the p-value for the mechanized scenario was 0.083. The null hypothesis was rejected for both scenarios, light infantry and mechanized, executed in Southwest Asia with p-values less than 0.002.

d. Rounds Fired

In all cases, the null hypothesis that HLA Warrior and Janus fire the same number of rounds was rejected with p-values of less than 0.00391 in each instance case. In all cases, the number of rounds fired by Janus was much greater than the number of rounds fired by HLA Warrior. In one instance, the Hunter-Liggett light scenario, Janus fired an order of magnitude greater than HLA Warrior.

2. Paired *t*-Test

After the analysis using the Wilcoxon Signed Ranks Test, the data was analyzed using the paired *t*-test for those data sets satisfying conditions of normality. The first step of the paired *t*-test was to determine if the data followed a normal distribution using normal probability plots. The results of the normality evaluations are found in Table 5 below. The normal probability plots are shown in Appendix D.

			Measure Of Performance					
Environment	Scenario	Mode	Blue Detection Range	Red Detection Range	Blue Kill Range	Red Kill Range	Force Exchange Ratio	Rounds Fired
Hunter-Liggett	Light	Warrior	Normal	Normal	Normal	Not Normal	Normal	Normal
Hunter-Liggett	Light	Janus	Normal	Normal	Normal	Not Normal	Normal	Normal
Hunter-Liggett	Mech	Warrior	Normal	Not Normal	Normal	Normal	Not Normal	Normal
Hunter-Liggett	Mech	Janus	Normal	Normal	Normal	Normal	Normal	Normal
Southwest Asia	Light	Warrior	Normal	Not Normal	Normal	Normal	Normal	Normal
Southwest Asia	Light	Janus	Normal	Normal	Normal	Normal	Normal	Normal
Southwest Asia	Mech	Warrior	Normal	Normal	Normal	Normal	Normal	Normal
Southwest Asia	Mech	Janus	Normal	Normal	Normal	Not Normal	Normal	Normal

Table 5. Normal Probability Plot Results

Those MOPs found to be normally distributed were then subjected to the paired *t*-test. The paired *t*-test confirms the Wilcoxon Signed Ranks Test's findings that HLA Warrior and Janus generally do not produce similar output. Appendix C contains the paired *t*-test results. Table 6 summarizes the results of the paired *t*-test.

		Measure Of Performance					
Environment	Scenario	Blue Detection Range	Red Detection Range	Blue Kill Range	Red Kill Range	Force Exchange Ratio	Rounds Fired
Hunter-Liggett	Light	Not Similar	Not Similar	Not Similar	NA	Similar	Not Similar
Hunter-Liggett	Mech	Not Similar	NA	Similar	Not Similar	NA	Not Similar
Southwest Asia	Light	Not Similar	NA	Not Similar	Not Similar	Not Similar	Not Similar
Southwest Asia	Mech	Not Similar	Not Similar	Not Similar	NA	Not Similar	Not Similar

Table 6. Paired *t*-Test Results

a. Detection Range

Similar to the Wilcoxon Signed Ranks Test, in all combinations of scenario and environment the null hypothesis that HLA Warrior detection range is statistically similar to Janus' detection range was rejected. P-values were less than 0.000567 for the detection range in every case.

b. Kill Range

The null hypothesis that the results are similar was rejected in all cases of kill range with the exception of the Hunter-Liggett mechanized scenario, which resulted in a p-value of 0.983. P-values for the cases where the null hypothesis was rejected ranged from 1.84E-06 to 0.00219.

c. Force Exchange Ratio

The results from the paired *t*-test for Force Exchange Ratio confirmed the results of the Wilcoxon Signed Ranks Test. In both scenarios executed in the Hunter-Liggett environment, the null hypothesis was not rejected with p-values of 0.529 and 0.082 for the light and mechanized scenarios, respectively. However, the Hunter-Liggett mechanized scenario failed to pass the normality test and therefore the results are not reliable. The null hypothesis was rejected for both scenarios executed in Southwest Asia with p-values of 0.000153 and 3.88E-07 for the light and mechanized scenarios, respectively.

d. Rounds Fired

The paired *t*-test for the number of rounds fired also confirmed the Wilcoxon Signed Ranks Test. In all cases the null hypothesis that the number of rounds fired in both simulations was similar was rejected. The p-values ranged from 0.0118 for the Hunter-Liggett mechanized scenario to 3.65E-12 for the Hunter-Liggett light scenario.

D. ANALYSIS OF RESULTS

The results of the Wilcoxon Signed Ranks Test and the paired *t*-test clearly indicate that HLA Warrior and Janus do not produce statistically similar results with respect to the tested MOPs. With few exceptions the null hypothesis that Janus MOPs are statistically similar to HLA Warrior MOPs was rejected. The next step was to analyze why differences exist and identify potential causes. Two sources of the differences investigated were HLA Warrior source code errors and differences in the implementation of the Janus algorithms in HLA Warrior.

1. Source Code Errors

Given that HLA Warrior is a new simulation still undergoing verification and validation testing, a starting point for identifying causes to the disparate results was the source code logic. Analysis of the code began with the search and detection algorithms and kill algorithms. An error in the detection algorithm would likely lead to errors in the other MOPs. For instance, changes to detection range would likely affect the kill range since these MOPs are closely linked. Also, the number of rounds fired will impact the number of kills and potentially kill ranges. Further the number of kills will ultimately affect the force exchange ratio in the battle.

Initial investigation into the search and detection algorithm and the kill algorithm found two errors in the HLA Warrior source code. The first error was in the inter-fire time calculations. In Janus, there are several parameters that can be specified for each weapon system. Among them are range, rounds per trigger pull, trigger pulls per reload, and reload times. Recall all scenarios were developed in Janus then converted to HLA Warrior. As HLA Warrior read the Janus data, a conversion error occurred when processing the number of trigger pulls per reload. Specifically, HLA Warrior exaggerated the inter-fire times for systems with the trigger pulls per reload parameter exceeding one. Therefore the overall number of rounds fired by HLA Warrior was less than expected.

The second error in the source code allowed the AH-64s in the mechanized scenarios to detect and engage targets behind them. In essence the AH-64s fired Hellfire missiles backwards, which is not possible. This was evident while watching the mechanized scenario executed in Southwest Asia. In each run, the red AH-64s over flew then systematically killed the blue tanks. As a result the blue force suffered almost total annihilation while inflicting almost no casualties on the red force.

HLA Warrior developers corrected both errors and all of the Hunter-Liggett light infantry scenarios and Southwest Asia mechanized scenarios were re-executed. Analysis of the results showed that corrections implemented to HLA Warrior source code lessened the gap between Janus and HLA Warrior in most MOPs. In the Southwest Asia mechanized scenario, the p-value for number of rounds fired changed from 1.02E-07 prior to the corrections to 0.018 afterward. Although the null hypothesis that HLA Warrior and Janus produce similar results was still rejected, the gap between them was significantly reduced. In the case of red kill ranges, prior to implementing the changes, the null hypothesis that the simulations were the same was rejected with a p-value of 0.0013. After the changes, the null hypothesis is no longer rejected with a p-value of 0.108.

In the Hunter-Liggett light infantry scenario, the disparity between Janus and HLA Warrior was reduced in four of the six MOPs, blue detection range, blue kill range, FER, and rounds fired. The largest improvement was in the number of rounds fired. While HLA Warrior still fires significantly less than Janus, the magnitude of the difference was reduced by a factor of 10. Tables 7 and 8 below summarize the results of the Wilcoxon Signed Ranks Test and the paired *t*-test for the Hunter-Liggett light infantry and the Southwest Asia mechanized scenarios following the corrections to HLA Warrior. Increased p-values indicate greater similarity between Janus and HLA Warrior results. P-values greater than 0.05 fail to reject the null hypothesis that the results are statistically similar. Appendix E contains the raw data and analysis output for the comparison of and the Hunter-Liggett light infantry and the Southwest Asia mechanized scenarios utilizing the corrected version of HLA Warrior.

		Measure of Performance					
		Blue Detection Range	**Red Detection Range**	**Blue Kill Range**	**Red Kill Range**	**Force Exchange Ratio**	**Rounds Fired**
H.L. Light	Before	0.000000	0.000000	0.000121	0.000229	0.529000	0.000000
H.L. Light	After	0.000000	0.000000	0.000806	0.000007	0.585000	0.000000
SWA Mech	Before	0.000036	0.000001	0.001033	0.001309	0.000000	0.000000
SWA Mech	After	0.000002	0.000067	0.013039	0.108290	0.000001	0.018440

Table 7. Signed Ranks Test Results (p-Values) Before and After HLA Warrior Modifications

		Measure of Performance					
		Blue Detection Range	Red Detection Range	Blue Kill Range	Red Kill Range	Force Exchange Ratio	Rounds Fired
H.L. Light	Before	0.000000	0.000000	0.000000	0.000000	0.492100	0.003906
H.L. Light	After	0.000000	0.000000	0.001950	0.000000	0.500000	0.001950
SWA Mech	Before	0.001950	0.001950	0.003906	0.005895	0.001950	0.003906
SWA Mech	After	0.001950	0.001950	0.009770	0.084000	0.001950	0.000000

Table 8. Paired *t*-Test Results (p-Values) Before and After HLA Warrior Modifications

While the modifications reduced the disparity between Janus and HLA Warrior, differences still exist between the two simulations. In all of the 30 light infantry scenarios (including the 10 runs following the corrections to the programming), HLA Warrior entities recorded detection events at a greater distance than Janus entities. Conversely, in every instance in the mechanized scenarios, Janus detection ranges exceeded HLA Warrior detection ranges. As one might expect, kill ranges tended to follow the pattern observed in the detection ranges. In the light scenarios, HLA Warrior tended to have longer kill ranges. Conversely, in the mechanized scenarios, Janus tended to have longer kill ranges. Therefore, further investigation into the programming may be warranted.

2. Methodology Differences

Investigation into the methodology of the programming of HLA Warrior led to several possibilities that could account for the differences between the two simulations. Among them are the way HLA Warrior reads terrain files and the way HLA Warrior implements some Janus algorithms.

a. Terrain Conversion

As mentioned previously, HLA Warrior possesses the capability to read scenario files constructed in Janus. This thesis took advantage of the capability to ensure that all corresponding scenarios began in exactly the same situation. When reading entity locations from Janus, HLA Warrior converts all Universal Transverse Macerator (UTM) grid locations into Latitude-Longitude locations [Ref. 7]. Due to the inherent errors in the conversion process, when HLA Warrior positions entities, their locations may be displaced slightly when compared to their original locations in Janus. This displacement could ultimately effect the line of sight for those entities. In hilly or rough terrain similar to Fort Hunter-Liggett, entities that previously had clear fields of view in Janus may be placed behind terrain features once converted to HLA Warrior, inhibiting line of sight. Reducing the line of sight will adversely effect detection ranges.

b. Event Scheduling

While HLA Warrior developers took great efforts to ensure that the Janus algorithms remained intact, the algorithms were often implemented differently in HLA Warrior. The primary implementation difference is in the way events are scheduled prior to the execution of the individual algorithms. Janus has approximately ten major events processing at regular intervals. Among them are move events, search events, detection events, and impact events. As the simulation clock advances, each of the major events is processed in a predetermined priority. The search event is executed as follows. Prior to starting the simulation run, the user can specify a variable called *dtsearch.* This variable represents the time required for an entity to conduct a search. For instance, let *dtsearch* equal 6. The simulation then divides *dtsearch* by the number of sides in the scenario (say

2). Each side in the scenario is then assigned an equal portion of *dtsearch* to conduct its searches. So, for example, each entity on side one conducts its first search at time zero. All entities on side one then conduct the next search *dtsearch* time units later, at time six in this example. The entities on side two conduct their first search at time three in this example. Their subsequent search will commence *dtsearch* time units later, at time nine. This search pattern continues throughout the duration of the simulation. Had there been three sides, the first side would have conducted searches at times zero, six, twelve, and so on; side two would have conducted searches at time two, eight, fourteen, and so on; and side three would have conduct searches at times four, ten, sixteen and so on. [Ref. 7]

Each search event then stochastically determines if a future detection event will be scheduled through use of the line-of-sight and detection algorithms. Similarly, detections can schedule engagements, and subsequent kill events, all of which are executed as the simulation clock advances. [Ref. 7]

HLA Warrior utilizes the same major events as Janus, but they are implemented differently. In the case of the search event, HLA Warrior also utilizes a variable called *dtsearch*, defined identically to the Janus variable. However, HLA Warrior applies a different method to determine when entities conduct searches. Every entity is assigned an initial search time according to a uniform random variable on the interval zero to *dtsearch*. Recall that in Janus, all entities on a side conduct searches at the same time. The second search for each HLA Warrior entity takes place *dtsearch* time units after the first search. As a result individual entities on both sides are conducting searches throughout the *dtsearch* time period. Consequently, searches by both sides are ongoing continuously for the duration of the simulation. Once searches commence, the algorithm to determine detections is identical to the Janus algorithm. [Ref. 7]

These scheduling difference may lead to differences in detections and provide a partial explanation as to why the detection ranges in the HLA Warrior are different from the detection ranges in Janus. Recall that in Janus, all detections for a particular side occur at the same time, then are repeated *dtsearch* time units later, where as in HLA Warrior, detection events occur continuously throughout the simulation. In the time between search events in Janus, all entities will have the opportunity to move greater distances than HLA Warrior entities. The differences in entity position between each detection event may account for the disparity in average detection range between Janus and HLA Warrior.

While the event scheduling in HLA Warrior is different from the implementation in Janus, HLA Warrior more closely models reality. In an actual combat environment, individual soldiers and weapons systems are not limited to conducting searches at specific times. Rather, they conduct searches throughout the course of the battle. Given that, HLA Warrior's results may be more realistic than Janus'.

c. Line-of-Sight Algorithm

HLA Warrior's line-of-sight algorithm has also been modified compared to Janus' line-of-sight algorithm. The modifications were implemented in order to reduce the overall complexity, and thus execution time of the algorithm. In basic terms, when determining the line of sight between two entities, Janus first determines which opposing entities are within range of the sensor of the searching entity. For those entities within range, Janus then "walks the line" between the entities three times. The first time it walks the line, Janus collects data on the terrain and features in the vicinity of the line. On the second walk Janus checks to determine if terrain interferes with the line of sight. The third walk then determines if any features in the vicinity of the line (trees, buildings, etc) interfere with the line of sight. These calculations are then computed for every entity combination on the battlefield. [Ref. 7]

HLA Warrior, on the other hand, only walks the line of sight twice. On the first walk, HLA Warrior determines which features on the terrain are in the proximity of the line of sight and could possibly interfere with the line. On the second walk, both terrain and features are analyzed. Additionally, the HLA Warrior designers developed a proximity manager that reduces the number of entity pairs that have to be examined. The proximity manager is essentially a database that tracks the locations of all entities in the simulation. It is updated after the execution of each move event. When determining line of sight, the searching entity queries the proximity manager as to which entities of the opposing force are within its sensor search pattern, then only those entity pairs within the search pattern are investigated further for line of sight. (The proximity manager is also utilized in artillery casualty assessment, chemical casualty assessments, and movement delays caused by obstacles and terrain features). Once line of sight is determined, the detection and kill algorithms in HLA Warrior and Janus are identical. [Ref. 7]

A probable difference in the outcome of the detection algorithm as a result of implementation differences is likely in the proximity manager. When determining line of sight, Janus looks at all terrain and features within the range of the sensor, while HLA Warrior looks at only those entities passed to the detection algorithm by the proximity manager. Future investigation into the implementation of the proximity manager is required to determine if all applicable terrain features are being processed for line-of-sight determination, particularly with regard to mechanized and light infantry scenarios.

The net result of these different implementations is that HLA Warrior tends to be more efficient in its calculations and the execution of the algorithms. However, the implementation of the algorithms may cause the disparate results in the two simulations.

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V. CONCLUSIONS

The initial comparison between HLA Warrior and Janus indicated that the simulations do not produce statistically similar results with respect to most of the selected MOPs. In almost all cases the null hypothesis that the simulations were the same was rejected. Following the initial analysis, two HLA Warrior programming errors, inter-fire times between reloads and helicopter search and fire sectors, were identified and corrected. The subsequent analysis revealed that, while the simulations were still statistically dissimilar, some differences between Janus and HLA Warrior were reduced. Specifically, differences in number of rounds fired and kill ranges were reduced and the FER was indistinguishable following the corrections. However, consistent differences remain in detection ranges between Janus and HLA Warrior.

Certain areas in HLA Warrior warrant further investigation. First, modification of the HLA Warrior search sequence to match Janus' search sequence and re-running the scenarios would help isolate whether HLA Warrior's current search sequence is causing a disparity between the simulations. Modifying the search sequence would be a relatively straightforward and inexpensive modification to HLA Warrior. Also, follow-on studies should focus on examining the algorithms in both simulations to determine if they are in fact identical. Finally, additional research is necessary to assess HLA Warrior's line-of-sight algorithm. Specifically researchers should investigate the implementation of the proximity manager to ensure all applicable terrain features are being processed for line-of-sight calculations.

Janus is considered valid primarily through user confidence and face-validity. After observing 40 scenarios executed in Janus and the same scenarios executed 60 times in HLA Warrior, both Janus and HLA Warrior scenarios produce generally similar outcomes and the HLA Warrior results were plausible. Following the HLA Warrior source code corrections, the entities appeared to engage and kill opposing entities at believable distances and locations, and the flow of the battles occurred as one might expect. Furthermore, Janus and HLA Warrior did produce statistically similar force exchange ratios, the quantitative measure of the scenario outcome. Consequently, while HLA Warrior and Janus produce statistically different detection and kill ranges, scenario outcomes are similar and HLA Warrior demonstrates a degree of face-validity.

APPENDIX A – RAW DATA

SCENARIO #1 HL Light

	Detection Range Blue		Detection Range Red		Kill Range Blue		Kill Range Red		FER		Rounds Fired	
Run	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus
1	1297.10	1098.42	1353.50	1168.03	1049.25	883.86	1200.88	1067.67	0.217	0.220	6616	72618
2	1311.90	1113.54	1388.80	1146.07	1060.41	870.63	1114.91	1045.07	0.154	0.150	6183	66579
3	1307.00	1080.47	1359.20	1155.76	1107.67	901.79	1100.87	1033.92	0.178	0.140	6900	77797
4	1296.00	1042.76	1338.90	1174.89	1037.43	970.36	1130.08	1047.87	0.238	0.130	7597	68683
5	1309.30	1063.36	1375.90	1156.48	1032.46	940.58	1117.25	1085.00	0.167	0.230	6520	69923
6	1301.40	1106.17	1326.80	1152.94	954.48	904.74	1061.21	1062.74	0.226	0.090	6848	70233
7	1317.20	1111.20	1377.10	1165.32	1052.65	853.86	1157.30	1045.92	0.162	0.270	6707	78171
8	1306.70	1081.64	1356.30	1157.09	992.80	933.66	1121.31	1045.81	0.152	0.200	6771	76740
9	1308.70	1029.20	1376.70	1146.74	1072.54	825.17	1129.76	1013.87	0.178	0.140	6729	67050
10	1287.00	1095.05	1337.60	1156.57	1010.95	832.76	1134.82	998.27	0.194	0.140	6031	71037
Average	1304.23	1082.18	1359.08	1157.99	1037.06	891.74	1126.84	1044.61	0.187	0.171	6690.2	71883.1
Variance	78.88	838.73	416.76	82.73	1851.44	2271.77	1304.39	634.77	0.0009	0.0031	180643.3	18628348.3
Standard Deviation	8.88	28.96	20.41	9.10	43.03	47.66	36.12	25.19	0.0306	0.0559	425.0	4316.1

SCENARIO #2 HL Mech

	Detection Range Blue		Detection Range Red		Kill Range Blue		Kill Range Red		FER		Rounds Fired	
Run	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus
1	3546.19	4077.79	3092.52	3243.25	3008.90	2603.06	2756.89	3099.05	0.894	0.740	319	657
2	3532.47	3947.62	3099.91	3227.77	2869.33	2584.04	2790.48	3028.95	0.628	1.190	275	763
3	3553.42	4080.81	3044.10	3339.80	2791.31	2802.86	2679.50	3205.00	0.821	1.180	315	681
4	3482.95	4512.96	3062.95	3686.48	2830.76	3526.67	2607.39	3475.63	0.821	0.410	377	441
5	3534.32	4018.41	3093.82	3242.85	2901.20	2834.78	2820.08	2883.33	0.773	1.660	337	409
6	3612.19	3896.11	3109.91	3387.61	3096.67	3001.56	2808.21	2857.86	0.749	1.390	288	296
7	3548.88	4170.06	3174.27	3766.03	3155.58	3140.30	2831.13	3295.88	0.556	0.840	287	314
8	3444.83	3900.53	2949.61	3402.75	2832.18	2753.80	2497.97	3076.25	0.801	1.360	338	749
9	3545.60	3982.52	3192.82	3479.09	2939.94	2824.12	2763.62	2956.15	1.087	1.700	368	386
10	3477.94	4477.38	2896.87	3677.49	2799.30	3132.31	2642.98	3656.25	0.797	0.350	334	419
Average	3527.88	4106.42	3071.68	3445.31	2922.52	2920.35	2719.82	3153.43	0.793	1.082	323.80	511.50
Variance	2258.05	49261.11	8297.72	40165.09	16074.85	82158.59	11992.05	67025.93	0.0205	0.2303	1153.51	32754.28
Standard Deviation	47.52	221.95	91.09	200.41	126.79	286.63	109.51	258.89	0.1431	0.4799	33.96	180.98

RAW DATA

SCENARIO #3 SWA Light

Run	Detection Range Blue		Detection Range Red		Kill Range Blue		Kill Range Red		FER		Rounds Fired	
	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus
1	1481.00	1059.99	1822.90	1081.07	1200.82	619.70	1131.82	852.95	1.170	0.380	20243	37716
2	1572.20	1035.30	1826.10	1106.32	931.31	645.52	956.81	776.80	0.577	0.240	17014	25822
3	1512.00	1135.79	1803.40	1138.70	1281.35	677.66	923.04	845.98	0.887	0.470	16813	31584
4	1458.70	1089.99	1757.00	1088.31	723.36	704.71	925.42	796.24	0.592	0.370	19167	26326
5	1415.80	1125.44	1714.00	1115.19	812.65	684.79	1029.09	824.82	0.856	0.210	19668	26138
6	1477.30	1095.57	1832.50	1116.47	985.64	621.91	1058.81	855.80	0.691	0.250	20857	29079
7	1534.60	995.47	1803.10	1089.60	1062.25	643.94	939.87	745.60	0.821	0.450	16704	26184
8	1460.40	1051.76	1796.30	1043.45	974.01	671.62	910.94	748.53	0.709	0.280	17365	24654
9	1426.40	1095.20	1787.10	1100.69	1107.16	693.43	986.87	782.86	0.831	0.300	18376	24379
10	1468.90	1023.98	1826.10	1074.15	716.65	617.92	1008.03	830.67	0.330	0.310	17532	25351
Average	1480.73	1070.85	1796.85	1095.39	979.52	658.12	987.07	806.02	0.746	0.326	18373.9	27723.3
Variance	2273.85	2043.70	1365.57	699.80	36463.15	1050.69	5016.07	1742.33	0.0505	0.0078	2307111.7	17031082.5
Standard Deviation	47.68	45.21	36.95	26.45	190.95	32.41	70.82	41.74	0.2247	0.0886	1518.9	4126.9

SCENARIO #4 SWA Mech

Run	Detection Range Blue		Detection Range Red		Kill Range Blue		Kill Range Red		FER		Rounds Fired	
	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus	Warrior	Janus
1	3792.37	4514.06	2543.64	3795.37	3582.41	3098.14	2127.63	2855.00	0.121	1.330	41	226
2	3709.24	4524.34	2603.43	4135.74	3124.60	3218.29	2052.46	3293.75	0.169	2.220	40	293
3	3608.05	4357.00	2652.03	3371.48	3248.24	2787.25	2257.17	2741.82	0.145	1.580	51	251
4	3924.61	4337.02	2858.22	3486.64	2900.43	2842.25	2521.61	2248.13	0.121	1.080	42	327
5	3533.10	4662.36	2849.94	3880.45	3714.92	3272.33	2322.32	3146.00	0.121	1.870	74	292
6	3424.19	4509.96	2801.35	3768.72	3731.13	3145.95	2149.47	2908.75	0.145	2.280	52	346
7	3235.43	4564.56	2356.39	3746.04	3475.73	3125.58	2042.83	2935.56	0.121	2.070	40	258
8	3534.35	4270.55	2566.15	3540.80	3618.89	2708.78	2291.12	2889.17	0.072	1.480	32	362
9	3202.67	4478.59	2500.31	3579.34	3324.15	2892.20	2123.71	2598.18	0.121	1.620	42	227
10	4239.12	4480.99	3018.88	3910.49	3764.42	3095.00	2700.39	2931.25	0.143	2.170	53	337
Average	3620.31	4469.94	2675.03	3721.51	3448.49	3018.58	2258.87	2854.76	0.128	1.770	46.70	291.90
Variance	98800.28	13651.35	40574.55	52378.20	84358.73	37852.22	45086.55	82289.41	0.0006	0.1706	134.90	2498.32
Standard Deviation	314.33	116.84	201.43	228.86	290.45	194.56	212.34	286.86	0.0255	0.4130	11.61	49.98

APPENDIX B - WILCOXON SIGNED RANKS TEST RESULTS

Scenarrio	Run	Blue Det Range Warrior	Blue Det Range Janus	Difference	Rank		Red Det Range Warrior	Red Det Range Janus	Difference	Rank	
HL Light	1	1297.1	1098.42	198.7	4		1353.5	1168.028	185.5	4	
HL Light	2	1311.9	1113.541	198.4	3		1388.8	1146.065	242.7	10	
HL Light	3	1307.0	1080.474	226.5	7		1359.2	1155.756	203.4	6	
HL Light	4	1296.0	1042.757	253.2	9		1338.9	1174.892	164.0	1	
HL Light	5	1309.3	1063.363	245.9	8		1375.9	1156.483	219.4	8	
HL Light	6	1301.4	1106.171	195.2	2		1326.8	1152.94	173.9	2	
HL Light	7	1317.2	1111.197	206.0	5		1377.1	1165.323	211.8	7	
HL Light	8	1306.7	1081.638	225.1	6		1356.3	1157.088	199.2	5	
HL Light	9	1308.7	1029.201	279.5	10		1376.7	1146.741	230.0	9	
HL Light	10	1287.0	1095.045	192.0	1		1337.6	1156.567	181.0	3	
	Average	1304.23	1082.18	222.05	55	sum	1359.08	1157.9883	201.0917	55	sum
	Variance	78.885	838.727		0	p-Value	416.764	82.729		0	p-Value
	Standard Deviation	8.882	28.961		(9,46)	Accept region	20.415	9.096		(9,46)	Accept region

Scenarrio	Run	Blue Det Range Warrior	Blue Det Range Janus	Difference	Rank		Red Det Range Warrior	Red Det Range Janus	Difference	Rank	
HL Mech	1	3546.2	4077.791	-531.6	0		3092.5	3243.252	-150.7	0	
HL Mech	2	3532.5	3947.62	-415.2	0		3099.9	3227.77	-127.9	0	
HL Mech	3	3553.4	4080.812	-527.4	0		3044.1	3339.795	-295.7	0	
HL Mech	4	3482.9	4512.963	-1030.0	0		3062.9	3686.477	-623.5	0	
HL Mech	5	3534.3	4018.409	-484.1	0		3093.8	3242.853	-149.0	0	
HL Mech	6	3612.2	3896.107	-283.9	0		3109.9	3387.609	-277.7	0	
HL Mech	7	3548.9	4170.064	-621.2	0		3174.3	3766.03	-591.8	0	
HL Mech	8	3444.8	3900.532	-455.7	0		2949.6	3402.746	-453.1	0	
HL Mech	9	3545.6	3982.519	-436.9	0		3192.8	3479.088	-286.3	0	
HL Mech	10	3477.9	4477.379	-999.4	0		2896.9	3677.49	-780.6	0	
	Average	3527.878	4106.42	-578.54	0	sum	3071.6782	3445.311	-373.6328	0	sum
	Variance	2258.053	49261.111		0.001953125	p-Value	8297.719	40165.087		0.001953125	p-Value
	Standard Deviation	47.519	221.948		(9,46)	Accept region	91.092	200.412		(9,46)	Accept region

Scenarrio	Run	Blue Det Range Warrior	Blue Det Range Janus	Difference	Rank		Red Det Range Warrior	Red Det Range Janus	Difference	Rank	
SWA Light	1	1481.0	1059.985	421.0	7		1822.9	1081.068	741.8	8	
SWA Light	2	1572.2	1035.304	536.9	9		1826.1	1106.317	719.8	7	
SWA Light	3	1512.0	1135.793	376.2	4		1803.4	1138.703	664.7	2	
SWA Light	4	1458.7	1089.992	368.7	3		1757.0	1088.305	668.7	3	
SWA Light	5	1415.8	1125.443	290.4	1		1714.0	1115.187	598.8	1	
SWA Light	6	1477.3	1095.567	381.7	5		1832.5	1116.474	716.0	6	
SWA Light	7	1534.6	995.467	539.1	10		1803.1	1089.595	713.5	5	
SWA Light	8	1460.4	1051.763	408.6	6		1796.3	1043.445	752.9	10	
SWA Light	9	1426.4	1095.201	331.2	2		1787.1	1100.693	686.4	4	
SWA Light	10	1468.9	1023.983	444.9	8		1826.1	1074.152	751.9	9	
	Average	1480.73	1070.85	409.88	55	sum	1796.85	1095.3939	701.4561	55	sum
	Variance	2273.847	2043.700		0	p-Value	1365.569	699.803		0	p-Value
	Standard Deviation	47.685	45.207		(9,46)	Accept region	36.954	26.454		(9,46)	Accept region

Scenarrio	Run	Blue Det Range Warrior	Blue Det Range Janus	Difference	Rank		Red Det Range Warrior	Red Det Range Janus	Difference	Rank	
SWA Mech	1	3792.4	4514.058	-721.7	0		2543.6	3795.37	-1251.7	0	
SWA Mech	2	3709.2	4524.336	-815.1	0		2603.4	4135.74	-1532.3	0	
SWA Mech	3	3608.0	4356.996	-748.9	0		2652.0	3371.475	-719.5	0	
SWA Mech	4	3924.6	4337.016	-412.4	0		2858.2	3486.64	-628.4	0	
SWA Mech	5	3533.1	4662.361	-1129.3	0		2849.9	3880.451	-1030.5	0	
SWA Mech	6	3424.2	4509.962	-1085.8	0		2801.3	3768.718	-967.4	0	
SWA Mech	7	3235.4	4564.557	-1329.1	0		2356.4	3746.042	-1389.7	0	
SWA Mech	8	3534.3	4270.554	-736.2	0		2566.1	3540.8	-974.7	0	
SWA Mech	9	3202.7	4478.59	-1275.9	0		2500.3	3579.338	-1079.0	0	
SWA Mech	10	4239.1	4480.992	-241.9	0		3018.9	3910.486	-891.6	0	
	Average	3620.3128	4469.94	-849.63	0	sum	2675.0325	3721.506	-1046.4735	0	sum
	Variance	98800.277	13651.354		0.001953125	p-Value	40574.549	52378.197		0.001953125	p-Value
	Standard Deviation	314.325	116.839		(9,46)	Accept region	201.431	228.863		(9,46)	Accept region

WILCOXON SIGNED RANKS TEST RESULTS

Scenario	Run	Blue Kill Range Warrior	Blue Kill Range Janus	Difference	Rank		Red Kill Range Warrior	Red Kill Range Janus	Difference	Rank	
HL Light	1	1049.25	883.86	165.39	5		1200.88	1067.67	133.21	9	
HL Light	2	1060.41	870.63	189.79	7		1114.91	1045.07	69.84	4	
HL Light	3	1107.67	901.79	205.88	9		1100.87	1033.92	66.95	3	
HL Light	4	1037.43	970.36	67.08	3		1130.08	1047.87	82.22	6	
HL Light	5	1032.46	940.58	91.88	4		1117.25	1085.00	32.25	3	
HL Light	6	954.48	904.74	49.74	1		1061.21	1062.74	-1.53	0	
HL Light	7	1052.65	853.86	198.79	8		1157.30	1045.92	111.38	7	
HL Light	8	992.80	933.66	59.14	2		1121.31	1045.81	75.50	5	
HL Light	9	1072.54	825.17	247.37	10		1129.76	1013.87	115.90	8	
HL Light	10	1010.95	832.76	178.19	6		1134.82	998.27	136.55	10	
	Average	1037.06	891.74	145.32	55	sum	1126.84	1044.61	82.23	55	sum
	Variance	1851.44	2271.77		(9,46)	accept region	1304.39	634.77		(9,46)	accept region
	Standard Deviation	43.03	47.66		0	p-value	36.12	25.19		0	p-value

Scenario	Run	Blue Kill Range Warrior	Blue Kill Range Janus	Difference	Rank		Red Kill Range Warrior	Red Kill Range Janus	Difference	Rank	
HL Mech	1	3008.90	2603.06	405.85	9		2756.89	3099.05	-342.16	0	
HL Mech	2	2869.33	2584.04	285.30	7		2790.48	3028.95	-238.46	0	
HL Mech	3	2791.31	2802.86	-11.54	0		2679.50	3205.00	-525.50	0	
HL Mech	4	2830.76	3526.67	-695.91	0		2607.39	3475.63	-868.24	0	
HL Mech	5	2901.20	2834.78	66.42	3		2820.08	2883.33	-63.26	0	
HL Mech	6	3096.67	3001.56	95.11	5		2808.21	2857.86	-49.65	0	
HL Mech	7	3155.58	3140.30	15.28	2		2831.13	3295.88	-464.76	0	
HL Mech	8	2832.18	2753.80	78.38	4		2497.97	3076.25	-578.28	0	
HL Mech	9	2939.94	2824.12	115.82	6		2763.62	2956.15	-192.53	0	
HL Mech	10	2799.30	3132.31	-333.00	0		2642.98	3656.25	-1013.28	0	
	Average	2922.52	2920.35	2.17	55	sum	2719.82	3153.43	-433.61	55	sum
	Variance	16074.85	82158.59		(9,46)	accept region	11992.05	67025.93		(9,46)	accept region
	Standard Deviation	126.79	286.63		0	p-value	109.51	258.89		0	p-value

Scenario	Run	Blue Kill Range Warrior	Blue Kill Range Janus	Difference	Rank		Red Kill Range Warrior	Red Kill Range Janus	Difference	Rank	
SWA Light	1	1200.82	619.70	581.12	9		1131.82	852.95	278.87	10	
SWA Light	2	931.31	645.52	285.78	4		956.81	776.80	180.02	5	
SWA Light	3	1281.35	677.66	603.69	10		923.04	845.98	77.06	1	
SWA Light	4	723.36	704.71	18.65	1		925.42	796.24	129.18	2	
SWA Light	5	812.65	684.79	127.86	3		1029.09	824.82	204.27	9	
SWA Light	6	985.64	621.91	363.73	6		1058.81	855.80	203.01	7	
SWA Light	7	1062.25	643.94	418.31	8		939.87	745.60	194.27	6	
SWA Light	8	974.01	671.62	302.39	5		910.94	748.53	162.42	3	
SWA Light	9	1107.16	693.43	413.73	7		986.87	782.86	204.01	8	
SWA Light	10	716.65	617.92	98.73	2		1008.03	830.67	177.36	4	
	Average	979.52	658.12	321.40	55	sum	987.07	806.02	181.05	55	sum
	Variance	36463.15	1050.69		(9,46)	accept region	5016.07	1742.33		(9,46)	accept region
	Standard Deviation	190.95	32.41		0	p-value	70.82	41.74		0	p-value

Scenario	Run	Blue Kill Range Warrior	Blue Kill Range Janus	Difference	Rank		Red Kill Range Warrior	Red Kill Range Janus	Difference	Rank	
SWA Mech	1	3582.41	3098.14	484.27	7		2127.63	2855.00	-727.37	0	
SWA Mech	2	3124.60	3218.29	-93.70	0		2052.46	3293.75	-1241.29	0	
SWA Mech	3	3248.24	2787.25	460.99	6		2257.17	2741.82	-484.65	0	
SWA Mech	4	2900.43	2842.25	58.18	1		2521.61	2248.13	273.48	2	
SWA Mech	5	3714.92	3272.33	442.59	5		2322.32	3146.00	-823.68	0	
SWA Mech	6	3731.13	3145.95	585.18	8		2149.47	2908.75	-759.28	0	
SWA Mech	7	3475.73	3125.58	350.15	3		2042.83	2935.56	-892.73	0	
SWA Mech	8	3618.89	2708.78	910.11	10		2291.12	2889.17	-598.04	0	
SWA Mech	9	3324.15	2892.20	431.96	4		2123.71	2598.18	-474.47	0	
SWA Mech	10	3764.42	3095.00	669.42	9		2700.39	2931.25	-230.86	0	
	Average	3448.49	3018.58	429.91	55	sum	2258.87	2854.76	-595.89	55	sum
	Variance	84358.73	37852.22		(9,46)	accept region	45086.55	82289.41		(9,46)	accept region
	Standard Deviation	290.45	194.56		0	p-value	212.34	286.86		0	p-value

WILCOXON SIGNED RANKS TEST RESULTS

Scenario	Run	FER Warrior	FER Janus	Difference	ABS Dif	Rank	Signed Rank
HL Light	1	0.217	0.220	-0.003	0.003	1	0
HL Light	2	0.154	0.150	0.004	0.004	2	2
HL Light	3	0.178	0.140	0.038	0.038	3	3
HL Light	4	0.238	0.130	0.108	0.108	9	9
HL Light	5	0.167	0.230	-0.063	0.063	7	0
HL Light	6	0.226	0.090	0.136	0.136	10	10
HL Light	7	0.162	0.270	-0.108	0.108	8	0
HL Light	8	0.152	0.200	-0.048	0.048	5	0
HL Light	9	0.178	0.140	0.038	0.038	4	4
HL Light	10	0.194	0.140	0.054	0.054	6	6
	Average	0.18662	0.171	0.0156201		sum	34
	Variance	0.000936	0.003121			P-Value	0.4921875
	Standard Deviation	0.030601	0.055867			accept region	(9,46)

Scenario	Run	FER Warrior	FER Janus	Difference	ABS Dif	Rank	Signed Rank
SWA Light	1	1.170	0.380	0.790	0.790	10	10
SWA Light	2	0.577	0.240	0.337	0.337	3	3
SWA Light	3	0.887	0.470	0.417	0.417	5	5
SWA Light	4	0.592	0.370	0.222	0.222	2	2
SWA Light	5	0.856	0.210	0.646	0.646	9	9
SWA Light	6	0.691	0.250	0.441	0.441	7	7
SWA Light	7	0.821	0.450	0.371	0.371	4	4
SWA Light	8	0.709	0.280	0.429	0.429	6	6
SWA Light	9	0.831	0.300	0.531	0.531	8	8
SWA Light	10	0.330	0.310	0.020	0.020	1	1
	Average	0.746192	0.326	0.4201917		sum	55
	Variance	0.050468	0.007849			P-Value	0
	Standard Deviation	0.224651	0.088594			accept region	(9,46)

Scenario	Run	FER Warrior	FER Janus	Difference	ABS Dif	Rank	Signed Rank
HL Mech	1	0.894	0.740	0.154	0.154	1	1
HL Mech	2	0.628	1.190	-0.562	0.562	7	0
HL Mech	3	0.821	1.180	-0.359	0.359	3	0
HL Mech	4	0.821	0.410	0.411	0.411	4	4
HL Mech	5	0.773	1.660	-0.887	0.887	10	0
HL Mech	6	0.749	1.390	-0.641	0.641	9	0
HL Mech	7	0.556	0.840	-0.284	0.284	2	0
HL Mech	8	0.801	1.360	-0.559	0.559	6	0
HL Mech	9	1.087	1.700	-0.613	0.613	8	0
HL Mech	10	0.797	0.350	0.447	0.447	5	5
	Average	0.792652	1.082	-0.2893481		sum	10
	Variance	0.020465	0.230262			P-Value	0.0839844
	Standard Deviation	0.143056	0.479856			accept region	(9,46)

Scenario	Run	FER Warrior	FER Janus	Difference	ABS Dif	Rank	Signed Rank
SWA Mech	1	0.121	1.330	-1.209	1.209	2	0
SWA Mech	2	0.169	2.220	-2.051	2.051	9	0
SWA Mech	3	0.145	1.580	-1.435	1.435	4	0
SWA Mech	4	0.121	1.080	-0.959	0.959	1	0
SWA Mech	5	0.121	1.870	-1.749	1.749	6	0
SWA Mech	6	0.145	2.280	-2.135	2.135	10	0
SWA Mech	7	0.121	2.070	-1.949	1.949	7	0
SWA Mech	8	0.072	1.480	-1.408	1.408	3	0
SWA Mech	9	0.121	1.620	-1.499	1.499	5	0
SWA Mech	10	0.143	2.170	-2.027	2.027	8	0
	Average	0.127833	1.77	-1.6421671		sum	0
	Variance	0.000648	0.170556			P-Value	0.0019531
	Standard Deviation	0.025458	0.412984			accept region	(9,46)

WILCOXON SIGNED RANKS TEST RESULTS

Scenarrio	Run	Rounds Warrior	Rounds Janus	Difference	ABS Difference	Rank	Signed Rank
HL Light	1	6616	72618	-66002	66002	7	0
HL Light	2	6183	66579	-60396	60396	2	0
HL Light	3	6900	77797	-70897	70897	9	0
HL Light	4	7597	68683	-61086	61086	3	0
HL Light	5	6520	69923	-63403	63403	5	0
HL Light	6	6848	70233	-63385	63385	4	0
HL Light	7	6707	78171	-71464	71464	10	0
HL Light	8	6771	76740	-69969	69969	8	0
HL Light	9	6729	67050	-60321	60321	1	0
HL Light	10	6031	71037	-65006	65006	6	0
	Average	6690.20	71883.10	-65192.90		sum	0
	Variance	180643.29	18628348.32			accept region	(9,46)
	Standard Deviation	425.02	4316.06			p-value	0.0039063

Scenarrio	Run	Rounds Warrior	Rounds Janus	Difference	ABS Difference	Rank	Signed Rank
SWA Light	1	20243	37716	-17473	17473	10	0
SWA Light	2	17014	25822	-8808	8808	7	0
SWA Light	3	16813	31584	-14771	14771	9	0
SWA Light	4	19167	26326	-7159	7159	3	0
SWA Light	5	19668	26138	-6470	6470	2	0
SWA Light	6	20857	29079	-8222	8222	6	0
SWA Light	7	16704	26184	-9480	9480	8	0
SWA Light	8	17365	24654	-7289	7289	4	0
SWA Light	9	18376	24379	-6003	6003	1	0
SWA Light	10	17532	25351	-7819	7819	5	0
	Average	18373.90	27723.30	-9349.40		sum	0
	Variance	2307111.66	17031082.46			accept region	(9,46)
	Standard Deviation	1518.92	4126.87			p-value	0.0039063

Scenarrio	Run	Rounds Warrior	Rounds Janus	Difference	ABS Difference	Rank	Signed Rank
HL Mech	1	319	657	-338	338	7	0
HL Mech	2	275	763	-488	488	10	0
HL Mech	3	315	681	-366	366	8	0
HL Mech	4	377	441	-64	64	4	0
HL Mech	5	337	409	-72	72	5	0
HL Mech	6	288	296	-8	8	1	0
HL Mech	7	287	314	-27	27	3	0
HL Mech	8	338	749	-411	411	9	0
HL Mech	9	368	386	-18	18	2	0
HL Mech	10	334	419	-85	85	6	0
	Average	323.80	511.50	-187.70		sum	0
	Variance	1153.51	32754.28			accept region	(9,46)
	Standard Deviation	33.96	180.98			p-value	0.0039063

Scenarrio	Run	Rounds Warrior	Rounds Janus	Difference	ABS Difference	Rank	Signed Rank
SWA Mech	1	41	226	-185	185	1	0
SWA Mech	2	40	293	-253	253	6	0
SWA Mech	3	51	251	-200	200	3	0
SWA Mech	4	42	327	-285	285	8	0
SWA Mech	5	74	292	-218	218	4	0
SWA Mech	6	52	346	-294	294	9	0
SWA Mech	7	40	258	-218	218	5	0
SWA Mech	8	32	362	-330	330	10	0
SWA Mech	9	42	227	-185	185	2	0
SWA Mech	10	53	337	-284	284	7	0
	Average	46.70	291.90	-245.20		sum	0
	Variance	134.90	2498.32			accept region	(9,46)
	Standard Deviation	11.61	49.98			p-value	0.0039063

APPENDIX C - PAIRED *t*-TEST RESULTS

Detection Range

Hunter Liggett Light Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	1304.23	1082.181
Variance	78.88456	838.7271
Observations	10	10
Pearson Correlation	0.085404	
Hypothesized Mean Difference	0	
df	9	
t Stat	23.75604	
P(T<=t) one-tail	9.9E-10	
t Critical one-tail	1.833114	
P(T<=t) two-tail	1.98E-09	
t Critical two-tail	2.262159	

Hunter Liggett Light Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	1359.08	1157.988
Variance	416.764	82.72893
Observations	10	10
Pearson Correlation	-0.387218	
Hypothesized Mean Difference	0	
df	9	
t Stat	25.07204	
P(T<=t) one-tail	6.14E-10	
t Critical one-tail	1.833114	
P(T<=t) two-tail	1.23E-09	
t Critical two-tail	2.262159	

Hunter Liggett Mech Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	3527.878	4106.42
Variance	2258.053	49261.11
Observations	10	10
Pearson Correlation	-0.429349	
Hypothesized Mean Difference	0	
df	9	
t Stat	-7.433366	
P(T<=t) one-tail	1.98E-05	
t Critical one-tail	1.833114	
P(T<=t) two-tail	3.96E-05	
t Critical two-tail	2.262159	

Hunter Liggett Mech Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	3071.678	3445.311
Variance	8297.719	40165.09
Observations	10	10
Pearson Correlation	-0.089057	
Hypothesized Mean Difference	0	
df	9	
t Stat	-5.19564	
P(T<=t) one-tail	0.000284	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.000567	
t Critical two-tail	2.262159	

PAIRED *t*-TEST RESULTS
Detection Range

SWA Light Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	1480.73	1070.85
Variance	2273.847	2043.7
Observations	10	10
Pearson Correlation	-0.500798	
Hypothesized Mean Difference	0	
df	9	
t Stat	16.10573	
P(T<=t) one-tail	3.04E-08	
t Critical one-tail	1.833114	
P(T<=t) two-tail	6.07E-08	
t Critical two-tail	2.262159	

SWA Light Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	1796.85	1095.394
Variance	1365.569	699.8031
Observations	10	10
Pearson Correlation	-0.120087	
Hypothesized Mean Difference	0	
df	9	
t Stat	46.25105	
P(T<=t) one-tail	2.58E-12	
t Critical one-tail	1.833114	
P(T<=t) two-tail	5.17E-12	
t Critical two-tail	2.262159	

SWA Mech Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	3620.313	4469.942
Variance	98800.28	13651.35
Observations	10	10
Pearson Correlation	-0.203658	
Hypothesized Mean Difference	0	
df	9	
t Stat	-7.527086	
P(T<=t) one-tail	1.79E-05	
t Critical one-tail	1.833114	
P(T<=t) two-tail	3.59E-05	
t Critical two-tail	2.262159	

SWA Mech Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	2675.033	3721.506
Variance	40574.55	52378.2
Observations	10	10
Pearson Correlation	0.147282	
Hypothesized Mean Difference	0	
df	9	
t Stat	-11.74603	
P(T<=t) one-tail	4.62E-07	
t Critical one-tail	1.833114	
P(T<=t) two-tail	9.24E-07	
t Critical two-tail	2.262159	

PAIRED *t*-TEST RESULTS
Kill Range

Hunter Liggett Light Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	1037.063	891.74
Variance	1851.439	2271.772
Observations	10	10
Pearson Correlation	-0.239252	
Hypothesized Mean Difference	0	
df	9	
t Stat	6.432146	
P(T<=t) one-tail	6.03E-05	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.000121	
t Critical two-tail	2.262159	

Hunter Liggett Light Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	1126.839	1044.613
Variance	1304.389	634.7711
Observations	10	10
Pearson Correlation	-0.001657	
Hypothesized Mean Difference	0	
df	9	
t Stat	5.90019	
P(T<=t) one-tail	0.000115	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.000229	
t Critical two-tail	2.262159	

Hunter Liggett Mech Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	2922.519	2920.349
Variance	16074.85	82158.59
Observations	10	10
Pearson Correlation	0.0145	
Hypothesized Mean Difference	0	
df	9	
t Stat	0.022014	
P(T<=t) one-tail	0.491459	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.982917	
t Critical two-tail	2.262159	

Hunter Liggett Mech Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	2719.824	3153.435
Variance	11992.05	67025.93
Observations	10	10
Pearson Correlation	-0.45706	
Hypothesized Mean Difference	0	
df	9	
t Stat	-4.232935	
P(T<=t) one-tail	0.001099	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.002197	
t Critical two-tail	2.262159	

PAIRED *t*-TEST RESULTS
Kill Range

SWA Light Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	979.5198	658.1215
Variance	36463.15	1050.695
Observations	10	10
Pearson Correlation	-0.085774	
Hypothesized Mean Difference	0	
df	9	
t Stat	5.17472	
P(T<=t) one-tail	0.000292	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.000583	
t Critical two-tail	2.262159	

SWA Light Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	987.0693	806.0225
Variance	5016.073	1742.328
Observations	10	10
Pearson Correlation	0.670276	
Hypothesized Mean Difference	0	
df	9	
t Stat	10.82863	
P(T<=t) one-tail	9.19E-07	
t Critical one-tail	1.833114	
P(T<=t) two-tail	1.84E-06	
t Critical two-tail	2.262159	

SWA Mech Blue
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	3448.491	3018.577
Variance	84358.73	37852.22
Observations	10	10
Pearson Correlation	0.358888	
Hypothesized Mean Difference	0	
df	9	
t Stat	4.757753	
P(T<=t) one-tail	0.000516	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.001033	
t Critical two-tail	2.262159	

SWA Mech Red
t-Test: Paired Two Sample for Means

	Warrior	*Janus*
Mean	2258.87	2854.76
Variance	45086.55	82289.41
Observations	10	10
Pearson Correlation	-0.337755	
Hypothesized Mean Difference	0	
df	9	
t Stat	-4.590263	
P(T<=t) one-tail	0.000654	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.001309	
t Critical two-tail	2.262159	

PAIRED *t*-TEST RESULTS
Force Exchange Ratio

Hunter Liggett Light
t-Test: Paired Two Sample for Means

	Warrior	Janus
Mean	0.18662	0.171
Variance	0.000936	0.003121
Observations	10	10
Pearson Correlation	-0.478422	
Hypothesized Mean Difference	0	
df	9	
t Stat	0.654641	
P(T<=t) one-tail	0.264536	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.529072	
t Critical two-tail	2.262159	

Hunter Liggett Mech
t-Test: Paired Two Sample for Means

	Warrior	Janus
Mean	0.792652	1.082
Variance	0.020465	0.230262
Observations	10	10
Pearson Correlation	0.234107	
Hypothesized Mean Difference	0	
df	9	
t Stat	-1.957084	
P(T<=t) one-tail	0.041014	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.082028	
t Critical two-tail	2.262159	

SWA Light
t-Test: Paired Two Sample for Means

	Warrior	Janus
Mean	0.746192	0.326
Variance	0.050468	0.007849
Observations	10	10
Pearson Correlation	0.32288	
Hypothesized Mean Difference	0	
df	9	
t Stat	6.23177	
P(T<=t) one-tail	7.65E-05	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.000153	
t Critical two-tail	2.262159	

SWA Mech
t-Test: Paired Two Sample for Means

	Warrior	Janus
Mean	0.127833	1.77
Variance	0.000648	0.170556
Observations	10	10
Pearson Correlation	0.553716	
Hypothesized Mean Difference	0	
df	9	
t Stat	-13.00034	
P(T<=t) one-tail	1.94E-07	
t Critical one-tail	1.833114	
P(T<=t) two-tail	3.88E-07	
t Critical two-tail	2.262159	

PAIRED *t*-TEST RESULTS
Rounds Fired

Hunter Liggett Light
t-Test: Paired Two Sample for Means

	Warrior	Janus
Mean	6690.2	71883.1
Variance	180643.3	18628348
Observations	10	10
Pearson Correlation	0.11606	
Hypothesized Mean Difference	0	
df	9	
t Stat	-48.08282	
P(T<=t) one-tail	1.82E-12	
t Critical one-tail	1.833114	
P(T<=t) two-tail	3.65E-12	
t Critical two-tail	2.262159	

Hunter Liggett Mech
t-Test: Paired Two Sample for Means

.	Warrior	Janus
Mean	323.8	511.5
Variance	1153.511	32754.28
Observations	10	10
Pearson Correlation	-0.139225	
Hypothesized Mean Difference	0	
df	9	
t Stat	-3.145005	
P(T<=t) one-tail	0.005916	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.011832	
t Critical two-tail	2.262159	

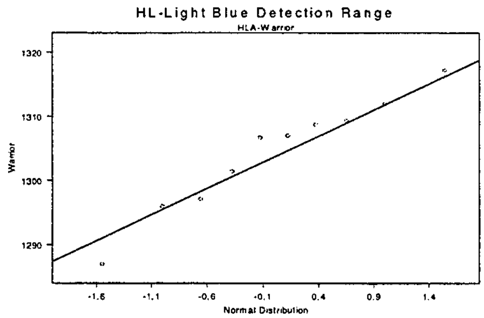
SWA Light
t-Test: Paired Two Sample for Means

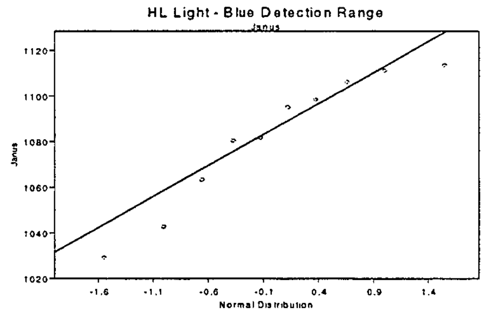
	Warrior	Janus
Mean	18373.9	27723.3
Variance	2307112	17031082
Observations	10	10
Pearson Correlation	0.409474	
Hypothesized Mean Difference	0	
df	9	
t Stat	-7.844541	
P(T<=t) one-tail	1.29E-05	
t Critical one-tail	1.833114	
P(T<=t) two-tail	2.59E-05	
t Critical two-tail	2.262159	

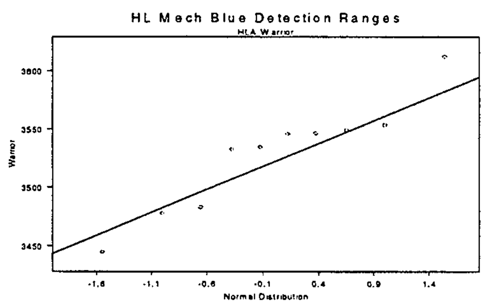
SWA Mech
t-Test: Paired Two Sample for Means

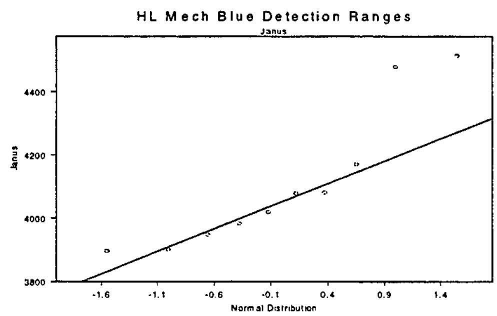
	Warrior.	Janus
Mean	46.7	291.9
Variance	134.9	2498.322
Observations	10	10
Pearson Correlation	0.019656	
Hypothesized Mean Difference	0	
df	9	
t Stat	-15.17634	
P(T<=t) one-tail	5.1E-08	
t Critical one-tail	1.833114	
P(T<=t) two-tail	1.02E-07	
t Critical two-tail	2.262159	

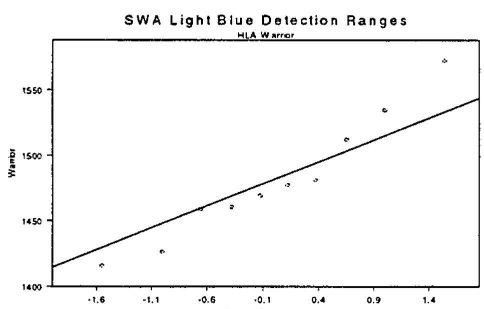
APPENDIX D – NORMAL PROBABILITY PLOTS

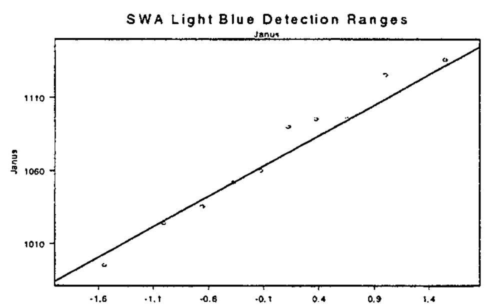




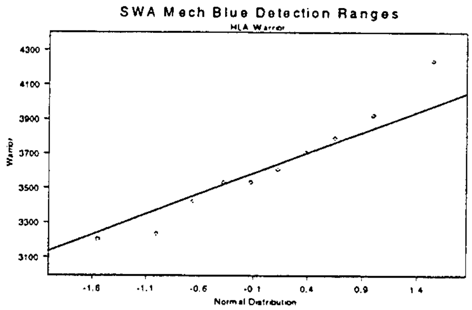


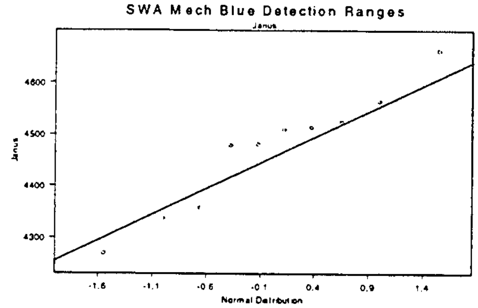


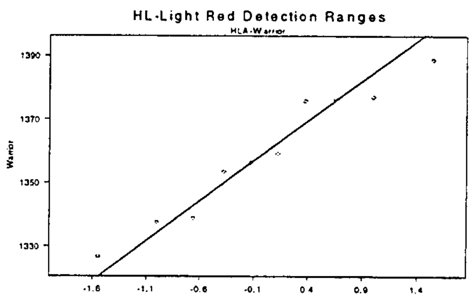


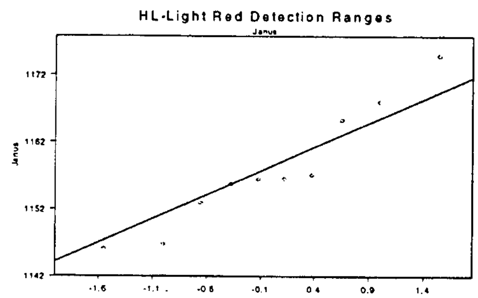


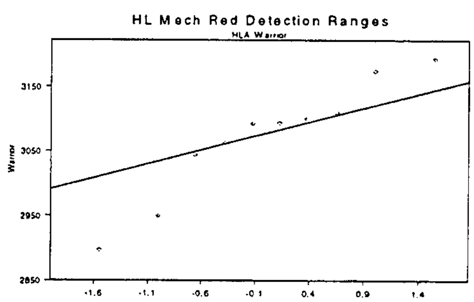
NORMAL PROBABILITY PLOTS

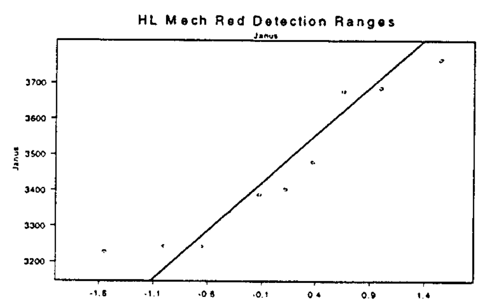




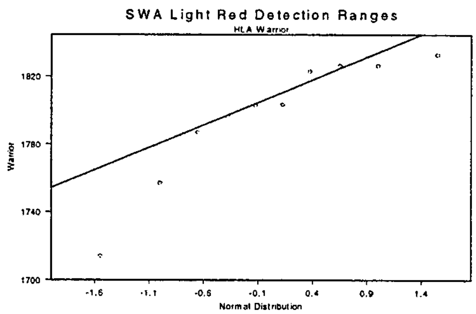


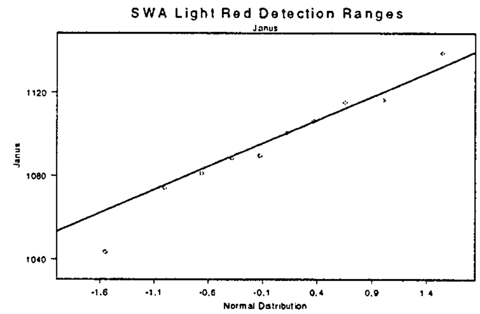


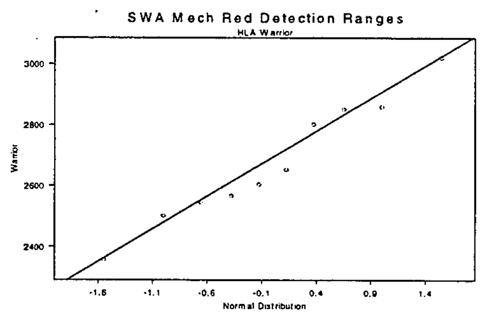


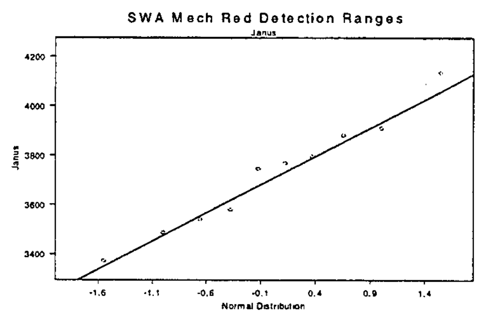


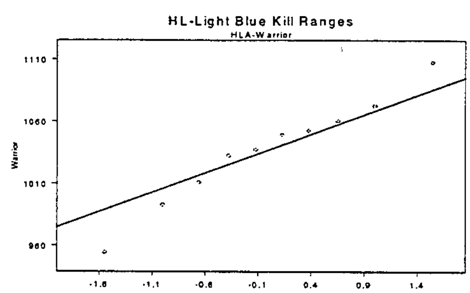
NORMAL PROBABILITY PLOTS

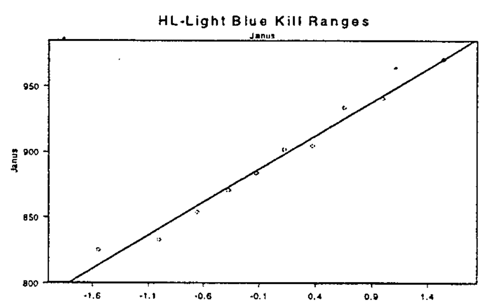




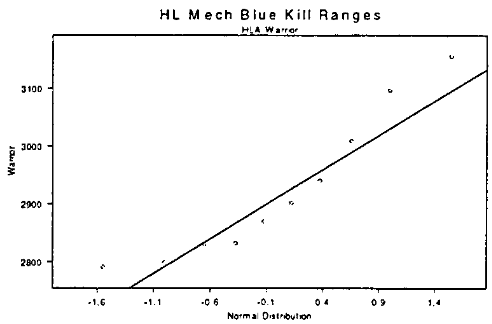


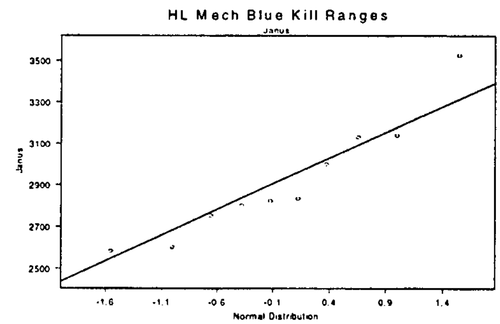


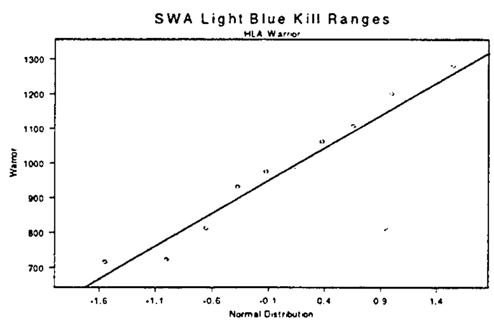


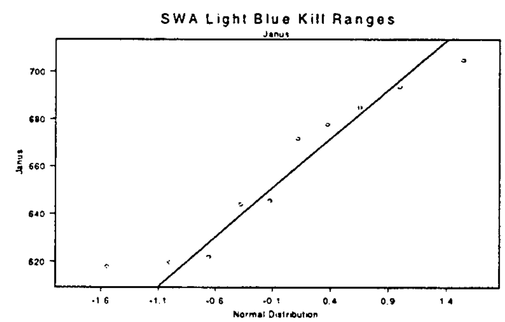


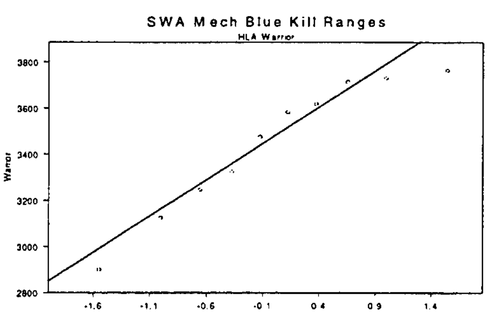
NORMAL PROBABILITY PLOTS

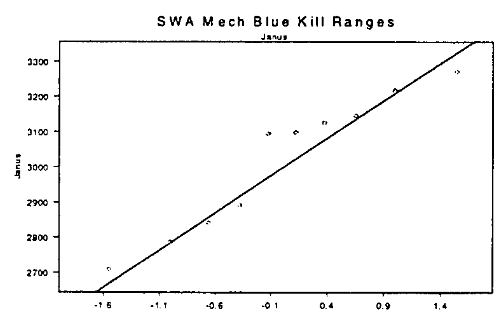




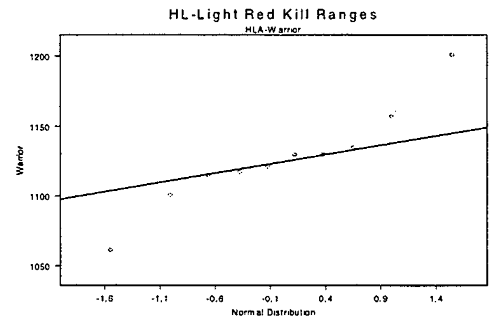


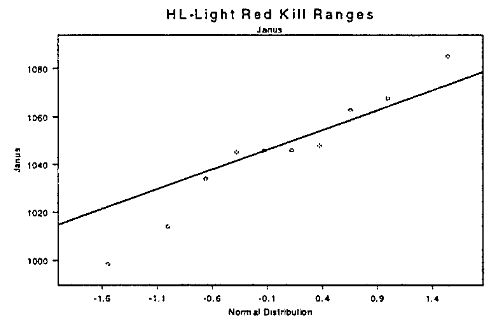


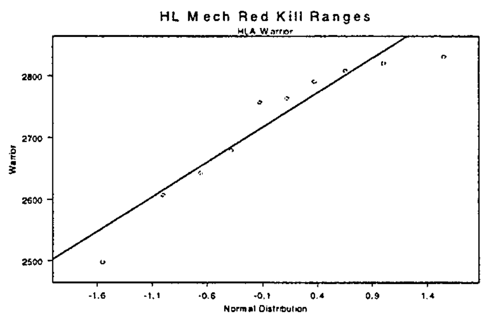


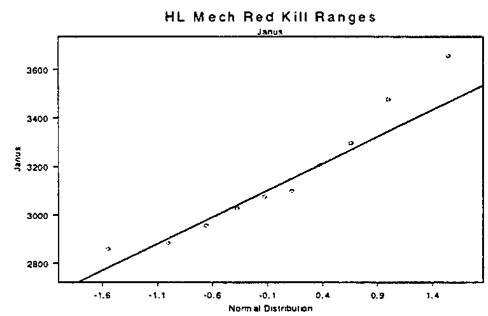


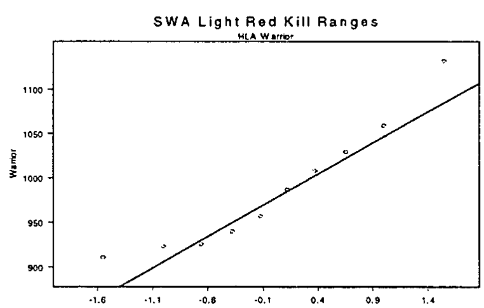
NORMAL PROBABILITY PLOTS

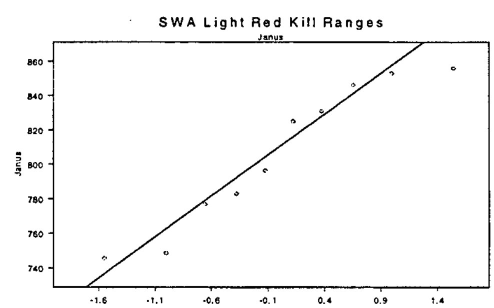




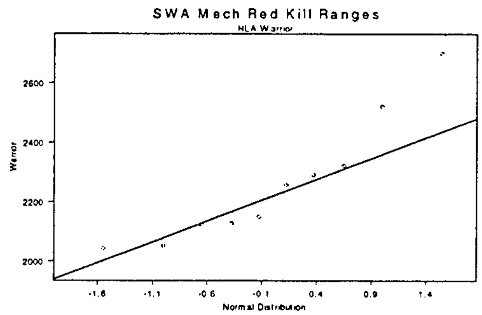


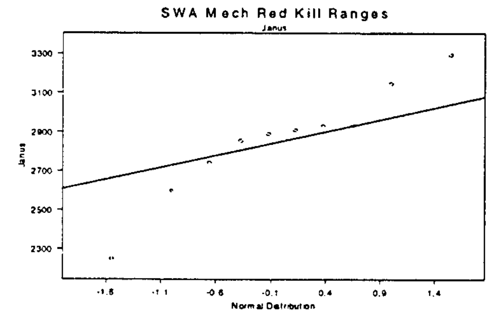


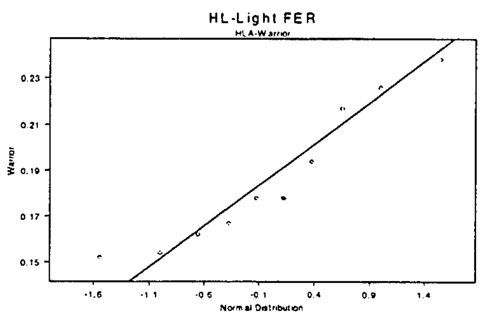


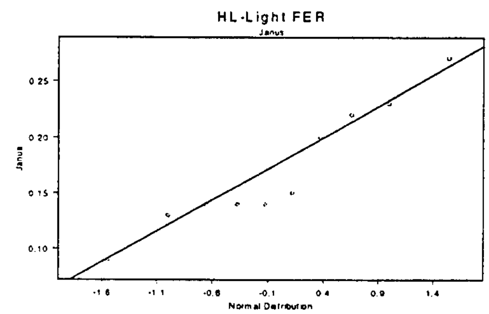


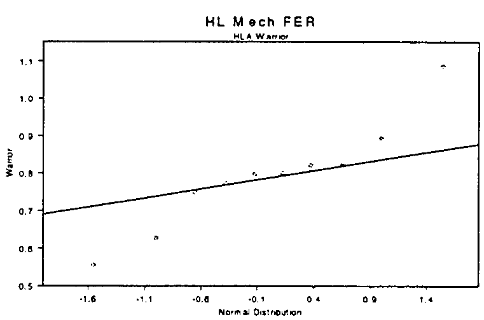
NORMAL PROBABILITY PLOTS

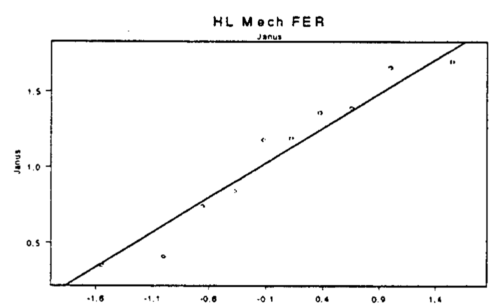




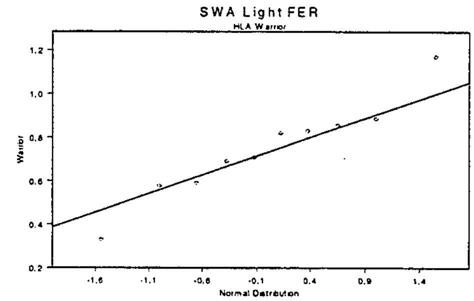


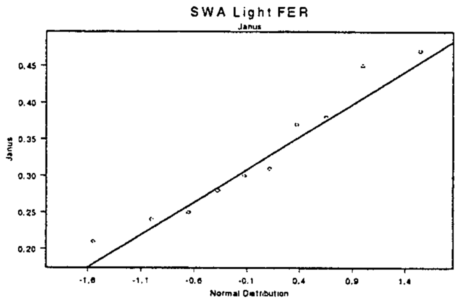


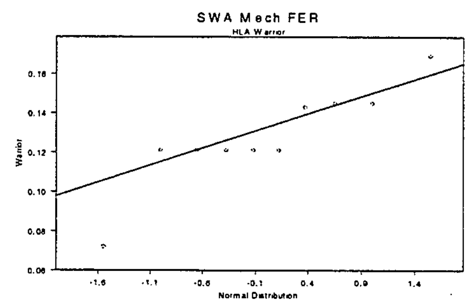


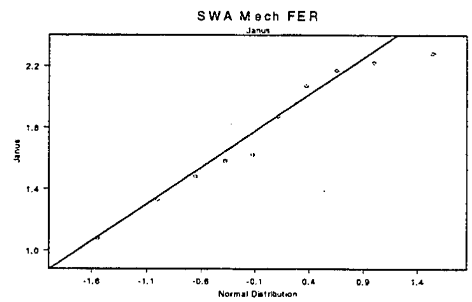


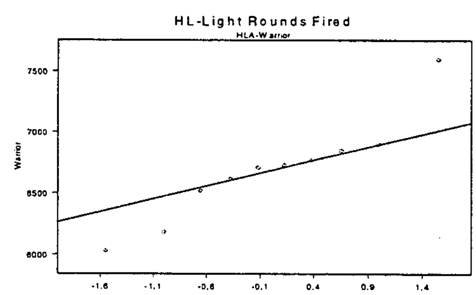
NORMAL PROBABILITY PLOTS

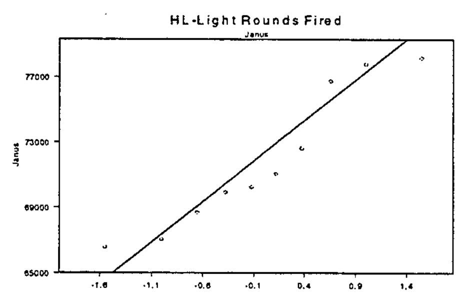




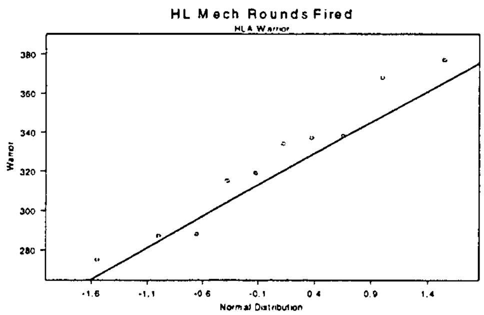


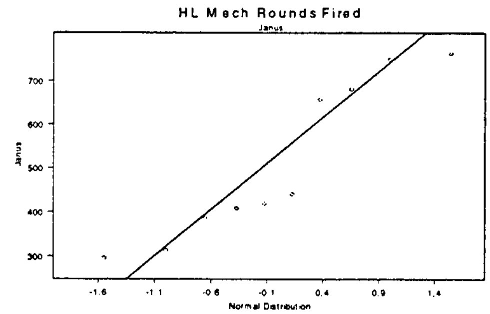


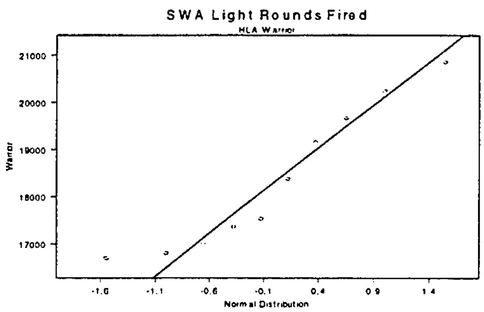


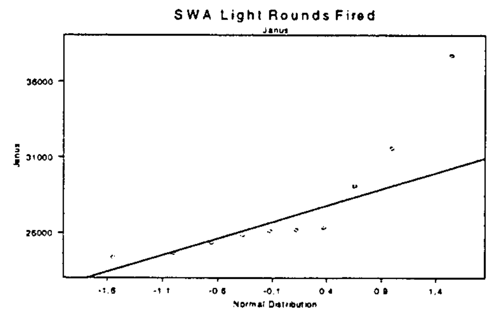


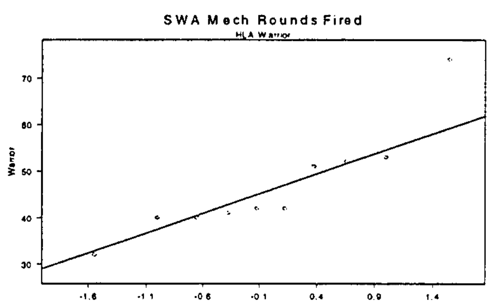
NORMAL PROBABILITY PLOTS

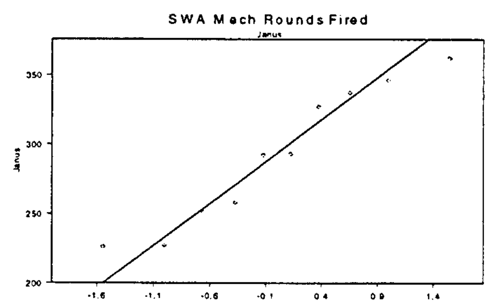












APPENDIX E – RAW DATA AND ANALYSIS RESULTS FOLLOWING HLA WARRIOR SOURCE CODE CORRECTIONS

Southwest Asia Mechanized (Wilcoxon Signed Ranks Test Results)

	Blue Detection Range					Red Detection Range				
run	HLA Warrior	Janus	difference	rank		HLA Warrior	Janus	difference	rank	
1	3668.40	4514.06	-845.66	0		3174.60	3795.37	-620.77	0	
2	3983.60	4524.34	-540.74	0		3352.60	4135.74	-783.14	0	
3	4006.90	4357.00	-350.10	0		3213.90	3371.48	-157.58	0	
4	4000.30	4337.02	-336.72	0		3370.70	3486.64	-115.94	0	
5	3904.80	4662.36	-757.56	0		3297.70	3880.45	-582.75	0	
6	3917.70	4509.96	-592.26	0		3070.10	3768.72	-698.62	0	
7	3799.70	4564.56	-764.86	0		3164.60	3746.04	-581.44	0	
8	3778.10	4270.55	-492.45	0		3133.50	3540.80	-407.30	0	
9	3930.40	4478.59	-548.19	0		3217.70	3579.34	-361.64	0	
10	3943.50	4480.99	-537.49	0		3311.60	3910.49	-598.89	0	
Average	3893.34	4469.94	-576.60	0	Sum	3230.70	3721.51	-490.81	0	Sum
Variance	12193.79	13651.35		(9,46)	Accept Region	9855.70	52378.20		(9,46)	Accept Region
Standard Deviation	110.43	116.84		0.001953	P-Value	99.28	228.86		0.001953	P-Value

	Blue Kill Ranges					Red Kill Ranges				
run	HLA Warrior	Janus	difference	rank		HLA Warrior	Janus	difference	rank	
1	3205.10	3098.14	106.96	2		3274.30	2855.00	419.30	5	
2	3264.00	3218.29	45.71	1		2850.80	3293.75	-442.95	0	
3	3263.00	2787.25	475.75	7		2653.30	2741.82	-88.52	0	
4	3111.90	2842.25	269.65	5		2261.40	2248.13	13.28	1	
5	3431.40	3272.33	159.07	3		2539.40	3146.00	-606.60	0	
6	2890.60	3145.95	-255.35	0		2751.90	2908.75	-156.85	0	
7	3450.70	3125.58	325.12	6		2476.90	2935.56	-458.66	0	
8	3550.70	2708.78	841.92	10		3001.00	2889.17	111.83	4	
9	3372.80	2892.20	480.61	8		2488.40	2598.18	-109.78	0	
10	3654.00	3095.00	559.00	9		2456.10	2931.25	-475.15	0	
Average	3319.42	3018.58	300.84	51	Sum	2675.35	2854.76	-179.41	10	Sum
Variance	49370.27	37852.22		(9,46)	Accept Region	90462.01	82289.41		(9,46)	Accept Region
Standard Deviation	222.19	194.56		0.009766	P-Value	300.77	286.86		0.083984	P-Value

	FER					Rounds Fired				
run	HLA Warrior	Janus	difference	rank		HLA Warrior	Janus	difference	rank	
1	0.181	1.330	-1.149	0		367	226	141	3	
2	0.334	2.220	-1.886	0		466	293	173	6	
3	0.339	1.580	-1.241	0		694	251	443	9	
4	0.286	1.080	-0.794	0		424	327	97	1	
5	0.453	1.870	-1.417	0		572	292	280	8	
6	0.381	2.280	-1.899	0		487	346	141	4	
7	0.238	2.070	-1.832	0		529	258	271	7	
8	0.215	1.480	-1.265	0		1545	362	1183	10	
9	0.191	1.620	-1.429	0		381	227	154	5	
10	0.215	2.170	-1.955	0		436	337	99	2	
Average	0.283	1.770	-1.487	0	Sum	590	292	298	55	Sum
Variance	0.008	0.171		(9,46)	Accept Region	121950	2498		(9,46)	Accept Region
Standard Deviation	0.091	0.413		0.001953	P-Value	349	50		0	P-Value

RAW DATA AND ANALYSIS RESULTS FOLLOWING HLA WARRIOR SOURCE CODE CORRECTIONS

Southwest Asia Mechanized
(Paired *t*-Test Results)

t-Test: Paired Two Sample for Means
Blue Detection Range After Warrior Modifications

	HLA Warrio	*Janus*
Mean	3893.34	4469.942
Variance	12193.79	13651.35
Observations	10	10
Pearson Correlation	-0.119579	
Hypothesized Mean Difference	0	
df	9	
t Stat	-10.72004	
P(T<=t) one-tail	1E-06	
t Critical one-tail	1.833114	
P(T<=t) two-tail	2E-06	
t Critical two-tail	2.262159	

t-Test: Paired Two Sample for Means
Red Detection Range After Warrior Modifications

	HLA Warrio	*Janus*
Mean	3230.7	3721.506
Variance	9855.698	52378.2
Observations	10	10
Pearson Correlation	0.2714	
Hypothesized Mean Difference	0	
df	9	
t Stat	-6.947913	
P(T<=t) one-tail	3.35E-05	
t Critical one-tail	1.833114	
P(T<=t) two-tail	6.7E-05	
t Critical two-tail	2.262159	

t-Test: Paired Two Sample for Means
Blue Kill Range After Warrior Modifications

	HLA Warrio	*Janus*
Mean	3319.42	3018.577
Variance	49370.27	37852.22
Observations	10	10
Pearson Correlation	-0.091261	
Hypothesized Mean Difference	0	
df	9	
t Stat	3.084757	
P(T<=t) one-tail	0.00652	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.013039	
t Critical two-tail	2.262159	

t-Test: Paired Two Sample for Means
Red Kill Range After Warrior Modifications

	HLA Warrio	*Janus*
Mean	2675.35	2854.76
Variance	90462.01	82289.41
Observations	10	10
Pearson Correlation	0.414261	
Hypothesized Mean Difference	0	
df	9	
t Stat	-1.782835	
P(T<=t) one-tail	0.054145	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.10829	
t Critical two-tail	2.262159	

t-Test: Paired Two Sample for Means
FER After Warrior Modifications

	HLA Warrio	*Janus*
Mean	0.2833	1.77
Variance	0.008266	0.170556
Observations	10	10
Pearson Correlation	0.340082	
Hypothesized Mean Difference	0	
df	9	
t Stat	-12.00814	
P(T<=t) one-tail	3.83E-07	
t Critical one-tail	1.833114	
P(T<=t) two-tail	7.66E-07	
t Critical two-tail	2.262159	

t-Test: Paired Two Sample for Means
Rounds Fired After Warrior Modifications

	HLA Warrio	*Janus*
Mean	590.1	291.9
Variance	121950.3	2498.322
Observations	10	10
Pearson Correlation	0.474476	
Hypothesized Mean Difference	0	
df	9	
t Stat	2.870962	
P(T<=t) one-tail	0.009224	
t Critical one-tail	1.833114	
P(T<=t) two-tail	0.018448	
t Critical two-tail	2.262159	

RAW DATA AND ANALYSIS RESULTS FOLLOWING HLA WARRIOR SOURCE CODE CORRECTIONS

Hunter-Liggett Light Infantry (Wilcoxon Signed Ranks Test Results)

	Blue Detection Range					Red Detection Range				
run	HLA Warrior	Janus	difference	rank		HLA Warrior	Janus	difference	rank	
1	1326.87	1098.42	228.45	5		1395.72	1168.03	227.69	6	
2	1311.55	1113.54	198.01	3		1367.49	1146.07	221.43	3	
3	1310.21	1080.47	229.74	6		1379.42	1155.76	223.66	4	
4	1297.55	1042.76	254.79	8		1346.00	1174.89	171.11	1	
5	1335.00	1063.36	271.64	9		1406.23	1156.48	249.75	9	
6	1321.21	1106.17	215.04	4		1402.34	1152.94	249.40	8	
7	1307.28	1111.20	196.08	2		1391.24	1165.32	225.92	5	
8	1328.45	1081.64	246.81	7		1408.18	1157.09	251.09	10	
9	1311.44	1029.20	282.24	10		1393.02	1146.74	246.28	7	
10	1283.65	1095.05	188.61	1		1361.13	1156.57	204.56	2	
Average	1313.32	1082.18		55	Sum	1385.08	1157.99		55	Sum
Variance	236.29	838.73		(9,46)	Accept Region	437.26	82.73		(9,46)	Accept Region
Standard Deviation	15.37	28.96		0	P-Value	20.91	9.10		0	P-Value

	Blue Kill Ranges					Red Kill Ranges				
run	HLA Warrior	Janus	difference	rank		HLA Warrior	Janus	difference	rank	
1	1061.60	883.86	177.74	5		1133.75	1067.67	66.08	2	
2	1068.13	870.63	197.51	8		1139.72	1045.07	94.65	6	
3	1062.57	901.79	160.78	4		1147.54	1033.92	113.62	8	
4	888.70	970.36	-81.66	0		1101.10	1047.87	53.23	1	
5	1121.10	940.58	180.52	6		1169.61	1085.00	84.61	4	
6	1062.97	904.74	158.23	3		1158.35	1062.74	95.61	7	
7	1042.84	853.86	188.98	7		1130.61	1045.92	84.69	5	
8	1052.57	933.66	118.91	2		1125.77	1045.81	79.96	3	
9	1094.38	825.17	269.21	9		1155.77	1013.87	141.90	9	
10	1181.20	832.76	348.44	10		1161.56	998.27	163.29	10	
Average	1063.61	891.74		54	Sum	1142.38	1044.61		55	Sum
Variance	5472.45	2271.77		(9,46)	Accept Region	418.92	634.77		(9,46)	Accept Region
Standard Deviation	73.98	47.66		0.00195	P-Value	20.47	25.19		0	P-Value

	FER					Rounds Fired				
run	HLA Warrior	Janus	difference	rank		HLA Warrior	Janus	difference	rank	
1	0.14	0.22	-0.08	0		15686.00	72618.00	-56932.00	0	
2	0.20	0.15	0.05	5		16784.00	66579.00	-49795.00	0	
3	0.12	0.14	-0.02	0		14669.00	77797.00	-63128.00	0	
4	0.42	0.13	0.29	10		22918.00	68683.00	-45765.00	0	
5	0.16	0.23	-0.08	0		12718.00	69923.00	-57205.00	0	
6	0.20	0.09	0.11	9		15238.00	70233.00	-54995.00	0	
7	0.19	0.27	-0.08	0		17177.00	78171.00	-60994.00	0	
8	0.21	0.20	0.01	1		14598.00	76740.00	-62142.00	0	
9	0.16	0.14	0.02	2		13613.00	67050.00	-53437.00	0	
10	0.11	0.14	-0.03	0		15001.00	71037.00	-56036.00	0	
Average	0.19	0.17		27	Sum	15840.20	71883.10		0	Sum
Variance	0.01	0.00		(9,46)	Accept Region	7943005.29	18628348.32		(9,46)	Accept Region
Standard Deviation	0.09	0.06		0.5	P-Value	2818.33	4316.06		0.00195	P-Value

RAW DATA AND ANALYSIS RESULTS FOLLOWING HLA WARRIOR SOURCE CODE CORRECTIONS

Hunter-Liggett Light Infantry (Paired *t*-Test Results)

Hunter-Liggett Light Blue Detection Range
t-Test: Paired Two Sample for Means

	HLA Warrior	*Janus*
Mean	1313.321	1082.181
Variance	236.2907433	838.7271
Observations	10	10
Pearson Correlation	0.026785455	
Hypothesized Mean Difference	0	
df	9	
t Stat	22.54443499	
P(T<=t) one-tail	1.57506E-09	
t Critical one-tail	1.833113856	
P(T<=t) two-tail	3.15012E-09	
t Critical two-tail	2.262158887	

Hunter-Liggett Light Red Detection Range
t-Test: Paired Two Sample for Means

	HLA Warrior	*Janus*
Mean	1385.077	1157.988
Variance	437.2590456	82.72893
Observations	10	10
Pearson Correlation	-0.28114945	
Hypothesized Mean Difference	0	
df	9	
t Stat	28.68035701	
P(T<=t) one-tail	1.85458E-10	
t Critical one-tail	1.833113856	
P(T<=t) two-tail	3.70915E-10	
t Critical two-tail	2.262158887	

Hunter-Liggett Light Blue Kill Range
t-Test: Paired Two Sample for Means

	HLA Warrior	*Janus*
Mean	1063.606	891.74
Variance	5472.449471	2271.772
Observations	10	10
Pearson Correlation	-0.62083907	
Hypothesized Mean Difference	0	
df	9	
t Stat	4.936256062	
P(T<=t) one-tail	0.000403188	
t Critical one-tail	1.833113856	
P(T<=t) two-tail	0.000806376	
t Critical two-tail	2.262158887	

Hunter-Liggett Light Red Kill Range
t-Test: Paired Two Sample for Means

	HLA Warrior	*Janus*
Mean	1142.378	1044.613
Variance	418.9244178	634.7711
Observations	10	10
Pearson Correlation	-0.07247826	
Hypothesized Mean Difference	0	
df	9	
t Stat	9.203287939	
P(T<=t) one-tail	3.5548E-06	
t Critical one-tail	1.833113856	
P(T<=t) two-tail	7.10959E-06	
t Critical two-tail	2.262158887	

Hunter-Liggett Light FER
t-Test: Paired Two Sample for Means

	HLA Warrior	*Janus*
Mean	0.1908	0.171
Variance	0.007399956	0.003121
Observations	10	10
Pearson Correlation	-0.17982756	
Hypothesized Mean Difference	0	
df	9	
t Stat	0.565725575	
P(T<=t) one-tail	0.292703215	
t Critical one-tail	1.833113856	
P(T<=t) two-tail	0.58540643	
t Critical two-tail	2.262158887	

Hunter-Liggett Light Rounds Fired
t-Test: Paired Two Sample for Means

	HLA Warrior	*Janus*
Mean	15840.2	71883.1
Variance	7943005.289	18628348
Observations	10	10
Pearson Correlation	-0.12546122	
Hypothesized Mean Difference	0	
df	9	
t Stat	-32.5612979	
P(T<=t) one-tail	5.97732E-11	
t Critical one-tail	1.833113856	
P(T<=t) two-tail	1.19546E-10	
t Critical two-tail	2.262158887	

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