INFORMATION SYSTEMS AND THE HEAVY FORCE: BLESSING OR CURSE?

A MONOGRAPH
BY
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This monograph investigates the results of task force level maneuver exercises conducted with equipment projected for Force XXI fielding. Specifically, the monograph seeks to answer the question of whether digital equipment improves the ability of the heavy task force to generate combat power.

The monograph first surveys the professional literature to determine the improvements which senior Army leaders expect will result from fielding digital equipment in heavy units. The author then develops an analytic construct which defines combat power as a combination of firepower, maneuver, force protection and leadership. The major emphasis of the monograph goes toward an empirical inquiry into firepower improvements brought by the presence of digital systems through a three stage inquiry. First, the author investigates vehicle kills by source to gain an understanding of the digital unit's ability integrate fires. The author then investigates the direct fire function through the use of a production model to determine the significance of various factors which influence the task force's ability to produce direct fire vehicle kills. Finally, the author investigates the effectiveness of indirect fires in the digital task force compared to conventional units.

The author establishes evidence that indicates digital units have a superior ability to integrate fires among the combat arms. In addition, the author establishes that digital units are more productive direct fire killers. Finally, digital units fire a greater volume of artillery compared to conventional units, but demonstrate similar patterns of artillery effectiveness. Several qualitative improvements in the digital force also improve the task force's ability to maneuver and protect itself.

The author concludes with a consideration of why despite demonstrated capability improvements, digital units were unable to defeat OPFOR forces in force on force maneuver. The conclusion indicates that basic tactical proficiency is necessary to fully realize the benefits of digital equipment.

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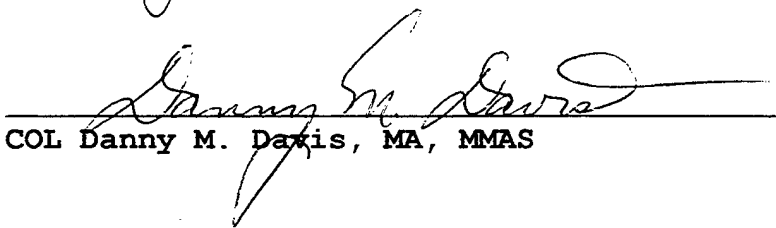
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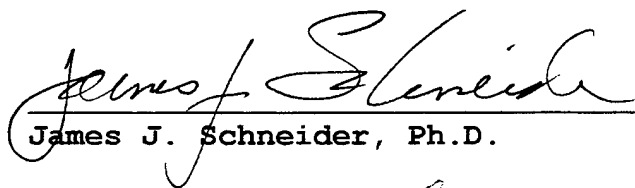
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Chapter 1: The Force XXI Vision

Few trends have stirred the excitement of revolutionary military thought since the Second World War as the development of digital equipment. Several individuals have written that the combination of information systems and precision strike weapons promise to create units of dominant combat power and lethality, thus making obsolete the heavy task force in its present form. So inviting is this promise that senior Army leaders plan to redesign and equip Army units around information technology. At present, the leadership envisions a digitally equipped corps by 1999 and a fully digital Army by early in the next century.[1] Needless to say, this is change with far reaching implications.

Information systems and combat units are certainly not a new combination in the US Army. The Army used the first digital computer developed during World War Two, the ENIAC, to compute artillery ballistic firing tables.[2] The 1970s and 80s saw large scale deployment of information processing systems which facilitated functions such as reporting and artillery targeting. However, one may argue that the 1990s has seen the first large scale attempt to link fire and maneuver into a digital control network.

Perhaps the most forceful advocate of the information system-precision weapon combination and its potential for revolutionary impact has been former Army Chief of Staff Gordon R. Sullivan. Believing that the Army has entered an era of unprecedented uncertainty and declining budgets, Sullivan feels the Army's chief priority is to produce a force which can achieve the enduring goal of decisive victory at minimal cost.[3] Sullivan feels that future warfare will be dominated by five key trends: lethality and dispersion, volume and precision fire, integrated technology, mass effects, and invisibility and

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dectectibility.[4] The force which masters these trends, Sullivan argues, will operate at a tempo faster than its opponent and retain a dominant battlefield edge. Mastery of these trends lies in the integration of information processing systems with highly lethal, precision strike weapons.[5] Sullivan asserts that the Army can produce smaller, more lethal forces by pursuing a combination of promising technologies operated by well trained soldiers exercising sound doctrine. In the information age, asserts Sullivan, those forces able to master the technologies and doctrine which exploit speed and precision execution will dominate the future battlefield.[6] Before the end of his tenure as Chief of Staff, GEN Sullivan set into motion a host of initiatives designed to bring this vision to reality. GEN Reimer, Sullivan's successor as Army Chief of Staff, has continued the development of Force XXI equipment and doctrine. In his view, information systems show greater promise in heavy units than in light but are in general proceeding on track.[7] In order to more quickly realize the possibilities of information technology, the Army has modified its time consuming development process into a series of "Warfighter Experiments" designed to identify promising capabilities, explore their likely technological applications and rapidly field them.[8]

Senior Army tactical leaders have the clearest expectations of how information based units will perform in actual practice. MG Paul Funk, formerly commander of the US Army Armor School, stated that digitizing the Army would improve situation awareness, the knowledge of friendly and enemy force locations on a fast moving battlefield. Also, digitization would improve the heavy task force's ability to accurately mass direct and indirect fires on its enemy. Further, digital equipment would give heavy

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units the ability to provide real time intelligence to subordinate units and more efficiently transfer targets from one battlefield force to another, such as from armor to artillery[9] Funk added in a separate article that "...digitally equipped units are able to maneuver faster, under greater control, while inflicting greater damage against the enemy and suffering fewer losses within their own ranks."[10] Sharing this view, BG Joseph Oder added that the presence of information systems would allow forces to incorporate all elements of combat power and combat multipliers into a battle of depth against a potential adversary.[11] In perhaps the clearest view of all, MG Wesley Clark graphically portrayed the virtues of digital equipped units in a vignette set in June of 2005. In his vignette, Clarke's notional information age task force maneuvered dispersed and at a high tempo, destroying its adversary with standoff precision weapons targeted by advanced sighting equipment and links to remote sensors. The task force commander was able to detect incoming enemy indirect fire with friendly counterbattery radar, use on board computer simulations to predict its impact and issue a fragmentary order with graphics directing the unit's axis of advance away from the strike.[12]

From these three independent views we can describe a common expectation of information age capabilities which matches the senior leadership vision. In their view, the digital force will exhibit two prominent characteristics:

1) Relatively smaller though qualitatively superior, the digital force can defeat a larger adversary through increased tempo and precise, highly lethal firepower enhanced by the orchestration of all battlefield systems.

2) Improved "situation awareness" produced by access to greater battlefield information and its incorporation into maneuver plans before and during operations, increasing tempo and force protection.

These two characteristics combined, expect the Army's senior leadership, will produce units of such unprecedented lethality as to render present heavy forces virtually obsolete.

The Army's plan to digitize the force follows an appliqué strategy, fitting information processing equipment, improved communications and more precise targeting systems to existing weapon platforms. In addition, specially designed command vehicles will create a digital information processing network at the task force level to connect the various vehicle appliqués. The strategy to date has fielded systems such as the M1A2 and M2A2 vehicle families, the AH-64C/D and OH58D helicopters, M109A6 Paladin howitzer and Battalion and Brigade Command and Control (B2C2) vehicles. The major weapons systems and their appliqué improvements appear in Annex 1.

Chapter 2: Force XXI; The Work to Date

The Army has in recent years conducted three exercises designed to investigate the effect of digital technology on the heavy task force. Digital units first maneuvered in 1993 as part of National Training Center (NTC) Rotation 9310, which involved an armor task force from Fort Hood's First Cavalry Division. Though the unit fielded 120 digital systems for the exercise, the task force was not completely digital. Seventeen M1A2 and six M2A2 vehicles deployed with the task force and provided digital capability for the task force command group and all company commanders. In one armor and one mechanized

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team within the task force, each of the platoon leaders had an IVIS equipped vehicle.[13] Though not a fully digitized unit, the rotation nevertheless gave indications of the capabilities envisioned by Army leaders. Both participants and evaluators agreed that digital equipment promised to improve the volume and accuracy of information flow, allowing task force leaders to conduct continuous planning. Digital equipment appeared to improve synchronization by passing exact graphics and reports up and down the command structure. Units noted an improved awareness of friendly and enemy unit locations, and stated that this increased participation and improved the unit's ability to mass combat power and indirect fires.[14] Finally, both units and evaluators noted more efficient logistics procedures and attributed these improvements to precise unit information provided by the Inter Vehicular Information System (IVIS).[15]

Less than six months after the Fort Hood rotation, the Army attempted a second battalion level maneuver using a heavy task force deployed from Fort Knox, Kentucky. Rotation 94-07 attempted to build on and expand the findings of 93-10 by more fully incorporating digital equipment into the task force. This unit had a fully digital command structure which equipped vehicles to the platoon leader level with IVIS, and in most cases provided digital capability to platoon sergeant vehicles. In addition, the task force headquarters included a digital command and control vehicle (B2C2) to supplement the task force digital communications net. The brigade headquarters included more modern intelligence assets similar to those projected for fielding in an information age unit and designed to enhance situation awareness. Among these were an unmanned aerial vehicle linked to a brigade level collection and dissemination apparatus designed to give the task

force commander real time tactical intelligence. Finally, the unit maneuvered with digitally equipped aerial assets, most notably the OH-58D scout helicopter.[16] In many respects, the equipment envisioned for the digital Army was present during Rotation 94-07.

Though the unit demonstrated capabilities similar to and in some cases exceeding Rotation 93-10, the task force performed more poorly than expected. The unit failed to defeat OPFOR forces on a consistent basis or perform better on standard measures of NTC success. Task force loss exchange ratios were no better than, and in some cases poorer than, non-digital forces.[17]

The final heavy force test of information equipped units to date has been exercise Focused Dispatch, conducted between September 1994 and August 1995.[18] This exercise consisted of five parts, the first three conducted using the JANUS simulation, the fourth trial using the Fort Knox SIMNET development facility and the final phase consisting of live maneuver conducted at a local training area supplemented by a computer driven virtual opposing force.[19] In general, Focused Dispatch tested maneuver and fire support concepts developed for digital forces and was not intended as a comparative capability test.[20] Though Focused Dispatch was a task force level exercise, its largest live maneuver force never exceeded a combined arms team and scout platoon plus support assets.[21] Because of these two aspects, its results are difficult to compare with the two digital NTC rotations.

The general conclusions of exercise Focused Dispatch were encouraging, but limited. Though the exercise indicated better unit maneuver and planning capabilities, the improvements were not characterized as revolutionary.[22] However, the digital unit

exhibited an enhanced ability to modify plans during execution, providing some evidence that simultaneous and continuous planning are valid concepts in the digital unit.[23] The exercise highlighted the problem of information overload and inappropriate information distribution to various command levels, particularly in the area of intelligence data.[24] Though the exercise did not specifically validate any doctrine, it did showcase some innovative concepts. Among these was a "striker" platoon, or an exclusively fire support maneuver force consisting of observer-designators linked directly to howitzer platoons and consolidated at the battalion level. These forces proved capable of providing accurate, responsive and massed fires at the task force commander's discretion.[25] Finally, Focused Dispatch furnished solid evidence that information processing systems give maneuver units better logistical awareness and more precise logistical support, provided support units are fully staffed and trained in digital techniques.[26]

General Conclusions

Though the rotations and exercises thus far have demonstrated some enhanced capabilities, critics of the digital effort generally point to poor digital unit performance in three areas. First, critics assert that digital technology is immature and does not support Army needs. The technology requires a daunting level of training, and complicates rather than streamlines its user's duties.[27] Second, some sources stress the fact that digital units have failed to perform better than conventional units in live maneuver. Specifically, they point to the fact that digital units have failed to defeat OPFOR forces or produce more favorable loss-exchange ratios as proof the Army should change its plans for Force XXI fielding until further experimental results can show evidence of tangible capabilities.[28]

Other critics level the charge that the Army is too wedded to its present doctrine and has failed to look for those organizations and processes which will exploit unique digital capabilities.[29] In sum, critics of the digital program charge that the Army is rushing headlong to field an unproved technology, thereby embarking on an extraordinarily high risk venture.[30]

The Army's digital program, and by implication its ability to field the first force of the next century, rests on its ability to demonstrate the reality of its vision. The Army is seemingly on a track to fully equip forces with information age equipment, effectively determining the shape of tomorrow's Army. So, it is a reasonable question to ask whether the forces so equipped have produced a glimpse of the vision espoused by its leaders. Do information equipped forces perform as envisioned? It is the aim of this study to investigate the two digital task force maneuvers conducted to date and answer this question in preliminary fashion. The findings of this study will not be exhaustive, but are an investigation to find promising trends and directions for future research.

Chapter 3: Methodology

It is clear that the senior Army leadership has a well developed vision from which it plans to build a fully digitized Army. However, critics of the Army's proposed modernization characterize it as high risk because the existing experimental results do not indicate any significant capability increase of digital over conventional units.[31] As stated in Chapter Two, the present analysis of existing exercises does not indicate measurably superior digital unit capabilities. Therefore it seems there are no significant differences between digital and conventional units and little reason to pursue digital fielding.

Several possible explanations exist for this result. Digital equipment may simply not work as advertised or may be inappropriate for heavy unit needs. However, it is also plausible that unit performance has improved in ways not captured by the analytic methods used to investigate existing data. It is the contention of this study that present analytic methods have overlooked some measurable differences between conventional and digital units. A consideration of the analytic methods used to investigate the data will make the case for an improved analytic construct.

The Army Warfighter Experiments have in reality not been a series of experiments. The trials proceeded without the experimental construct needed to isolate digital technology effects and identify differences between digital and conventional units. At best, the Warfighter Experiments are quasi or field experiments. In this technique, a researcher takes the results of an event and through statistical modeling compares it with a database constructed of similar events drawn from a relevant comparative population. The quasi-experimental technique has several merits, principally its low cost, as it avoids the costly process of running controlled experimental trials to gather data. In addition, the quasi-experiment is a more natural technique which eschews the artificial constructs of an experiment in favor of observations drawn from the real world. As such, its results are more valid for real world application. Army Warfighter Experiment Desert Hammer VI (NTC Rotation 94-07) fits the quasi experiment pattern, as it analyzed digital task force performance against a database constructed of conventional unit results from Rotations 94-04 through 94-08.

The quasi experiment's main disadvantage is its relatively weak ability to control for influences which might prevent the researcher from establishing a causal explanation. For example, differences between rotations such as the amount of unit home station training conducted prior to an exercise could explain some performance differences. Even differences between unit engagements such as terrain or weather variations could affect performance. The existing analysis merely compared the loss exchange ratios of various units without correcting for other contributing factors. Though the analytic reports do include a consideration of those factors, it is in the form of background information, not as factors included in the analysis.[32] If the quasi experimental technique is to provide solid causal evidence of a phenomenon, the analysis must attempt to control for factors which the researcher suspects might contribute to the phenomenon and are present in the natural environment. A simple consideration of the loss exchange ratio without correction for other contributing factors is insufficient to perform this controlling function.

This study's analysis corrected for previous deficiencies in two ways. First, the researcher broadened the Desert Hammer database by including data from Rotation 93-10. Second, the researcher used regression analysis to correct for contributing factors and better isolate the effects of technology. In order to use regression analysis, it is necessary to develop a new analytic construct past a mere consideration of loss exchange ratios.

A New Analytic Construct.

The Force XXI vision laid out in chapter one provides us with a good starting point for an analytic model to re-investigate the existing research. For the Army leadership's plan to be valid, say the critics, we should see some evidence of promised

digital capabilities before their fielding. The relevant question is whether the presence of digital equipment makes a positive improvement in the heavy task force's ability to accomplish critical combat functions. The Force XXI vision presented earlier indicates that the senior leadership believes digital units will posses superior characteristics of firepower, maneuver and situation awareness which when combined will allow the unit to generate superior combat power. FM 100-5 states that combat power consists of firepower, maneuver, protection and leadership.[33] These attributes seem to capture the essence of the senior leadership vision and form a useful construct with which to conduct analysis. We can therefore restate our question as follows: does the digitally equipped force exhibit a superior ability to generate combat power when compared to similarly configured conventional forces?

The analysis of this study will divide the broad combat power question into two narrower inquires driven by the available data. The database described earlier offers a wealth of direct and indirect fire results from which the researcher may derive some general answers to the firepower portion of the combat power model. Accordingly, our first task is to investigate deeply the first question, stated as follows:

> *Do digital units demonstrate the ability to generate superior firepower compared with their non-digital counterparts?*

An empirical analysis of data drawn from NTC after action reviews for Rotations 93-10 and 94-04 through 94-08 will form the basis of that answer.

Additionally, there exists in the NTC Take Home Packages and writings of exercise participants a rich qualitative database from which we can evaluate the contribution of digital systems to maneuver, protection and leadership. Of these aspects,

leadership is the hardest to evaluate because of its particularly subjective nature and sparse treatment in after action reports. Consequently, this attribute will not receive an in depth investigation in this study. We may state the second broad question as follows:

> *Do digital units demonstrate attributes which we would expect to translate into superior maneuver and better force protection relative to conventionally equipped units, or allow leaders to lead better than their counterparts in conventional units?*

Given the quantitative data, this study will concentrate on the effects of digital equipment on the unit's ability to develop firepower, then conclude with a brief survey of broad trends in maneuver, force protection and leadership.

The Firepower Construct

The first question of this study is whether digital units exhibit an improved ability to generate firepower compared to their conventional counterparts. FM 100-5 states that firepower manifests its effects in both physical and psychological forms, and that units deliver firepower both by direct and indirect means.[34] Of the two effects, the physical manifestation is easier to capture, quantify and compare. However, we may take as a point of departure that units cause effects in the cybernetic and moral realm by inflicting destructive force on enemy units through firepower.[35] Therefore, if we consider all other effects constant, it will be the unit generating the greater firepower which can produce the greater physical, moral and cybernetic degradation of its opponent. Therefore, we shall confine ourselves to a consideration of the physical effects, arguing that the other effects will follow as a matter of course.

Unit Firepower Integration: Vehicle Kill Distributions

A consideration of directly and indirectly delivered firepower leads us down three analytic vectors. First, we should investigate the digital task force's distribution of firepower. One implied digital synergy identified in the literature is an improved level of coordination between battlefield arms, particularly between direct and indirect sources. We would expect to see evidence of this attribute manifested in digital units as a better distribution of enemy casualties between direct and indirect fire systems. Heavy unit battles are primarily conducted between fighting vehicles of both sides. Therefore, we could surmise that the unit which better distributes vehicle kills between different firepower sources achieves this effect through superior integration of those sources. This would imply a more efficient use of firepower sources, which would imply a potential to generate greater combat power.

In order to investigate the pattern of vehicle kills, the researcher used data generated by the Desert Hammer analysis group and divided OPFOR vehicle kills by engagement into four general categories. These categories captured kills by direct fire systems, artillery kills, close air support kills and kills from other sources such as obstacles. The researcher calculated the percentage of vehicle kills in the various categories. The chi-square test, used to test for differences in distribution patterns and described in Annex 3, answered the question of whether there were significant differences in the distribution patterns of digital and conventional units.

Having established some first order conclusions regarding the distribution of vehicle kills, the researcher then deepened the analytic model to investigate the direct and

indirect fire functions. With a full understanding of the distribution, direct and indirect fire portions, we should have good preliminary findings with which to establish the general firepower attributes of the digital team.

The Direct Fire Function

The Force XXI vision implicitly rests on the assumption that digital technology represents a significant improvement in the heavy task force's ability to generate direct fire. Our analytic challenge then is to determine whether digital technology is a significant factor in the direct fire battle and its relationship to other direct fire factors. To find this answer, we need to develop a "factor contributions" model to determine which attributes matter in the direct fire battle.

A common economic model used to derive the relative contributions of inputs to a process is the production function. This concept models the production process as a multiplicative combination of several constant or variable inputs. The technique uses a Cobb-Douglas form which appears below and whose full derivation appears in Annex 2.

$$Y = A \; x_1^{\beta 1} \, x_2^{\beta 2} \cdots$$

The form above postulates that we can describe the production process in terms of a constant of regression, "A", and a series of factors represented by the variables X_1, X_2 and so forth. Some factors are determined across production runs, while some change from one production run to the next. The parameters β_1 and β_2 represent the magnitude of the factor's contribution to the production process. As derived in Annex 2, we can use regression analysis to fit the model to real world data and determine the effect of the factors on production and their relationship to each other in the production process. The

coefficients derived through regression analysis take on the form of "elasticity" or the responsiveness of the production process to factor changes.[36]

Though Cobb-Douglas is a highly useful model, what is the production process of the heavy task force in the direct fire engagement? Production is measured as units produced in a given time period, and the heavy unit's function in the direct fire battle is to produce enemy casualties, particularly vehicle kills. Therefore we can define production of the heavy unit as its ability to produce direct fire vehicle kills over time in a given "production run" or engagement. A simple consideration of this form relative to its inputs will establish the usefulness of this model as an analytic construct.

Several factors impact on the heavy unit's ability to produce direct fire vehicle kills. First, we would naturally suspect that vehicle kills are directly related to the number of friendly direct fire systems and enemy targets involved in the engagement. The more friendly shooters, the more enemy kills. Likewise, the more enemy targets presented, the greater should be the friendly side's ability to produce direct fire kills. Second, Clausewitz, observing that "...defense is the stronger form of combat" would have us believe that the type of engagement, whether defensive or offensive, should contribute to the ability of the task force to produce direct fire kills.[37] Training has been identified through empirical research as a positive and important influence on the unit's ability to establish a favorable loss exchange ratio, so we expect that better trained forces should be able to establish this favorable ratio in part by killing enemy vehicles faster.[38] Finally, we suspect that technology matters, so we should include a factor which reflects the presence

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of digital equipment in the force. This leaves us with a simplified version of the model which appears below and is fully explained in Annex 2.

$$Y = A \, x_1^{\beta 1} \, x_2^{\beta 2} \, x_3^{\beta 3} \, x_4^{\beta 4} \, x_5^{\beta 5}$$

Where:

Y = task force direct fire kills of OPFOR vehicles per hour (kills/time)
A = A constant of regression
X_1 = Type of engagement
X_2 = Presence or absence of digital technology.
X_3 = OPFOR vehicles present in the engagement
X_4 = Blue force vehicles present in the engagement
X_5 = A proxy variable (OPTEMPO miles) reflecting the unit's training level

The researcher evaluated the model against a data set of the proposed factors drawn from the results of three type battles reported in NTC take home packages. The researcher limited the inquiry to two types of offensive engagements, the movement to contact and deliberate attack, and one defensive engagement, the defend in sector mission. The researcher made the decision to limit inquiry to these engagements because these three types were the only common "production runs" across the six rotations and formed a common analytic framework. The researcher only considered day engagements to control for the light conditions. Other possible variables such as weather and terrain were excluded due to the lack of data and the limited number of unit data points available. However, these are important factors whose effects will be considered in the concluding chapter.

The Indirect Fire Function

The final inquiry into the firepower function concerned the effectiveness of indirect fire in digital and conventional units. Specifically, the researcher sought to determine

whether digital units were able to deliver a higher volume of missions and whether the missions fired were more accurate than those of conventional units. In order to answer this question, the researcher examined a database of indirect fire missions compiled by the Desert Hammer analysis team to determine if digital units on average fired more missions and artillery rounds than their conventional counterparts. The researcher also conducted chi-square analysis on the percentage distribution of missions and artillery rounds rated as ineffective, suppressive and effective (killing) by observer-controllers. The researcher excluded Rotation 93-07 from this analysis due to the lack of an artillery database compatible with that prepared for exercise Desert Hammer.

Maneuver, Force Protection and Leadership

As a final analysis, the researcher reviewed unit Take Home Packages, observer-controller comments of the missions and professional journal literature concerning the two digital force rotations described in Chapter Two to establish general trends regarding maneuver, protection and leadership in digital units.

Chapter 4: Results

As a general observation, the research findings indicate significant, though weak evidence that digital units generate combat power superior to that of conventional units. The analytic results will follow the same order as the methodology explanation to present the findings and interpret their meaning. This section will conclude with an investigation of why, despite the evidence of improvements and unique capabilities, digital units failed to defeat OPFOR units during force on force exercises.

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Firepower Distribution of the Digital Task Force

The first research question asked whether significant differences in the distribution of vehicle kills existed between digital and conventional units. There is some indication that digital units exhibited a more efficient distribution of vehicle kills between different sources of firepower. The full statistical results and their derivation appear as Appendix 3, while Table 1 presents the general pattern of vehicle kill distributions in digital and conventional units.

Table 1: Vehicle Kill Distributions From Various Combat Power Sources

Kill Source	Movement To Contact		Defend In Sector		Deliberate Attack		
	Digital	Non-Dig	Digital	Non-Dig	Digital 1	Digital 2	Non-Dig
Direct	50%	46%	56%	79%	64%	33%	24%
Indirect	11%	7%	9%	3%	11%	47%	4%
Air	39%	46%	26%	18%	23%	13%	72%
OC	0%	0%	8%	0%	2%	7%	0%

Note: OC refers to observer-controller vehicle kills due to obstacles, chemical strikes, etc.

The strongest evidence of distribution differences appeared in the defend in sector mission. Digital forces in the defense killed OPFOR vehicles at a raw number commensurate with non-digital units, but with a more even distribution among direct and non-direct fire kills. Non-digital units in the defense tended to have a greater concentration of kills in the direct fire category. By contrast, artillery was a more significant killer in the digital unit, with vehicle kills more evenly distributed among the direct, indirect and air categories. Digital systems provide more precise targeting information quickly to indirect assets. The result is a more full integration of indirect fires into the unit scheme of maneuver and more pronounced firepower effects. We would further expect that a unit would better exploit the advantages of digital and advanced

sighting equipment when there is the opportunity for more deliberate integration of direct and indirect fires such as exists on the defense.

An analysis of the deliberate attack missions revealed a slightly different, yet consistent finding. Though the digital unit produced less aggregate vehicle kills than its conventional counterpart on both of its deliberate attacks, there is clear evidence of a difference in its kill distribution. As identified in Annex 3, the predominant vehicle killers in conventional unit deliberate attacks were close air and attack helicopter assets. By contrast, in both the digital force attacks, the predominant vehicle killers were direct fire and artillery fires. In the two deliberate attacks conducted by the digital task force, artillery fires account for three and over ten times the percentage of OPFOR vehicle kills when compared with conventional units. In only two cases were the differences in digital unit vehicle kill distributions found to be insignificant when compared to conventional units. The digital unit's potential for superior synchronization gained the attention of the OPFOR commander during rotation 94-07 who noted the ability of digital equipment such as the OH58D Kiowa Warrior to integrate combat systems and produce synergy. The commander noted that this capability properly used had the ability to pick apart a well constructed defense.[39] It is clear from the few trials conducted that digital equipment shows the promise of more fully integrating the disparate firepower assets of the heavy combined arms team.

The analysis of movement to contact missions was statistically inconclusive, though it reinforced the general patterns noticed in the defend and deliberate attack missions. The digital unit generated fewer aggregate vehicle kills, and the distribution was

not significantly different from non-digital units in three of the four comparisons conducted. However, it is clear from the analysis presented in Annex 3 that the presence of digital equipment seems to more fully integrate artillery fires into the overall unit firepower scheme. Artillery kills accounted for 11% of OPFOR vehicle kills in the digital task force compared with an average of 7% in conventionally equipped units. Though the findings are not statistically significant, they provide further evidence of a more efficient use of all firepower sources in digital units.

In general, there exists evidence that digital units are able to achieve a superior firepower integration compared to their non-digital counterparts. In particular, this attribute appears most strongly in the defense, but appears in both offensive missions studied. This result should not surprise us and stands as further validation of the inherent strength of the defense. We must consider the results in light of the fact that there are relatively few iterations of each type mission for the digital task force to compare with non-digital units. However, the evidence does suggest that digital systems create an improved synergy between battlefield arms.

Are Digitally Equipped Units More Productive Direct Fire Killers?

Using the model developed in the methodology section and laid out in Annex 2, the researcher used multiple regression to test the fit of vehicle direct fire kills to the Cobb-Douglas model. Three issues are important in the interpretation of production function model coefficients: significance, sign and magnitude. First, a coefficient must meet the test of statistical significance as outlined in Annex 4 for us to conclude that the factor influences the production process. Second, the coefficient's sign indicates whether

an increase in the factor increases or decreases the rate of production. Finally, the coefficient magnitude indicates the responsiveness of production to a change in the factor. In addition, the magnitude gives some indication as to the importance of a factor relative to other factors in the process. The model results appear below in equation form.

$$\begin{aligned}
\text{Vehicle} = &\ -12.6 &&-0.60\text{DATK} &&+1.0\text{DIS} &&+0.96\text{DIG} &&+1.16\text{TNG} &&+1.06\text{M1} &&+0.15\text{M2} \\
\text{Kills} & && (-1.7) && (1.6) && (1.9) && (1.18) && (1.06) && (0.29)
\end{aligned}$$

$$\begin{aligned}
&-0.44\text{OTNK} &&+0.98\text{ONT} \\
&(-.50) &&(0.96)
\end{aligned}$$

Where:

DATK:	Deliberate Attack	M1	Blue Force M1s Mission Capable
DIS	Defend In Sector	M2	Blue Force M2/TOW Systems Mission Capable
DIG	Digital Unit	OTNK	OPFOR Tanks Mission Capable
TNG	Unit Training Level (OPTEMPO Miles)	ONT	OPFOR Non-Tank vehicles Mission Capable

The constant term in this model takes on the meaning of the "base case" or movement to contact mission. All other mission variable coefficients take on their meaning relative to the movement to contact parameter. The coefficient representing the deliberate attack mission is negative and significant at the 95% confidence level. This result would have us conclude that the deliberate attack is in a direct fire sense less productive than the base case of the movement to contact. We expect a negative result, as an exposed Blue Force attacking against a protected OPFOR should be a less efficient casualty producer relative to the movement to contact, where both forces are exposed. Further, the coefficient indicates that on average, units conducting a deliberate attack

produce direct fire kills at a rate approximately 0.6% slower as a result of being on the offense.

By contrast, the defend in sector coefficient is not significant at the 95% confidence level. However, the coefficient is significant at the 90% confidence level, providing us an indication that the defense does indeed have a bearing on the unit's ability to produce direct fire kills. We expect the positive sign, as a protected Blue Force firing at an exposed OPFOR should be a more efficient casualty producer relative to the movement to contact case. The magnitude, though marginally significant, is roughly double that of the deliberate attack. This result further confirms for us the Clausewitzian notion that defense is inherently the stronger form of combat and therefore the more productive generator of enemy vehicle casualties.

The technology coefficient is positive and significant at the 95% confidence level. This result is firm evidence based on the engagements studied that digital units are more efficient producers of direct fire vehicle kills. The coefficient magnitude, though small, is measurable. The technological effect on direct fire kill productivity is roughly equivalent to a one percentage point increase in the Blue Force tank strength. For the units studied, this translates to the addition of less than one tank to the Blue Force. However, the result gives us clear and valid evidence that digital technology makes the heavy task force a more productive direct fire killer.

The training coefficient is positive, yet insignificant at the 95% or 90% confidence levels. Consequently, there is not sufficient evidence from the engagements studied to conclude that training confers an advantage that technology does not. However, we know

from previously accumulated National Training Center evidence that training does improve rotating unit performance.[40] This result is most likely an anomaly caused by insufficient data. Though insignificant, the coefficient magnitude gives us an indication of the probable influence of the training variable. Interestingly, the magnitude indicates that training is more influential than the mission or technology variables.

The equipment variables all appear to be insignificant at either the 95% or 90% confidence levels. This inconclusive result is likely due to small variations in the reported levels of mission capable vehicles found in Take Home Package data. Both the OPFOR and Blue Force units tended to begin with similar levels of mission capable equipment for like units executing a given type mission. A lack of variation in a factor will tend to produce insignificant coefficient estimates. However, even these results provide some indication as to the magnitude of effects which we might establish given further trials with greater variation in Blue Force and OPFOR vehicle types.

First, more Blue Force direct fire systems involved in an engagement will result in a greater ability to produce direct fire kills. This follows from the positive result on the coefficient estimates for both Blue tank and non-tank direct fire systems. Interestingly, the comparative results of the Blue tank and non-tank variables lead us to suspect that tanks are roughly seven times as productive as M2 or M901 systems in their direct fire kill ability. An interesting item for further study would be to investigate comparative productivity differences of units configured with varying mixes of M1A2 and M2A2 systems. This might provide us greater information regarding optimal weapons platform combinations to counter a given threat force structure.

The negative sign on the OPFOR tank variable at first appears to be a counterintuitive result, drawing us to conclude against reason that placing more tanks in the OPFOR battle order would reduce the likelihood of their being killed. However, this is not an unreasonable result considered in a substitution sense. Were a commander to exchange one tank for a non-tank vehicle in a given battle order, he would find his force improved in armor protection and its ability to deliver suppressive fire. Therefore, it would be reasonable to expect that Blue's ability to produce OPFOR casualties would suffer from such a substitution. This is much the manner in which OPFOR battle data behaves, with the overall number of vehicles in like engagements fixed and the data showing small variations in the tank to non-tank vehicle mix.

In general, the results represent a revealing first order explanation of comparative direct fire characteristics in digital and non-digital units, given the limited data available.[41] The adjusted R^2 indicates that the regression constructed explains 46% of the variation in task force direct fire productivity. However, we must temper our conclusions with the knowledge that there are relatively few iterations of digital engagements for us to compare with conventional unit missions.

Indirect Fire Effectiveness of Digital Task Force Units

The final firepower question concerned the task force's ability to deliver indirect fire accurately and in volume. The analysis in question focused on the unit's ability to integrate indirect fires into its battle, exclusive of any missions fired at the brigade level. Statistical results of the analysis appear as Annex 5, while general indirect fire effectiveness findings appear in the tables below.

Table 2: Average Artillery Missions and Rounds Fired

	Movement To Contact		Defend In Sector		Deliberate Attack	
	Digital	Non-Dig	Digital	Non-Dig	Digital	Non-Dig
Missions	11.0	2.6	28.0	16.0	19.7	14.7
Type Unit's Missions Rated More Effective	Non-digital		Not Significant		Not Significant	
Rounds	514.0	235.6	1817.0	1220.7	422.7	483.2
Type Unit's Rounds Rated More Effective	Non-digital		Not Significant		Digital	

Table 3: Average Mortar Missions and Rounds Fired

	Movement To Contact		Defend In Sector		Deliberate Attack	
	Digital	Non-Dig	Digital	Non-Dig	Digital	Non-Dig
Missions	1.0	2.5	4.0	9.0	7.3	6.5
Rounds	8.0	177.3	190.0	647.0	313.0	261.0

Offensive missions demonstrated the digital unit's ability to fire more missions, but with no increase in mission accuracy. In deliberate attacks, digital units fired 34% more artillery missions. Movement to contact missions exhibited a greater increase in the volume of indirect fires, as digital units fired indirect missions at a rate nearly five times that of the non-digital unit. By contrast, digital units showed a less consistent pattern of effective mortar fires. The digital unit was able to fire 12% more mortar missions on the deliberate attack. However, on the movement to contact, the unit was able to fire one mortar mission, whereas non-digitally equipped units on average fired 2.5 missions.

Though digital units were able to fire more artillery missions, it is difficult to conclude that these missions were more accurate. Analyzing observer-controller records of artillery fires reported effective, suppressive and ineffective revealed no significant patterns of increased effectiveness in digital force fires. In the sole case which revealed a clearly different pattern in digital units, it was the conventional unit which had the greater

concentration of rounds and missions reported as effective and suppressive. On movement to contact missions in particular, digital units had a difficult time generating effective artillery fire.

Despite the inconclusive evidence surrounding artillery mission effectiveness, we can clearly conclude that digital units have more effective indirect fire during offensive missions. Even without an increase in fires rated effective or suppressive, the digital unit's ability to fire a greater number of missions results in a higher rate of suppressive and destructive fire placed on the enemy. In the end, a higher volume of fire will result in more suppressive and destructive fire, even without an increase in the efficiency of those fires.

Digital units demonstrated similar indirect fire improvements during defensive missions. Digital units employed 75% more artillery missions at the task force level. However, digital unit mortar platoons fired fewer than half the missions of their non-digital counterparts. Overall, digital units employed far more indirect fire on their opponents than did conventional units.

Though firing a greater number of missions in the defense, digital units again failed to establish a pattern of more effective fire missions. Though the proportion of missions and rounds rated as effective or suppressive are marginally greater in digital units, the pattern of effective fire is not significantly different from that of conventional units. However, the same indirect fire argument holds in the defense as in the offense. Notwithstanding efficiency increases, digital units were able to place a greater volume of effective fire on the enemy. For instance, digital units were able on average to place 360

artillery rounds rated as effective on the enemy as compared to 271 for non-digital units, for an increase of 32.8% in effective rounds.[42] This figure seems to further confirm the vehicle kill distribution findings discovered earlier, one explanation of the phenomenon being a higher volume of indirect fires placed on OPFOR units.

Further Combat Power Improvements: Maneuver, Protection and Leadership

As the reader has by now detected, an important goal of this inquiry has been to establish attributes of digital performance which are empirically verifiable and quantifiable. However, several after action reviews and articles provide indications of combat power improvements which can only be captured in a non-quantitative way. First, digital units seem to prosecute battle at a more intense tempo. On average, digital unit deliberate attacks lasted 119 minutes compared with 170 minutes in conventional units. Deliberate defense mission lengths were virtually the same in digital and non-digital units, lasting an average of 120 minutes in conventional units and 123 minutes in digital units. Movements to contact were also virtually indistinguishable between digital and conventional units, lasting on average 93 minutes in conventional and 100 minutes in digital units. However, we would expect a smaller variation in tempo on the defense and movement to contact as a great deal of the initiative, and therefore control of time in both operations, lies with the OPFOR. However, the trend regarding tempo is clear. In those missions where the initiative belongs predominantly to digital units, commanders seem able to press the attack significantly faster.

Perhaps the greatest evidence of improved digital unit tempo came from the OPFOR commander aggressing against the digital task force during NTC Rotation 94-07.

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The commander remarked of the digital unit on the movement to contact mission that "...These guys were moving with a lot of authority, and closing surprisingly fast." [43] This observation came on the commander's first contact with the digital unit in a force on force engagement and represents a strong initial impression. Likewise on the defend in sector mission, the OPFOR commander noted the digital task force's ability to countermarch a significant part of its force and execute a vigorous counterattack into the flank of the lead OPFOR battalion. [44] All other factors equal, digital units appear able to press the attack more vigorously than their conventional counterparts.

Digital units appear able to exercise a higher degree of situation awareness than conventional units. Remarking on the Rotation 94-07 defend in sector mission, the Brigade Observer Controller observed that the unit enjoyed "...possibly the clearest view of any battlefield in history." [45] This aspect alone appeared to give the unit the ability to launch a very effective counterattack only negated by weaknesses in the use of terrain and rehearsal and a vigorous OPFOR counterattack. [46]

Digital units also seem able to exercise force protection superior to that of their non-digital counterparts. One company commander, writing of his unit's experience as part of a task force attack, related an experience which sounded remarkably similar to MG Clark's vision of the digital task force of 2005. In this vignette, the TOC was able to provide him with the precise location of an OPFOR persistent chemical strike via digital means. The commander then transmitted this information along with graphics for a change of movement which allowed his unit to bypass the strike location and avoid

contamination.[47] Observer-controller after action comments established that this message also proved instrumental in protecting a sister company from the strike's effects.[48]

Why Was Performance Not Improved in Digital Units?

Given the improvements in firepower, maneuver and force protection conferred by digital equipment, we would naturally expect that digital units performed better than their conventional counterparts. However, despite the demonstrated improvements, modest though they are, we are still left with the problem that digital units did not demonstrate the promised decisive edge in the heavy force fight. It is instructive for us to wrestle with some possible explanations of this failure in order to gain a full understanding of digital capabilities.

First, NTC battles are normally fought to exhaustion. Ending strengths of friendly and OPFOR force units of a few tanks and infantry fighting vehicles are common. At some point, losses conferred on one side or the other will begin to mask firepower improvements as the unit disintegrates. Thus, the loss exchange ratio will mask what is higher blue force productivity as it "sees" both sides attrition. After a time, it is difficult to detect productivity increases if both sides essentially become combat ineffective.

Second, the full capabilities of IVIS were not employed in the force on force exercises due to safety considerations. For instance, IVIS computes an enemy vehicle location by taking the laser range finder (LRF) reading and combining it with the vehicle position navigation system reading, then burst transmits this information to the remaining unit vehicles. This function also serves as the basis for sending precise calls for fire to supporting artillery units. However, the LRF of both the M1A2 and M2A2 is not an eye

safe system and must be disabled for force on force training.[49] Consequently, the unit was not able to exploit key aspects of the vehicle's advanced sighting and situation awareness capability, degrading the unit's ability to integrate battlefield arms and produce a decisive edge.

Third, digital systems appear to be insufficiently robust to handle some aspects of their expected workload. In some cases, voice transmissions block digital signals leading to the loss of some information. Intermittent digital signal losses forced leaders to follow digital transmissions with a voice message confirming receipt of the information.[50] Such cases increased soldier workload and reduced unit efficiency. One participant cited the interface difficulties as serious enough to warrant the creation of a dedicated digital radio net.[51] In addition, both rotating units were plagued by equipment breakdowns and the distraction of attempts to put equipment into operation up to the exercise start.[52]

Fourth, unit evaluations appeared to reveal specific Blue Force deficiencies and OPFOR strengths which seemed to confer a decisive advantage on the OPFOR. In the movement to contact, the lead unit blundered into an ambush which quickly annihilated the lead unit. The remaining task force stumbled into the same OPFOR ambush and was eliminated. After action reviews stated that the leaders became so focused on the IVIS display as to lose contact with their surroundings and neglect the practice of basic tactical skills.[53] The unit's evaluation pointed to specific deficiencies in terrain analysis, deliberate planning and rehearsal as explanations for its mission difficulties.[54] By contrast, the OPFOR account of the same action revealed detailed planning and thorough rehearsal.[55]

The rotation 94-07 defend in sector mission was a modest win for the OPFOR. However, it seemed that the margin of victory owed to the OPFOR commander's detection and exploitation of critical Blue Force weaknesses. However, digital unit evaluators again cited problems involving intelligence analysis, situation template development and ineffective rehearsals. In particular, rehearsals lacked the perspective of an aggressive, thinking enemy to test the Blue Force plan. The evaluators cited poorly built engagement areas which failed to maximize direct and indirect fires. Evaluators also critiqued the unit's counterattacks as unrehearsed and making use of unreconnoitered battle positions.[56] By contrast, the OPFOR commander developed a plan integrating combat functions with a sound deception plan and rehearsed it fully. In particular, the OPFOR commander attacked through terrain which minimized the Blue Force ability to mass fires.[57] The OPFOR commander exploited this weakness and was able to mass combat power on a single Blue Force team. The OPFOR found their attack greatly enhanced by the early destruction of the Blue Force vehicle serving as the task force digital communications hub.[58] In short, the OPFOR commander minimized his opponent's strengths through a sound application of fundamental tactical skills.

The deliberate attack missions pointed to clear areas of OPFOR tactical strength which the commander used to maximum effect. Evaluators repeatedly critiqued the digital unit for weaknesses in intelligence preparation and inadequate incorporation of higher headquarters intelligence. Planning processes and rehearsals emerged as weaknesses which led to ineffective artillery targeting.[59] By contrast, the OPFOR unit executed a defense in depth and made extensive use of intelligence preparation, rehearsals and

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coordination drills.[60] In addition, the OPFOR unit employed an effective deception which convinced the Blue Force commander to fire a large volume of artillery against false positions. The unit used a well rehearsed move into its defensive positions at the last minute which when combined with the deception plans, minimized the effect of accurate Blue Force direct and indirect fires until late in the attack.[61]

In general, the Blue Force of rotation 94-07 suffered from insufficient unit training, a deficiency known to the OPFOR which seemed also to affect the unit's morale.[62] The digital unit's key preparatory field training exercise for rotation 94-07 was canceled and the unit exercised 316 OPTEMPO miles compared with the average conventional unit's 749.[63] In addition, the unit had engaged in no task force level training for more than a year prior to the rotation, though the unit did receive a week's training prior to its exercises against the OPFOR.[64] However, it is instructive that once we control for this training disparity, the results seem to indicate that technology still positively influences unit performance.

In summary, both digital units presented new and formidable challenges which the OPFOR commander had to surmount. On those occasions OPFOR won, it did so by employing doctrinal fundamentals in a superior manner. The OPFOR simply performed basic tactical skills such as intelligence analysis, reconnaissance, planning and rehearsal better than the Blue Force. These factors enabled OPFOR to overcome the technological edge of digital units and provide victory. However, the OPFOR commander noted that the technological edge was difficult to defeat and properly used might have overcome unit

training deficiencies.[65] In many cases, the outcome was a near issue, but technology did not seem to overcome training deficiencies.

Chapter 5: Conclusions and Future Research Agenda.

The analysis of this study has established weak, yet significant evidence that digital systems improve heavy force combat power. We shall review these preliminary conclusions, assess their significance and relate them to future research.

First, digital units posses the capability to better integrate direct and indirect fires. This improvement came from better connectivity between battlefield participants which in turn maximized combined arms synergy. Where digital task force performance fell short, unit training rather than system capability best explained the deficiencies. Though some comments indicated problems with unit indirect fire coordination, the digital team on the defense clearly demonstrated a more thorough distribution of direct and indirect fires. Likewise, digital task force deliberate attacks indicated a better integration of battlefield systems brought about by superior connectivity.

Second, digital units are more efficient direct fire killers on the battlefield. As the analysis demonstrated, digital units created direct fire kills at a level commensurate with conventional units but did so in a faster manner. Where digital units failed to translate this superior tempo into battlefield dominance, the problem again seemed to lie with tactical training, not system characteristics. Some system attributes seem to decrease productivity by making soldier tasks more complicated, but these appear to be surmountable problems. Units must clearly be well grounded in tactical skills to fully exploit digital advantages.

Third, digital units show promising capabilities which might prove the edge for which senior leaders seek. Among these capabilities are a more intense tempo of operations, a greater awareness of friendly and enemy units, an improved level of force protection and an improved ability to maneuver and mass fires. However, the two digital maneuver exercises clearly indicate that these attributes are scant, immature and far from being decisive characteristics. However, they are the kind of developments which we desire for heavy units to produce and maintain a decisive tactical edge. These improvements come as a result of the synergy developed when we allow full connectivity between capable systems employed by well trained operators. For instance, units demonstrated significant force protection improvements when an individual player could quickly pass detailed hazard information to the entire unit. The Rotation 94-07 OPFOR commander on two occasions noted his respect for the connectivity potential of remotely piloted vehicles, digital vehicles, the OH58D and individual soldier links to higher headquarters.[66]

Fourth, digital systems and our ability to use them are in their infancy. Doubtless, both rotating units failed to exploit many digital capabilities because of insufficient unit training. Further, tactical training deficiencies such as shortcomings in the planning process and intelligence analysis muted many demonstrated system capabilities. As further units have learned the lessons of earlier units and developed technique, attributes of digital systems have emerged. For instance, exercise Focused Dispatch specifically tested doctrinal methods designed for digital forces and thereby demonstrated that continuous planning is a valid concept.[67] The few digital capabilities showcased in the maneuver

exercises soundly demonstrate the reality that any new technological development will require a significant investment in training, development and doctrine if the digital force is to realize its full capabilities. Lawrence Korb places technology in its proper relationship to other factors when he states "...we're always thinking that technology is going to make warfighting and a lot of things easier, and it never quite works out as quickly or the way we thought."[68] Our focus must be on finding and exploiting the leverage inherent in digitization, while retaining a mastery of timeless tactical fundamentals.

However, Army leaders would do well to consider two possibilities indicated by the digital experiments to date. In the first case, it may well be that the digital paradigm is correct but not practical reality in its present form. For instance, the first manifestation of mechanized, high volume infantry fire came in the Gatling Gun. However, the gun was heavy, mechanically unreliable and incorrectly employed as an artillery weapon. It was not until twenty years later with the development of the Maxim Gun and more appropriate tactical doctrine that the machine gun gained ascendancy as a dominant infantry weapon.[69]

Second, a key to successful digitization will be the significant investment in training, force structure alterations and doctrinal development necessary to fully exploit the system's characteristics. For example, the US Army did not realize radar's potential as an early warning device until well into the Second World War, even though Britain had made remarkable technological and doctrinal strides in its employment. In 1941, the US deployed the new technology in Hawaii with ill-trained operators and without a coherent alert network. The US thereby denied itself warning of an incoming Japanese attack on the morning of December 7th, 1941.[70]

Finally, though digital systems produce an advantage, they are not a panacea. They do not replace the need to fully master sound tactical and doctrinal principles.[71] However, it is ironic to consider that a unit having less than half the training of its conventional counterparts prior to the rotation performed roughly on a par with more fully trained units. While technology is not a substitute for good training, the leverage available from technology is clear.

Improvements and Directions for Future Research:

The analysis of this paper has clearly established that our analytic construct needs to be more sophisticated than a consideration of loss exchange ratios. Though an important statistic in its own right, this figure is not significantly robust to isolate causal factors and give a clear indication of technological effects. The Cobb-Douglas production model is an appropriate analytic tool which isolates the effects of factors on combat power. There are a number of additional factors whose effect on combat power and interaction with digital technology the Army should investigate. One important area which should receive attention is the interaction between soldier quality as measured by AFQT scores and the attributes of digital systems. In particular, we should look for the synergy which may be present when intelligent operators operate technologically sophisticated systems.[72] In addition, the Army should give consideration to those areas where the civilian sector produces skills compatible with digital technology. Perhaps the presence of these skills and their potential for maximizing the digital effect would call for changes in manpower accession policies.

The analysis of this study indicated that there might be an optimal mix of digital systems in a heavy digitized task force. Empirical evidence can provide us powerful clues as to how best to employ digital systems to maximize combat power. In addition, given the expense of digital systems, it would be appropriate to establish the marginal improvements conferred by successive levels of digitization. The basic model in this paper should also investigate effects of terrain and environmental conditions on digital system performance. Also, this analysis limited its study to daylight engagements. Further research should investigate whether digital systems confer any advantages during night and limited visibility operations. We would expect there to be some advantage evident, as navigation and target acquisition are more difficult propositions in limited visibility conditions.

This study also indicated a curious disparity between digital unit improvements in artillery fires along side a much poorer employment of mortar systems. We must consider that the mortar data was extremely limited, so this disparity is far from conclusive. However, further inquiry should focus on an examination of mortar performance differences given digital systems and areas in which digital systems can improve the employment of this important combat resource.

The more factors we wish to investigate, the more there is need for a robust and well constructed database from which analysts can derive valid conclusions. As a starting point, the Army should consider measuring direct and indirect fire kills at the company-team level through better use of MILES data. Additionally, the Army should consider a limited series of experimental trials to validate the results indicated by quasi-experimental

research. Such an effort would contribute greatly to the full understanding of digital capabilities and their effect on combat power.

It is clear that the results of trials to date should lead to specific training plans designed to maximize digital capabilities. Specifically, units must develop home station training plans which fully train the skills necessary to operate digital equipment. Further, units must master command and control functions, as this is primarily the domain of digital improvements. The emerging series of doctrinal manuals specifically designed for the digital forces should help greatly in this regard. Above all, participants in digital exercises should disseminate their experiences through the lessons learned network and professional journals.

Finally, it is clear that future development efforts should focus on correcting the glaring technical deficiencies which plague digital units. Information overload problems of staffs and system operators desperately need solutions. Digital equipment should leverage rather than hinder soldiers' efforts. Above all, the Army must ensure its efforts are holistic and approach digitization from a systems perspective. This will be a difficult challenge in the midst of an appliqué modernization effort. Only when designed as a comprehensive system will digital modernization efforts yield the connectivity necessary to foster synergy.

As the findings of this study indicate, the trials conducted to date, though not rousing endorsements of the digital concept, do validate promised digital improvements. The task now remains to fully explore, develop and implement these concepts. In so doing, we can achieve the vision of dominant maneuver and maintain the Army's landpower superiority into the next century.

ENDNOTES

[1] In 1994, the Army strongly indicated that it would entirely digitize itself by the year 2010, as reported in Barbara Starr, "Desert Hammer Puts US Digitized Army to the Test," *Jane's Defense Weekly*, 9 April 1994, 18. But, the present version of the Army's master digital plan states that while the Army plans to have a brigade fully digital by 1997, a division by 1998 and a corps by 1999, it only identifies the overall Army modernization timetable as beginning in the year 2000 and being completed on a date "to be designated." (From US Army, "Army Master Digitization Plan," 1996, http://www.ado.army.mil/admp/1996/00exec.htm). Accessed 22 November 1996.

[2] Kevin Kelly, *Out of Control*, 293.

[3] Gordon Sullivan, James M. Dubik, *Envisioning Future Warfare*, (Fort Leavenworth, KS: CGSC Press, 1995), 3.

[4] Ibid., 11.

[5] Ibid., 19.

[6] Ibid., 55.

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[9] Glenn Goodman, "US Army Synchronizes its Combat Arms With Digital Data," *Armed Forces Journal International* 130, no. 10 (May, 1993): 35.

[10] Paul E. Funk, "The Army's Digital Revolution," *Army* 44, no. 2 (February, 1994): 33.

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[12] Wesley K. Clark, "Digitization: Key to Landpower Dominance," *Army* 43, no. 11 (November, 1993): 28-29.

[13] Ibid., 30.

[14] Wade L. McVey, "The M1A2, IVIS and the NTC - A Company Commander's Perspective," *Armor* 102, no. 6 (November - December, 1993): 36-37.

[15] Lawrence G. Vowels, "Lessons of Operation DESERT HAMMER VI: Materiel Could Be Improved," *Armor* 104, no. 3 (May - June, 1995): 17.

[16] US Army Mounted Warfighting Battlespace Lab, *Advanced Warfighting Experiment Operation Desert Hammer VI; Final Report* (Fort Knox, KY: US Army Armor Center, 1994), BACKGROUND 7-8.

[17] General Accounting Office, *Battlefield Automation: Army's Digital Battlefield Plan Lacks Specific Measurable Goals* (Washington, D.C.: GPO, 1995), 7.

[18] US Army Mounted Warfighting Battlespace Lab, *Advanced Warfighting Experiment Focused Dispatch: Final Report* (Fort Knox, KY: US Army Armor Center, 1996), iv-v.

[19] Ibid., 1-3 to 1-4.

[20] Ibid., 1-4.

[21] Ibid., 5-7.

[22] Ibid., 1-5 to 8.

[23] Ibid., 1-7 to 8.

[24] Ibid., 6-16.

[25] Randall L. Rigby, "Fires for Division XXI: State of the Branch," *Field Artillery* (December 1995): 1-5.

[26] Mounted Battlespace Lab, *Focused Dispatch: Final Report*, 1-6 and 6-20 to 21.

[27] Jason Sherman, "Rush to Digitization: Has the Electronic Battlefield Been Oversold?" *Armed Forces Journal International* 133, no. 7 (February, 1996): 40. Available from http://www.afji.com/Mags/1996/Feb/digitization.html. Accessed 22 November 1996.

[28] General Accounting Office, *Battlefield Automation*, 9.

[29] Andrew Krepinevich as quoted in Sherman, "Rush to Digitization," 42.

[30] General Accounting Office, *Battlefield Automation: Army's Digital Battlefield Plan Lacks Specific Measurable Goals* (Washington, D.C.: GPO, 1995), 3-6.

[31] Ibid., 1.

[32] Mounted Battlespace Lab, *Desert Hammer Final Report*, TRAINING COMP 1-10.

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[34] Ibid., 2-10.

[35] James J. Schneider, "Cybershock: Cybernetic Paralysis as a New Form of Warfare," (School of Advanced Military Studies: Ft. Leavenworth, KS, 1995), 4-5.

[36] The general microeconomic form of the Cobb-Douglas model is found in Hal Varian, *Microeconomics*, (New York: Norton, 1984), 8-18. Examples of the model's econometric applications and the concept of elasticity may be found in Jan Kmenta, *Elements of Econometrics*, (New York: Macmillan, 1986), 252-253, and 511-512. Also, Ronald J. Wonnacott and Thomas H. Wonnacott, *Econometrics, 2nd edition*, (New York: John Wiley, 1979), 124-127. Also, Damodar N. Gujarati, *Basic Econometrics, 3rd Edition*, (New York: McGraw-Hill, 1995), 214-217.

[37] Carl von Clausewitz, *On War*, ed. trans. Michael Howard and Peter Paret (Princeton, NJ: Princeton University Press, 1976), 358.

[38] Robert Holz et al., eds., *Determinants of Effective Unit Performance*, (Alexandria, VA: Army Research Institute, 1994), 76-77.

[39] Simmeth, 104-105 and 123.

[40] Holz, et. al., 76-77.

[41] The data set consists of 38 observations. With eight factors included in the regression equation, this confers 29 degrees of freedom for statistical analysis. Though a robust enough data set to confer statistical significance, the findings would be stronger given more observations.

[42] *Operation Desert Hammer Database*, File arty.xls.

[43] Harry G. Simmeth, *Fighting the Digitized Force: Operation Circuit Breaker vs. Operation Desert Hammer VI*, (Carlisle Barracks, PA: U.S. Army War College, 1995), 51.

[44] Ibid., 71.

[45] Ibid., 73.

[46] Ibid., 74.

[47] McVey, 35.

[48] US Army, *National Training Center Rotation 93-10 Evaluation*, (Fort Irwin, CA: National Training Center, 1993), Chapter 3.IS, 11-14.

[49] McVey, 37.

[50] Vowels, 15.

[51] Owen T. Edwards, "The Digital Battlefield: Training and Tactical Insights of User," *Armor* 104, no. 3 (May-June, 1995): 13.

[52] Simmeth, 37.

[53] Ibid., 55-56.

[54] US Army, *National Training Center Rotation 94-07 Evaluation*, (Fort Irwin, CA: National Training Center, 1994), Chapter 1, 11-14.

[55] Simmeth, 42-44.

[56] US Army, *National Training Center Rotation 94-07 Evaluation*, Chapter 2, 11-13.

[57] Simmeth, 59-60.

[58] Ibid., 72.

[59] US Army, *National Training Center Rotation 94-07 Evaluation*, Chapter 5, 11 and Chapter 6, 11-14.

[60] Simmeth, 98-99.

[61] Ibid., 103-104.

[62] Ibid., 37.

[63] US Army Mounted Warfighting Battlespace Lab, *Operation Desert Hammer VI: Final Report*, TRAINING COMP 9.

[64] Ronald K. Kollhoff, "The Lessons of Operation Desert Hammer VI: Training: Digitization Will Impact Many Areas of Training," *Armor* 104, no. 5 (September-October, 1995): 41. Also, Simmeth, 37.

[65] Simmeth, 123.

[66] Ibid., 93 and 123.

[67] US Army, *Advanced Warfighting Experiment Focused Dispatch: Final Report*, A-31 to 32.

[68] Lawrence Korb, as quoted in Sherman, "Rush to Digitization," 42.

[69] J.F.C. Fuller, The Conduct of War, (new Brunswick, NJ: Rutgers University Press), 135.

[70] Eliot Cohen and John Gooch, *Military Misfortunes*, (New York: Random House, 1990), 50-51.

[71] Edwards, 13.

[72] One application of this interactive aspect of technology and intelligence may be found in Barry L. Scribner, et. al., "Are Smarter Tankers Better? AFQT and Military Productivity," *Armed Forces and Society* 12, no. 2 (Winter, 1986). In this research project, the researchers set out to find the contribution of soldier quality as captured in AFQT scores, to performance on tank table eight qualification scores. One of the variables they included was a dummy which corrected for the

presence of the M1 tank, at that time only partially fielded in USAREUR. In addition to intelligence and technological effects, they found an interactive effect between intelligence and the M1 tank. Smarter tankers firing on the M1 score even better than the additive combination of their intelligence and tank effects. This author strongly suspects that such an effect might be present in the case of digital systems.

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Annex 1: Key Platforms to be Digitized and Their Equipment

M1A2 Abrams Main Battle Tank
  Inter-Vehicular Information System (IVIS)
  Commander's Integrated Display
  Improved Commander's Weapons Station
  Commander's Independent Thermal Viewer
  Single Channel Ground/Air Radio System
    (SINCGARS)

M3A2 Bradley Cavalry Fighting Vehicle
  C2 Software
  Commander's Independent Viewer
  Ballistic Fire Control System
  SINCGARS

M2A2 Bradley Infantry Fighting Vehicle
  IVIS Appliqué
  Laser Range Finder (LRF)
  Global Positioning System (GPS)
  Driver's Thermal Viewer (DTV)
  SINCGARS

M2A2 Bradley Fire Support Team (BFIST)
  Horizontal Technology Integration
  Light Computer Unit with Tactical Interface
  Forward Entry Device
  Tactical Fire Control System (TACFIRE)
  SINCGARS

Battle Command Vehicle
  Brigade and Below Command and Control
    System (B²C²)
  Advanced Field Artillery Tactical Data
System
  All Source Analysis System (ASAS)
  Enhanced Position Location Reporting System
    (EPLRS)
  Tactical Satellite Downlink
  Phototelesis
  SINCGARS

Joint STARS Mobile Ground Station
  Joint STARS Downlink
  Improved data Modem
  TACFIRE/ASAS Digital Link
  UAV/FLIR Link
  SINCGARS

AH64C/D Apache
  Integrated ground Positioning System
  Phototelesis
  ATHS
  SINCGARS

OH-58D Kiowa Warrior
  ATHS
  Phototelesis/FLIR
  LRF
  Low Light TV Camera
  SINCGARS

M109A6 Paladin Self Propelled Gun
  Onboard Position Navigation System
  Onboard Fire Control System
  SINCGARS

**M106A2 Enhanced Mortar**
  GPS
  Digital Compass
  TACFIRE
  SINCGARS

Source: Jane's Defence Weekly, 9 April 1994, p. 18.

Annex 2: Development of the Cobb-Douglas Production Model

The Cobb-Douglas model postulates that production is the result of several fixed and variable factors. The fixed factors represent attributes which remain constant for unique production runs (in this case, a specific type of engagement) and factors which vary among production runs (such as the number of Blue Force tanks in an engagement area.). The general form of the model follows:

$$Y = A\, x_1^{\beta 1}\, x_2^{\beta 2}\, x_3^{\beta 3} \cdots$$
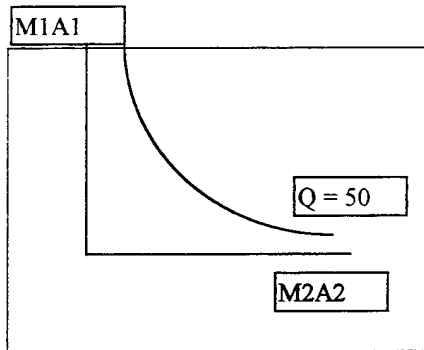
One of the useful aspects of the model is its ability to measure the contribution of and substitution between variable inputs. For instance, in the graph at left, we could use the evidence of past trials to determine the direct fire productivity of various Blue Force systems. In addition, we could also deduce the number of M2A2s we would have to substitute for M1A1s to keep the level of direct fire kills constant in a given engagement.

We can estimate the model's parameter values using regression analysis. However, to accomplish this, we must first convert the Cobb-Douglas function to a linear form using a logarithmic transformation. We can rewrite the function as follows:

$$\ln Y = \ln A + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 \cdots$$

Using multiple regression, we can use the form derived above to estimate the parameters β_1, β_2, and so forth, and perform tests of significance on the results. The significance tests derive from the null hypothesis that the factors have no effect on the production process (that is, $\beta_n = 0$). The alternate hypothesis rejects the null in favor of a conclusion that the factor's effect on production is best described by the estimated parameter β_n. These two hypotheses generate a t-statistic calculated by the expression:

$$\frac{\beta_n}{(\text{Standard Error})_n}$$

The calculated t-statistic is evaluated using a one sided t-test with (n-k-1) degrees of freedom.

We can further refine the transformed Cobb-Douglas model to yield a more useful interpretation of the regression results. For instance, we can ask what effect a right hand parameter change will have on production, the left hand variable. In order to do this, we

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take the partial first derivative, or rate of change of the function with respect to Y (production) as follows:

$$\frac{1}{Y}\left(\frac{\partial Y}{\partial Y}\right) = \frac{1}{A}\frac{\partial A}{\partial Y} + \beta_1\left(\frac{1}{X_1}\right)\left(\frac{\partial X_1}{\partial Y}\right) + \beta_2\left(\frac{1}{X_2}\right)\left(\frac{\partial X_2}{\partial Y}\right) + \beta_3\left(\frac{1}{X_3}\right)\left(\frac{\partial X_3}{\partial Y}\right)\ldots$$

Multiplying each side through by the term dY, we arrive at the expression below.

$$\frac{\partial Y}{Y} = \frac{\partial A}{A} + \beta_1\left(\frac{\partial X_1}{X_1}\right) + \beta_2\left(\frac{\partial X_2}{X_2}\right) + \beta_3\left(\frac{\partial X_3}{X_3}\right)\ldots$$

In each case, the term dX_n/X_n represents the proportion of change in the factor relative to its initial magnitude. Stated another way, the term indicates the percentage change in the given factor. Written in a more helpful shorthand, for small changes, we can rewrite the expression as it appears below:

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + \beta_1\left(\frac{\Delta X_1}{X_1}\right) + \beta_2\left(\frac{\Delta X_2}{X_2}\right) + \beta_3\left(\frac{\Delta X_3}{X_3}\right) + \ldots$$

This allows us to arrive at our interpretation of the coefficients, the "percent change" interpretation, as written below.

$$\%\Delta Y = \%\Delta A + \beta_1(\%\Delta X_1) + \beta_2(\%\Delta X_2) + \beta_3(\%\Delta X_3) + \ldots \xi$$

Seen in this light, the coefficients of regression take on the meaning of "elasticity" or sensitivity to change. For instance, an interpretation of the coefficient β_1 is the percentage change in output (production) we would expect from a one percent change in input. If the value of β_1 was 1.2, we would expect a 1.2% output increase to result from a 1% increase in factor X_1. Stated differently, if X_1 represented tanks committed to the direct fire engagement, and we increased the tank strength of the blue unit by 10%, we would expect OPFOR losses to increase by approximately 12%.

Annex 3: Vehicle Kill Distribution Analysis

Part 1: Average Vehicle Kill Distributions

Kill Source	Movement To Contact		Defend In Sector		Deliberate Attack		
	Digital	Non-Dig	Digital	Non-Dig	Digital 1	Digital 2	Non-Dig
Direct	50%	46%	56%	79%	64%	33%	24%
Indirect	11%	7%	9%	3%	11%	47%	4%
Air	39%	46%	26%	18%	23%	13%	72%
OC	0%	0%	8%	0%	2%	7%	0%

Part 2: Distribution Difference Tests

Movement To Contact

Rotation	94-08	94-05	94-06	94-06
χ-Stat	4.04	21.09	9.22	1.52
Result	NS	S	NS	NS

Defend In Sector

Rotation	94-05	94-06	94-06	94-05	94-06	94-07	94-08	94-08
χ-Stat	15.28	10.95	60.8	42.11	46.16	46.28	32.0	5.99
Result	NS	NS	S	S	S	S	S	NS

Deliberate Attack 1

Rotation	94-06	94-06	94-06	94-05	94-05	94-08
χ-Stat	17.06	35.62	71.9	58.64	19.78	5.58
Result	S	S	S	S	S	NS

Deliberate Attack 2

Rotation	94-06	94-06	94-06	94-05	94-05	94-08
χ-Stat	26.75	46.47	51.37	45.71	26.88	8.44
Result	S	S	S	S	S	NS

NS: Distribution differences not significant at the 0.95 level of significance
S: Distribution differences significant at the 0.95 level

Notes: The data are from tables prepared by the Desert Hammer analysis team which identified OPFOR vehicle kills by Blue type weapon system. The researcher separated the kills into the categories outlined above, then tested for distribution differences using the Chi-square statistical test. In this technique, the researcher calculates a test statistic based on the observed and expected distributions based on the following hypotheses:

H_0: There is no difference in digital and non-digital vehicle kill distributions
H_1: The distributions are different, with the most likely patterns suggested by the distributions calculated from the exercise data.

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The researcher used the following Chi-square critical values to evaluate significance:
$$\chi^2_{0.95,9} = 16.92 \qquad \chi^2_{0.90,9} = 14.68$$

Annex 4: Production Model Regression Results

		X Coefficient (Standard Error)	T-Statistic	Result
Mission	**Deliberate Attack**	-0.597 (0.346)	-1.726	Significant
	Defend in Sector	1.006 (0.639)	1.574	Insignificant (Significant at 0.9)
	Digital Equipment	0.959 (0.504)	1.903	Significant
	Training	1.157 (0.980)	1.181	Insignificant
Blue Mission capable	**M1**	1.057 (1.001)	1.056	Insignificant
	M2/TOW	0.145 (0.501)	0.289	Insignificant
Threat Mission capable	**Tank**	-0.442 (0.880)	-0.503	Insignificant
	Non-Tank	0.976 (1.013)	0.964	Insignificant

Notes: Data used to construct this table was drawn from NTC Take Home Packages 93-10, and 94-04 through 94-08.

The vehicle mission capable figures were those direct fire systems reported mission capable at the start of each engagement by the observer-controllers.

Direct fire OPFOR kills were those attributed by the observer-controllers to Blue Force M1, M2 or M901 systems.

The training variable is the average number of OPTEMPO miles which the respective unit logged in training prior to the rotation. Source for rotations 94-04 through 94-08 is the Desert Hammer VI Final Report. Source for rotation 93-10 data is G-3 Training, 1st Cavalry Division.

Engagement times for the various engagements were defined as starting at the criteria defined below in the Take Home Package battle summary. The engagement was considered ended at the time the unit received a change of mission or order to consolidate and reorganize.

Engagement Start Times:
- Move to Contact: Lead Blue Force company engages the OPFOR Forward Security Element.
- Deliberate Attack: Lead Blue Force company crosses the line of departure.
- Defend in Sector: Lead OPFOR battalion sized unit encounters the main Blue Force defense.

The data set consisted of 38 data points. Model coefficients were evaluated as a one-sided t-test with 29 degrees of freedom. The t-critical values used to evaluate significance were:

$$t_{0.95, 29} = 1.699 \qquad t_{0.90, 29} = 1.311$$

Annex 5: Artillery Distribution Analysis

Part 1: Average Missions Fired

Average Artillery Missions and Rounds Fired

	Movement To Contact		Defend In Sector		Deliberate Attack	
	Digital	Non-Dig	Digital	Non-Dig	Digital	Non-Dig
Missions	11.0	2.6	28.0	16.0	19.7	14.7
Rounds	514.0	235.6	1817.0	1220.7	422.7	483.2

Average Mortar Missions and Rounds Fired

	Movement To Contact		Defend In Sector		Deliberate Attack	
	Digital	Non-Dig	Digital	Non-Dig	Digital	Non-Dig
Missions	1.0	2.5	4.0	9.0	7.3	6.5
Rounds	8.0	177.3	190.0	647.0	313.0	261.0

Part 2: Artillery Effectiveness:

Artillery Missions Effective

	Movement To Contact		Defend In Sector		Deliberate Attack	
	Digital	Non-Dig	Digital	Non-Dig	Digital	Non-Dig
Effective	22%	50%	19%	14%	9%	7%
Suppressive	33%	33%	35%	27%	40%	46%
Ineffective	44%	17%	46%	59%	51%	47%
χ -Stat	9.0 (S 0.9)		1.5 (NS)		1.1 (NS)	

Artillery Rounds Effective

	Movement To Contact		Defend In Sector		Deliberate Attack	
	Digital	Non-Dig	Digital	Non-Dig	Digital	Non-Dig
Effective	32%	60%	20%	22%	11%	6%
Suppressive	27%	27%	40%	36%	35%	44%
Ineffective	42%	13%	41%	41%	54%	50%
χ -Stat	72.12 (S)		4.16 (NS)		11.4 (S)	

NS: Distribution differences not significant at the 0.95 level of significance
S: Distribution differences significant at the 0.95 level

Annex 5 Notes: The data are from tables prepared by the Desert Hammer analysis team which rated artillery missions and rounds fired as effective, suppressive or ineffective. The researcher then tested for distribution differences using the chi-square statistical technique. The null and alternate hypotheses are as follows:

Ho: There is no difference in digital and non-digital artillery mission/round distributions

H1: The distributions are different, with the most likely patterns suggested by the representative populations.

The researcher used the following chi-square critical values to evaluate significance:

$$\chi^2_{0.95,4} = 9.49 \qquad \chi^2_{0.90,4} = 7.78$$