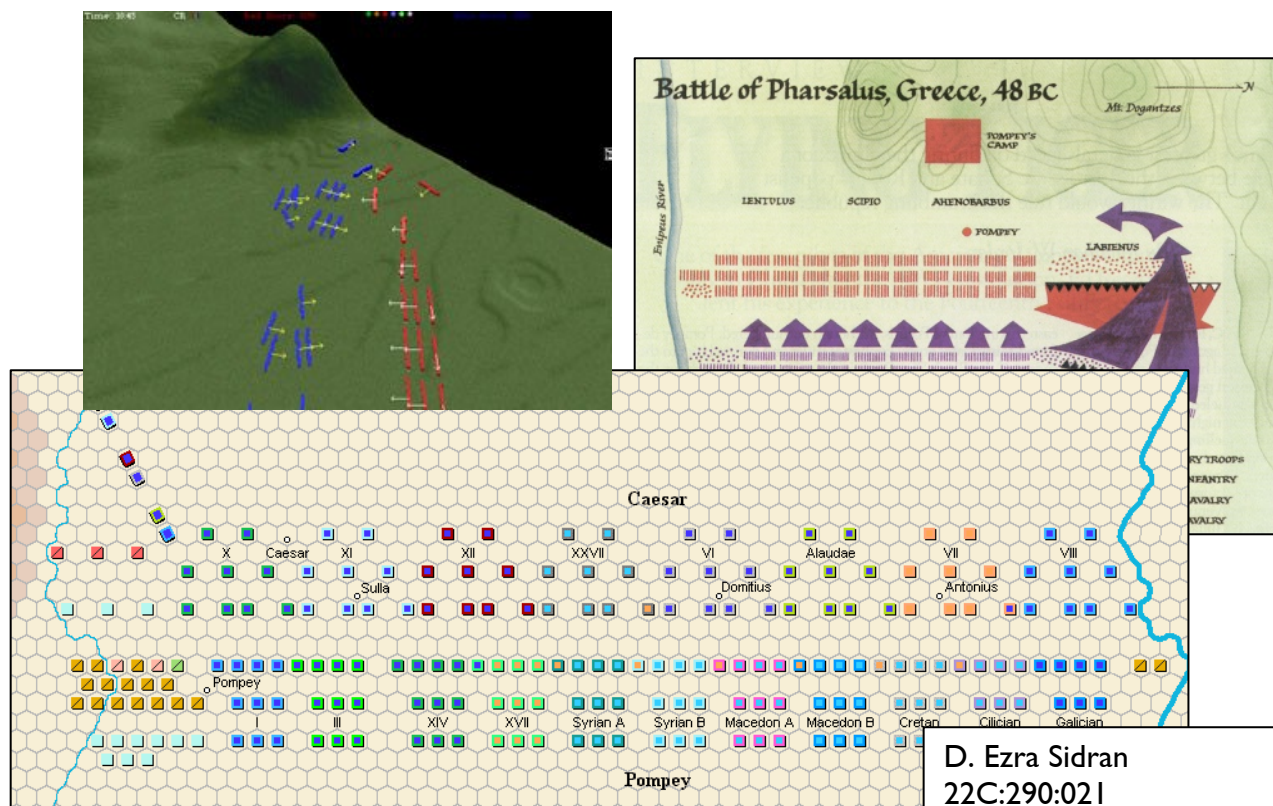


A Calculated Strategy:

Readings directed towards the creation of a strategic artificial intelligence.



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Computer Science
Readings for Research
Spring 2004
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Three views of the battle of Pharsalus (48 B.C.) above: top left: The War College computer game designed by the author (published by GameTek 1996), top right: Schlachten der Römer

http://www.lsg.musin.de/Geschichte/gesch_Karten/schlachten_der_r%C3%B6mer.htm, bottom: Great Battles in History board game <http://patriot.net/~townsend/GBoH/gboh-caesar.html>.

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Abstract

Since the nineteenth century extensive research has been conducted in constructing various models to simulate the results of military combat. It is the author's contention that the confluence of these models combined with high-speed and large memory personal computers and classic computer algorithm techniques such as 'MiniMax' and 'backtracking' allow for the creation of "human level"¹ artificial intelligence routines capable of planning strategic military maneuvers and campaigns.

After reviewing the classic literature in the field the author suggests an alternative to the "Lanchester Equations" and proposes new methods and tools that can be used to evaluate strategic and tactical positions.

This paper is a review of research and literature pertinent to this topic.

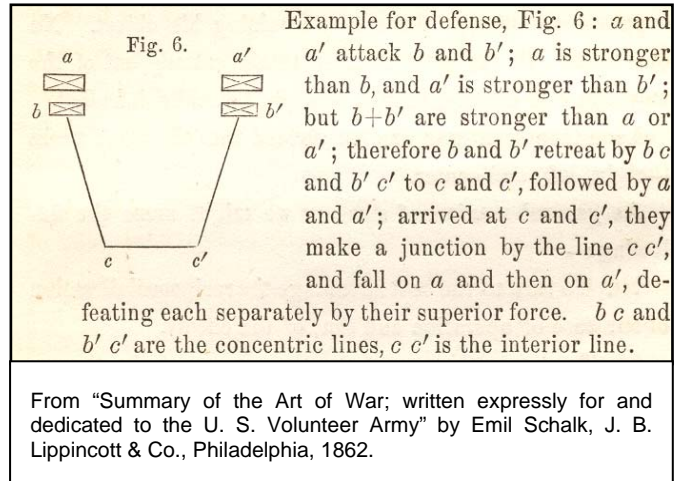
¹ John Laird coined the phrase "Human Level" in the paper, [Human-Level AI's Killer Application Interactive Computer Games. Laird; van Lent \(2001\)](#). It is available on this disk.

Background

Sun Tzu's sixth-century B.C. treatise "On the Art of War" (online version available here: <http://www.kimsoft.com/polwar.htm>) was the first known attempt to codify the basic underlying principles of warfare. "The Art of War" contains such pithy aphorisms as, "Go into emptiness, strike voids, bypass what he defends, hit him where he does not expect you."²

The Napoleonic wars of the late eighteenth and early nineteenth centuries were the laboratories for authors Carl von Clausewitz ("On War" available online here: http://www.clausewitz.com/CWZHOME/On_War/ONWARTOC.html) and A.H. Jomini "The Art of War" (not available online). Like Sun Tzu, von Clausewitz and Jomini also spoke in axioms ("A sudden powerful transition to the offensive – the flashing sword of vengeance – is the greatest moment for the defense."³ "In mountainous countries the people are the most formidable; next to these are countries covered with extensive forests."⁴).

The volunteer armies of the American Civil War (1861-65) created a ready audience for military treatises to educate the large untrained and newly minted officer corps. These books, available by mail-order, included such titles as Schalk's "Summary of the Art of War", Hardee's "Rifle and Light Infantry Tactics", Cooke's "U.S. Cavalry Tactics" and Duffield's "School of the Brigade and Evolutions of the Line." These books often included numerous diagrams (right) that were the first attempts to reduce military theory to mathematical or geometric reasoning.



² Sun Tzu, *The Art of War*, p. 106 Ts'ao Ts'ao translation. Note: there are numerous translation of Sun Tzu's *The Art of War*. Each footnote will identify the translated source.

³ Clausewitz, *On War*, p. 370.

⁴ Jomini, *The Art of War*, p. 30.

By the end of the nineteenth century war colleges and general staffs of the major powers began routine wargaming exercises. These included “Kriegspiel” used by the German and Prussian General Staffs for wargaming exercises and various fleet tactical exercises conducted with maps and model ships at the U. S. Naval War College (below).



Left: “One of the earliest illustrations of wargaming at the Naval War College. *Harper's Weekly* illustration of 1895. Right: “An apparent fleet-level action in Luce Hall at the Naval War College, about 1914. Both photos from “[The Art of Wargaming](#)” by Peter P. Perla, Naval Institute Press, Annapolis 1990

It is important to note that before World War I wargaming had evolved to the level where combat results were being accurately modeled which allowed for staffs to test theoretical strategies. Traditionally the senior officers played the “friendly” forces and junior officers commanded the enemy. This led to some unusual results such as when Rear Admiral Ugaki, in the role of referee of a pre-Midway (WW II) wargame, overruled the results of the junior officer’s successful counter-strike on the Japanese Nagumo Carrier Force; a *deus ex machina* that would not be repeated in the actual event some months later.⁵

The RAND Corporation in the late ‘50s developed the now classic hexagonal system of board wargaming. This was appropriated by the commercial wargaming market in 1961 when Charles Swan Roberts founded the legendary Avalon Hill company.⁶ Avalon Hill published a number of watershed wargames including Gettysburg, D-Day, Jutland and 1914 (the last two designed by Jim Dunnigan⁷). These board games included ‘combat result tables’ or CRTs (usually decided by dice rolls after calculating attack/defense combat ratios). A typical example is below:

⁵ From the author’s article “A Brief History of Computing & Wargaming”, *LeGuerrier*, Volume 2, Number 2. Article available on this disk here: [LeGuerrier.pdf](#).

⁶ Ibid.

⁷ Jim Dunnigan has written numerous books and treatises on wargaming including “[The Complete Wargames Handbook](#)” and is a frequent commentator on CNN and FOX.

GROUND COMBAT RESULTS TABLE:

Die Roll	1:5	1:4	1:3	1:2	...	1:1	...	3:2	2:1	3:1	4:1	5:1	...	7:1	10:1
6	D/AE	D	D	R2		R2		R2	R2	DE	BR	BR		BR			BR
5	AE	AD	S	R1		R1		R1	R2	R2	DE	BR		BR			BR
4	AE	D/AE	AD	-		D		R1	R1	R2	R2	DE		BR			BR
3	AE	AE	D/AE	AD		S		D	R1	R1	R2	R2		DE			BR
2	AE	AE	AE	D/AE		AD		S	D	D	R1	R2		R2			DE
1	AE	AE	AE	AE		AE		AD	-	S	D	R1		R1			R2

Note: Attacks at less than 1:5 odds are not allowed.

COMBAT RESULTS DEFINITIONS:

- BR = BREAKTHROUGH! All participating attacking units may tactically advance and attack (only) one more time (in conjunction with nonparticipating units which were about to attack, incidentally).
- DE = Defenders ELIMINATED.
- R2 = Defenders RETREATED 0-2 hexes as Attacker chooses and are DISPERSED. Possible Armor Overrun.
- R1 = Defenders RETREATED 0-1 hexes as Attacker chooses and are DISPERSED. Defender may then retreat them 1 (further) hex.
- D = All Defending Units DISPERSED. Defenders MAY be voluntarily RETREATED as for R1, if Defender chooses.
- S = All Defending Units SPENT. Any Defending unit MAY voluntarily RETREAT up to 2 hexes of the Defender's choice, if Defender chooses, but are then DISPERSED.
- - = No effect against either side.
- AD = Attackers (equal to defense factors) DISPERSED.
- AE = Attackers (equal to defense factors) ELIMINATED. AD for any surviving attackers.

Above: Typical combat results table. This is taken from the board game Stalingrad Attacked!
 Copyright 2003 Louis R. Coatney (from <http://members.tripod.com/~LCoat/stalcrt.htm>).

These simplistic tables proved to be extremely accurate for modeling combat results (note: to arrive at the 'odds' for attacker and defender numerous modifiers including unit type, morale, leadership and terrain were often factored in employing subsidiary tables).

By the mid '80s computer wargames based on previously published board game designs began to appear. It was a simple matter to convert the numerous tables to matrices that were easily manipulated by computer programs; dice rolls were replaced by pseudo-random number generator routines.

The one element that was lacking – that is still lacking – is the creation of strategic human level artificial intelligence; or the ability of the computer to ‘play’ one side of the wargame.

Art or Science?

“The art of war is simple enough. Find out where your enemy is. Strike at him as hard as you can and as often as you can. And keep moving on.” – U. S. Grant⁸

Since the time of Sun Tzu there has been a vociferous debate as to the nature of military study: is it an art or a science? If it is an ‘art’ it implies that there are no rules or laws that can be quantified. If it is a ‘science’ then the implication is that there is an underlying set of principles that can be acted upon.

Michael L. Handel in his *Masters of War: Classical Strategic Thought* (see [below](#)) makes it clear that both Sun Tzu and von Clausewitz considered the study of war an ‘art’ as exemplified in this quote from page 27 of his book, “Creation and production lie in the realm of art: science will dominate where the object is inquiry and knowledge. It follows that the term ‘art of war’ is more suitable than ‘science of war’.”⁹

Sun Tzu also suggests that it is not a science when he writes, “In the art of war there are no fixed rules”¹⁰

However, it is probable that both Sun Tzu and von Clausewitz would have considered playing the games of chess or go an art form with no fixed rules as well. Indeed, von Clausewitz’s statement, “For in the art of war, experience counts more than any amount of abstract truth,”¹¹ might well have been seconded by any number of chess masters such as Paul Morphy, Bobby Fischer or Boris Spassky. Garry Kasparov, the first grand master to be defeated by the Deep Blue computer, however, might have an entirely different perspective. Deep Blue had no experience, or any concept of such, but was equipped with a strong set of rules, a large ‘opening book’ and a massive amount of RAM and CPU speed that allowed it to analyze up to 25 moves (or ‘plies’) deep.

⁸ This is one of the more ubiquitous of Grant’s quotes yet I have never seen a reference to its source. That it sounds like Grant there is no doubt. To the best of my knowledge it does not appear in any of Grant’s writings and it is much more likely that it was an answer to officer’s or reporter’s question.

⁹ Clausewitz, *On War*, pp. 148-149.

¹⁰ Sun Tzu, *The Art of War*, p. 93. Chu’uan translation.

¹¹ Clausewitz, *On War*, p. 164.

However, when we analyze Grant's statement about the 'art of war' we see that it is, in fact, an algorithm; albeit an oversimplified one. This would lead support to the 'science' side of the argument.

U. S. Grant's 'art of war' algorithm	
<i>Find out where your enemy is.</i>	1. Various search routines and subroutines that locate enemy forces.
<i>Strike at him as hard as you can</i>	2. Various routines and subroutines that maximize the amount of force that can be brought upon the enemy while minimizing the amount of harm that the enemy can do to your forces. Subroutines include path algorithms and terrain and elevation effects calculations.
<i>and as often as you can.</i>	3. Has the enemy moved out of range? If not GOTO step 2.
<i>And keep moving on.</i>	4. If enemy still exists GOTO step 1.



The Lanchester Equation

F. W. Lanchester created his famous equation in 1914 which has become the standard equation for estimating casualty rates:

$$\begin{aligned}\frac{dR}{dt} &= -k_B B(t), & R(0) &= R_0 \\ \frac{dB}{dt} &= -k_R R(t), & B(0) &= B_0\end{aligned}$$

where R and B represent the numerical strength at time t of opposing Red and Blue forces, and k_B and k_R the killing rate of a Red/Blue individual.¹²

Another description comes from Drexel University's Lanchester Press Home Page (<http://mathforum.org/library/view/7065.html>):

“Lanchester's Linear Law is an equation of combat that relates to individual confrontations between soldiers where the outcome is dependent on the ratio of weapon efficiency (E) of the individual combatants and the combat strength of the army = E (number of troops). The outcome of the battle is the difference between the original troop numbers. Lanchester's N-Squared Law says that in mechanized warfare with modern weapons, each soldier can attack multiple targets but is also subject to incoming fire from many directions. In this case the attrition rate is proportional to the number of troops on the opposing side. The solution to the first order differential equation leads to Lanchester's Second Law: combat strength of the army = E (number of troops squared), also called Lanchester's N-Squared Law. Lanchester's Principle of Concentration: the basis of this strategy is concentration of the main strength of force at one point in the field of operations.”

And, yet a third description/problem is here (from http://artsandscience.concordia.ca/poli419n/pdf_word_excel/index/Poli_419_Lanchester_Equation_Hand_Spring_2004.doc):

¹² From [Describing Rates Of Interaction Between Multiple Autonomous Entities: An Example Using Combat Modelling; Lauren \(2001\)](#)

Given: 200 Red soldiers and 150 Blue soldiers, both with 0.01 effectiveness (r & b).

Equation to determine the time at which the loser's forces go to zero:

First, calculate which is the stronger side:

$rR^2(0)$ versus $bB^2(0)$

$(0.01)(200)^2$ versus $(0.01)(150)^2$

400 versus 225, therefore Red is stronger and is designated by rR in the equation.

Where rR is the stronger force, and $B(0)$ & $R(0)$ are values at the initial $t=0$:

$$T_{\text{end}} = \frac{1}{\sqrt{rb}} \tanh^{-1} \left[\frac{B(0)}{R(0)} \sqrt{\frac{b}{r}} \right]$$

$$T_{\text{end}} = \frac{1}{\sqrt{0.01 * 0.01}} \{ \tanh^{-1} \left[\frac{(150/200)}{\sqrt{0.01/0.01}} \right] \}$$

$$T_{\text{end}} = 1/0.01 \{ \tanh^{-1} [0.75(1)] \}$$

$$T_{\text{end}} = 100 \{ \tanh^{-1} 0.75 \}$$

$$T_{\text{end}} = \mathbf{97.29 \text{ turns}}$$

Note: \tanh^{-1} is simply the inverse hyperbolic tan (every scientific calculator has buttons for these, as does the scientific calculator on most PCs).

Equation for the number of units of the winner remaining at the end of the battle:

$$R_{\text{end}} = R(0) \sqrt{1 - [(bB^2(0))/(rR^2(0))]}$$

$$R_{\text{end}} = 200 \sqrt{1 - [(0.01 * 150^2)/(0.01 * 200^2)]}$$

$$R_{\text{end}} = 200 \sqrt{1 - [(225)/(400)]}$$

$$R_{\text{end}} = 200 \sqrt{1 - [(225)/(400)]}$$


$$R_{\text{end}} = \mathbf{132.28756 \text{ soldiers}}$$

$$B_{\text{end}} = \mathbf{0 \text{ soldiers}}$$

There are numerous obvious objections to the Lanchester Equation including Laurens: "However, the Lanchester equations make a number of gross assumptions, in particular, that all the battlefield entities are homogenous and evenly distributed. Such an equation is virtually useless in many modern scenarios, where the battlefield is often much more dispersed and likely to exhibit spatial and temporal correlations of deployments." – "[Describing Rates of Interaction Between Multiple Autonomous Entities: An Example Using Combat Models](#)"; Lauren; (2001)

In addition the variables k_B and k_R which represent the "killing rate of the Red/Blue individual" must, in reality, be the results of a series of extraordinarily complex calculations that take into effect a multitude of dependent variables such as weaponry, angle of attack, morale, fatigue, leadership, weather, etc., etc. Furthermore, the Lanchester equation does not factor in the opponent's efforts to keep from being killed such as armor, maneuver, fortifications or anti-weapons systems.

In essence, then, what the Lanchester equation states is: that all other variables being equal the army with the most men will win. While that is usually true (if nothing else, chance and probability will allow the smaller army to win some of the time) Lanchester simply ignores all the calculations that go into arriving at values for variables k_B and k_R . This is a much more complex problem; and one that T. N. Dupuy spent most of his life trying to analyze (see [below](#)).



An Alternative to the Lanchester Equation

The Lanchester Equations appear to be obvious and logical at first glance. “Lanchester's Linear Law is an equation of combat that relates to individual confrontations between soldiers where the outcome is dependent on the ratio of weapon efficiency (E) of the individual combatants and the combat strength of the army = E (number of troops). The outcome of the battle is the difference between the original troop numbers.”¹³

Now, consider the straightforward problem set forth in a college math class (**above**): two armies arrive on the battlefield; all things being equal the last man standing wins. The Red Army has 200 men; the Blue Army 150 men and, after 97.29 ‘turns’ the Lanchester Equation returns the result that the Red Army has 132.28756 men standing and the Blue army has been annihilated.

No doubt at some mathematical level this makes sense. However, there is no such thing as 97.29 turns in a battle anymore than there is such a thing as .28756 of a soldier. And, anyway, the whole proposition is absurd because armies do not stand up in front of each other and fire away until one army is utterly wiped out. And, last of all, every soldier in every army *does not have an equal probability of hitting a target as the man next to him*.

Consider this: is it possible for four men to defeat an army of a thousand? Yes, of course, if the four men are inside an M1A1 Abrams tank and the thousand are armed with spears. “Well,” the proponents of the Lanchester Equation might say,



The battle of Crécy (1346). A perfect Lanchester combat; two armies gamely walk towards each other and begin shooting - last man standing wins – at least in this contemporary painting.



The Last Men Standing (Bloody Lane, Antietam; picture by Gardener). The theoretical conclusion of a Lanchester Equation. However, the Confederate army was not annihilated at Antietam.

¹³ Drexel University's Lanchester Press Home Page (<http://mathforum.org/library/view/7065.html>).

“ k_B has a killing rate of 250 so it all works out mathematically.” But what if the four men are *outside* of the Abrams tank; what then?

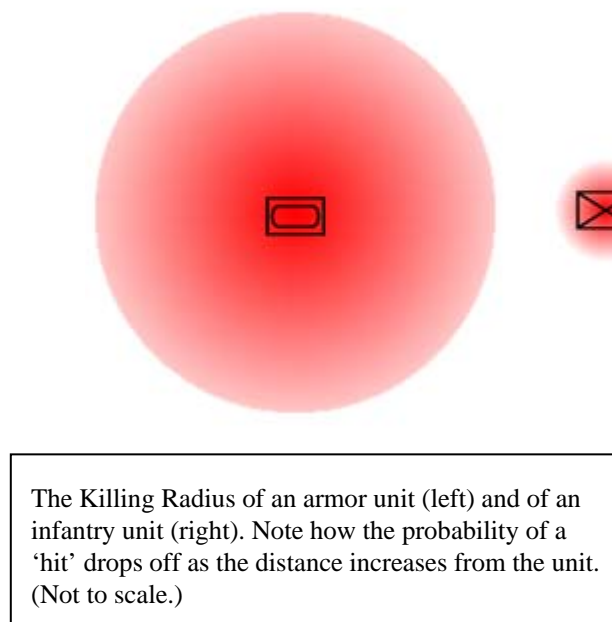
This is a very important point: the men do not have a killing rate of 250; individually or collectively. It is the Abrams tank that has the killing rate. It is the men that are servicing the weapon. It is the serviced weapon that has the killing rate of 250.

The Lanchester Equation is flawed because it is based on the killing rate of the individual soldier. Soldiers, individually or collectively, are just weapon platforms, or individuals servicing a weapon. It is the weapon that has the killing rate.

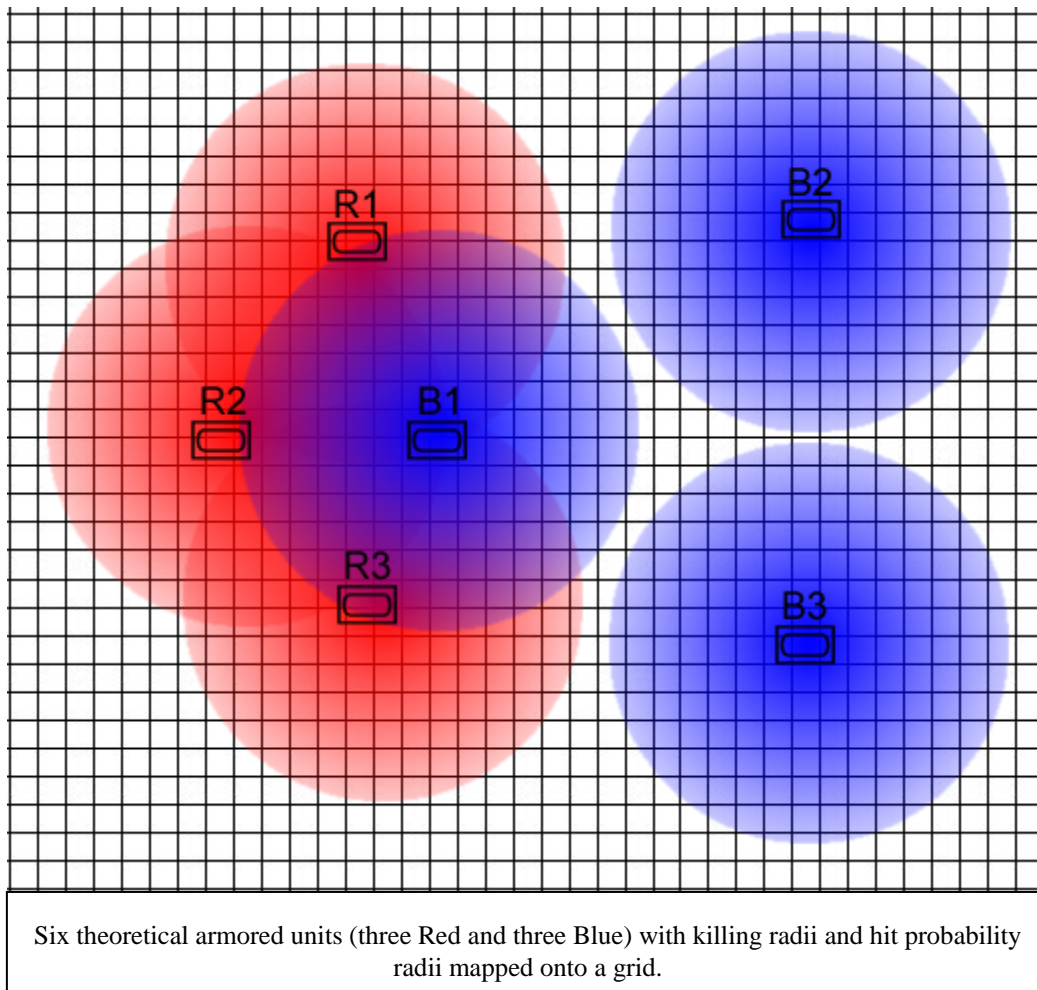
In other words, a *serviced* MIAI tank has an extremely high killing rate. An MIAI tank that is not serviced by people has a killing rate of 0. An Abrams tank crew, without tank, has a negligible killing rate.

It is the Lanchester Equation’s dependence upon “R” and “B”; i.e. number of troops in the respective armies, “at time t” that makes the equation meaningless. The number of troops is irrelevant. What matters is the killing rate of the serviced weapons in each army.

Let us consider two serviced weapons systems: an armor unit and an infantry unit. The probability of a hit for each serviced weapon system is inversely proportional to the distance of the target from the unit (see diagram below):



The graphic (below) represents mapping the Killing Radii for six armored units upon a grid (note that the effects of topography and terrain upon the units' Killing Radii are not taken into consideration in this example).



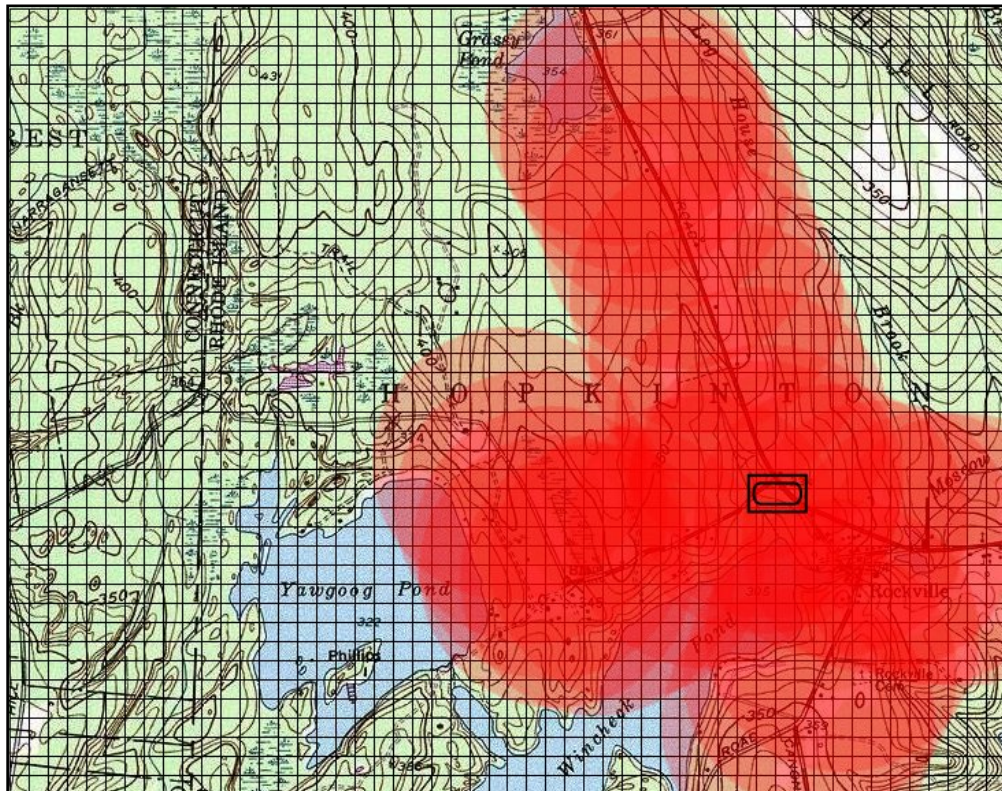
In the above example three Red armored units (R1, R2 and R3) are able to fire upon the Blue armored unit (B1). Blue armored units B2 and B3 have no bearing upon the combat resolution. This example graphically displays the basic flaw of the Lanchester equations: not all units in combat have an equal opportunity to inflict casualties.

If we were to now plot the killing radii / hit probability radii mapped on to a topographical map taking into consideration obstruction of elevation and plotting the results over time T it may look something like this (right):

Future research in this area ([click here](#)) will include the creation of a computer

program that automatically calculates and plots the killing radii / hit probability on terrain / topographic maps.

Superficially this method appears similar to influence mapping, however there are a significant number of differences (see [below](#)).



Theoretical killing radii / hit probability radii mapped over time T . Note that the armor unit travels faster along the road network and that the radii are obstructed by terrain elevation.

Influence Mapping

The new AI technique of “influence mapping” (Pottinger, 2000; Tozour 2001; Woodcock, 2002) is described by computer game AI researcher Penny Sweetzer (<http://www.itee.uq.edu.au/~penny/strategy.htm#Influence%20Maps>) as:

Each influence map's cells are a repository for some amount of data about the game world. Each cell is a database of relevant data for all the units and resources that occupy that cell. For example, the cells might contain:

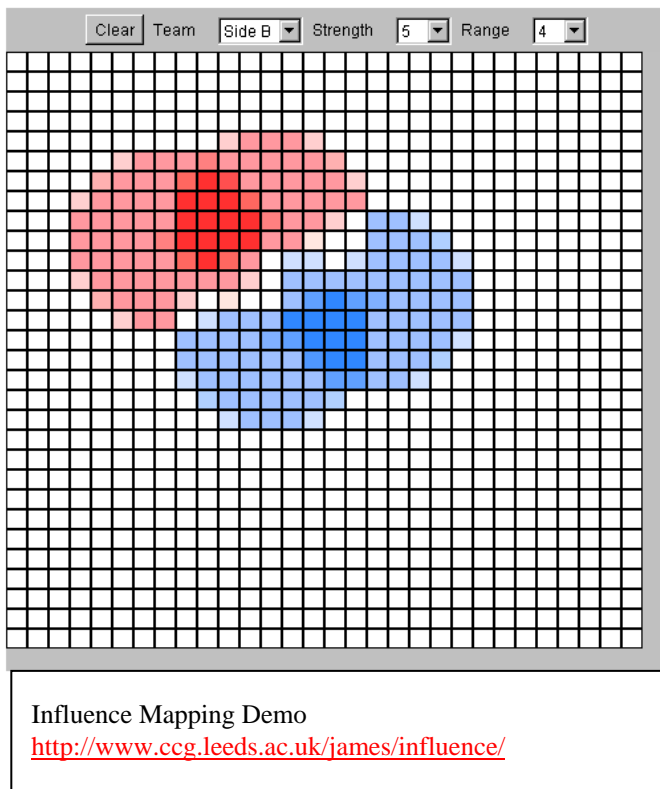
- combat strength (estimated combat effectiveness of the units currently in the cell)
- vulnerable assets (estimate of the value of a player's current assets in the cell)
- area visibility (indicates how long the area has been visible or invisible to the player)
- body count (indicates how many units have died in the cell in the past and when)
- resources (total resources still available for exploitation)
- passability (estimate of the difficulty of moving through the cell)

The influence map will typically track these variables separately for each player in the game, like multiple parallel influence maps. Each player maintains an influence map for itself and additional maps for its knowledge of every other player. This allows the AI to distinguish the separate strengths and weaknesses of specific opponents, or to combine any sets of friendly or enemy influences together. Alternatively, the game could keep a single influence map for everyone and let the other AI's access it, but with fog of war this is considered cheating and could lead to sub-optimal behaviour.

Once an initial value is calculated for each cell, then the value of each cell needs to be propagated to some number of nearby cells. This process is also referred to as “smoothing” or “blurring” as it has a lot in common with standard 2D image blurring techniques. This influence propagation gives a much more accurate picture of the

current tactical situation, as it not only shows where the units are and what they're doing, but also what they might do, the areas they potentially influence. Propagation is just a matter of spreading the influence of each cell to neighbouring cells using a "falloff rule" that determines how the influence of a given cell decreases with distance as it spreads across the map.

Influence Mapping Demo



An example of this influence mapping technique is shown here (left). Note, some of the major differences between influence mapping and the killing radii / hit probability radii proposed by the author above are:

1. In influence mapping Red and Blue forces negate each other creating "neutral areas" between units. In killing radii / hit probability radii mapping all values are cumulative.
2. In influence mapping "neighboring cells using a 'falloff rule'" while in killing radii / hit probability radii mapping actual values are calculated as well as the effects of intervening objects (Line of Sight or LOS).
3. Influence mapping does not actually calculate areas that can be reached by a unit in time T ; rather it uses the "falloff rule" to "guesstimate" where a unit can travel in time T .

An interesting article on the use of influence maps with Quake Bots can be found here:

http://www.cyd.liu.se/~bjoli035/botepidemic/aid/cgf/design_terrain_ranking.shtml.htm.

Future Research

The author intends to create, by a series of progressive steps, a computer program that:

1. Calculates and displays the killing radii / hit probability radii for different weapons platforms mapped on to topographical maps.
2. Calculates and displays the killing radii / hit probability radii for different weapons platforms mapped on to topographical maps over time T .
3. Uses these calculated radii to arrive at a human level strategy employing MiniMax and other methods.

In conclusion the author believes that this research will lead to refutation of the Lanchester Equations and Clausewitzian principles of strategy.

Bibliography & Readings

Masters of War: Classical Strategic Thought; Michael I. Handel; Frank Cass, Portland, Oregon (1992).

Handel is a professor of strategy at the U. S. Naval War College. In this book he compares and contrasts the writings of Sun Tzu and von Clausewitz (with a bit of Jomini thrown in for good measure).

Traditionally, Sun Tzu and von Clausewitz are considered to be contradictory but Handel asserts that that is not always the case (see tables below).

The essence of Clausewitzian strategy is that battle is not only necessary but the “most effective means of achieving the political goals of the state.” Indeed, Clausewitz’s famous quote, “War is regarded as nothing but the continuation of state policy with other means,¹⁴” has been one of the great axioms of military and political thought for almost two hundred years.

Sun Tzu considers forces meeting upon the battlefield a measure of only the last resort.

¹⁴ Karl Von Clausewitz, *On War*, trans. O. J. Matthijs Jolles, author’s note, p. xxix (1943). Originally published in 1833.

TABLE 2.1
SUN TZU AND CLAUSEWITZ AS OPPOSING
PARADIGMS OF WAGING WAR

	<u>Sun Tzu</u>	<u>Clausewitz</u>
THEIR PERSPECTIVES ON WAGING WAR	A <i>broad</i> perspective that includes a large variety of non-military means (e.g., diplomatic, economic, and psychological).	A <i>narrow</i> emphasis on the use of military means. Although the importance of other means is recognized, they are not the concern of the military leader.
THE ROLE OF FORCE	Force should be used sparingly and as the last resort.	The use of force is often both necessary and the most effective (i.e., preferred) method of achieving the political goals of the state. The maximum available force should be used from the outset to achieve decisive results in the shortest possible time.
THE IDEAL VICTORY	The greatest achievement is to win without fighting, to convince the enemy's forces to yield and if possible switch sides rather than be annihilated.	The shortest way to achieve one's political objectives is by the destruction of the enemy's forces in a major battle. (The principle of destruction.) Other, non-military methods of winning are recognized but are rarely effective.
PREFERRED METHOD OF WINNING	Extensive use of deception. Psychological war, non-violent methods. The center of gravity is the enemy's will and alliance system.	The maximum concentration of force at the decisive point of engagement. The center of gravity is the enemy's army.
ADVANTAGES AND DIS-ADVANTAGES OF THE THEORY	An idealized paradigm encouraging the strategist to achieve the least costly victories. This approach may lack realism and ignores the inevitable presence of violence in war. War can become an 'intellectual' or 'metaphysical' exercise. Deception or intelligence can become a 'panacea'.	Realistic; relevant for most types of war. Greater awareness of the material and violent nature of war. Excessive reliance on the use of force can be more costly; may underestimate some non-material aspects of war (e.g., deception, intelligence).

TABLE 12.1
SUN TZU, CLAUSEWITZ AND JOMINI COMPARED: COMMAND AND CONTROL, THE ROLES OF INTELLIGENCE, SURPRISE, DECEPTION, AND FORECASTING IN WAR

	SUN TZU	CLAUSEWITZ	JOMINI
Intelligence discussed	<ul style="list-style-type: none"> • <i>On all levels of warfare</i> 	<ul style="list-style-type: none"> • Primarily on the operational level and on the battlefield 	<ul style="list-style-type: none"> • <i>On strategic but primarily on higher operational level</i>
Attitude toward Intelligence	<ul style="list-style-type: none"> • <i>Positive; optimistic</i> • <i>Reliable intelligence can be obtained and is a major key to success in war</i> • <i>Very useful</i> 	<ul style="list-style-type: none"> • Negative, pessimistic • Intelligence is mostly unreliable, rapidly becomes obsolete, is a form of friction, makes a limited contribution to success in war • Useless 	<ul style="list-style-type: none"> • <i>Very positive attitude; cautiously optimistic. Intelligence can be properly analyzed, corroborated, and confirmed as a basis for planning and action</i> • Useful
Main sources of intelligence	<ul style="list-style-type: none"> • <i>Spies and observers</i> 	<ul style="list-style-type: none"> • Direct contact with the enemy • Commander's direct observations 	<ul style="list-style-type: none"> • <i>Spies, prisoners of war, logic, and systematic analysis</i> • <i>Balloons, special reconnaissance troops</i>
The possibility of making rational decisions and forecasts	<ul style="list-style-type: none"> • <i>Rational, carefully calculated plans can be made on the basis of reliable intelligence</i> • <i>Forecasting is possible, and careful planning is an important key to victory</i> 	<ul style="list-style-type: none"> • War is dominated by friction, chance, and uncertainty • Therefore, although every effort should be made to make rational decisions and prepare plans, they cannot be relied upon • Forecasting in war is next to impossible • The intuition of the commander is as important as rational calculations 	<ul style="list-style-type: none"> • <i>Rational and successful planning can be based on good intelligence</i> • <i>Familiarity with the principles of war makes decisions more rational, reduces friction and makes success more likely</i> • <i>Friction and chance can not be ignored</i> • <i>The intuition of the commander is important for the implementation of plans</i> • <i>Forecasts can be made and are useful even if not perfect</i>
Command and Control	<ul style="list-style-type: none"> • <i>Difficult but possible on local tactical level</i> 	<ul style="list-style-type: none"> • Very difficult if not impossible on tactical and operational level 	<ul style="list-style-type: none"> • <i>Difficult but not impossible on operational level if carefully prepared</i>
Deception and surprise	<ul style="list-style-type: none"> • <i>Deception is the basis for all successful operations</i> • <i>It is the weapon of choice</i> • <i>Surprise can be achieved and is key to success</i> 	<ul style="list-style-type: none"> • Deception is a waste of time, and of doubtful value • It is a weapon of the last resort • Surprise is impossible to achieve on the higher levels of war 	<ul style="list-style-type: none"> • <i>Deception is unimportant</i> • <i>Surprise is impossible to achieve on the higher levels of war</i>
Key to success in war in light of the value of intelligence	<ul style="list-style-type: none"> • <i>Make the utmost effort to obtain reliable intelligence</i> • <i>Base all planning on intelligence, and make extensive use of deception</i> • <i>Conversely, make the greatest possible effort to deny intelligence to the enemy</i> 	<ul style="list-style-type: none"> • Since intelligence is unreliable, field the largest possible force and keep your forces concentrated • Make use of the commander's intuition • By maintaining the initiative create uncertainty, (i.e., an intelligence problem for the enemy) • Shift the burden to the enemy 	<ul style="list-style-type: none"> • <i>Make every effort to obtain the best possible intelligence but remember that it is not perfect</i> • <i>Base your plans on the correct principles of war, always concentrate the largest possible force, and keep a force in reserve to meet unexpected situations</i>
Problems	<ul style="list-style-type: none"> • <i>Excessive reliance on intelligence, and deception which can become a panacea</i> • <i>Friction is underestimated, and the value of plans overestimated</i> 	<ul style="list-style-type: none"> • Ignores the possible value of intelligence and deception • Excessive reliance on the intuition of the Commander and on brute force • Assumes too little control over events 	<ul style="list-style-type: none"> • <i>A modern, balanced and realistic approach</i> • <i>Relies too much on the correct identification and application of the principles of war</i>

A Brief History of Computers & Wargaming; D. Ezra Sidran (1996)

(Hard copy attached.) This article in commercial wargaming publication briefly describes the history of wargaming and the very first commercial computer wargames.

The Complete Wargames Handbook; James F. Dunnigan; Quill, New York (1992)

James Dunnigan is an authority on wargaming, having designed a number of groundbreaking board simulations (*Jutland, 1914*, etc.) and is a frequent guest on CNN and Fox as a military commentator. He is also the moderator of the 'milgames' email list serv.

I met Jim Dunnigan at a conference at the Air Force Wargaming Center and he has frequently been very generous with his time offering critiques and suggestions of my work over the years.

The Art of Wargaming; Peter P. Perla; Naval Institute Press, Annapolis (1990)

Perla teaches at Annapolis. Traditionally, the U. S. Navy has been in the forefront of supporting wargaming and its practical lessons. The two pictures of early wargame sessions at Annapolis are from Perla's book. I met Dr. Perla at a conference at the Air Force Wargaming Center and he has been very gracious with his time and helped provide copies of the artwork that appears on page 6.

Summary of the Art of War; Emil Schalk; J. B. Lippincott & Co., Philadelphia (1862)

The graphic on page 5 is from this amazing book written as a “self-study” for uneducated volunteer officers created at the beginning of the American Civil War. This book offers practical advice though most of the military theory would be far beyond the scope of anything that a volunteer officer would likely encounter.

Realistic Evaluation of Terrain by Intelligent Natural Agents (RETINA); René G. Burgess; (2003)

LTC Burgess’ master thesis (available on this disk from the above hyperlink) proposes that fluid mechanics can be successfully employed to evaluate terrain and for pathfinding in military models and simulations. I met LTC Burgess at a conference this year at the Woodrow Wilson Institute for Advanced Scholarship and he and I have been corresponding. LTC Burgess is currently at the Army War College.

Decision Information; Edited by Chris P. Tsokos, Robert M. Thrall; Academic Press, New York (1979)

This is a collection of essays and papers that came out of the U. S. Air Force Office of Scientific Research workshops at the Decision Information for Tactical Command and Control in Virginia.

Even though these papers are over 20 years old they introduce some ideas that are still relevant today including:

- The Use of Fuzzy Sets in the Analysis of Military Command (Dockery)
- Man-Machine C³Simulation Studies in the Air Force (Topmiller)
- Decision Support in a Battlefield Environment (Modrick)

- Desired Features for Modeling Command, Control and Information (Robinson)
- A Summary Description of the Vector-2 Theater Level Campaign Model (Bonder)

There is also an attempt to modify the Lanchester Equation (Stochastic Combat Modeling – Lanchester’s First Law; Schultz and Tsokos).

Contemporary Strategy: Theories and Concepts (Second Edition); John Baylis, Ken Booth, John Garnett, Phil Williams; Holmes & Meier, New York (1987)

This collection of essays primarily deals with Nuclear Deterrence and Arms Control though there are chapters on:

- The Role of Military Power (Garnett)
- Technology and Strategy (Garnett)
- Limited War (Garnett)
- Revolutionary Warfare (Baylis)

Strategy: The Logic of War and Peace; Edward N. Luttwak; Belknap Press; Cambridge, Mass. (2001)

Luttwak writes, “Because the logic of strategy at the theater level relates military strength to territorial space, we can understand much of it in visual terms, examining forces and their movements in a bird’s eye view, or perhaps one should say in a satellite overview. Of course strategy has a spatial aspect at every level, but at the tactical level is the detailed nature of the terrain that matters, while the combat encounters of the operational level could be much the same in any number of different geographical settings. At the theater level, however, some *specific* territory is the very object of the struggle.” – page 138.

Luttwak is a disciple of Clausewitz and as such I disagree with some of his basic assertions. The object of any armed struggle is not “some specific territory”; rather it is the enemy’s ability to wage war (i.e. the elimination of enemy combatants). A case in point: the “coalition forces” easily occupied Iraq (a specific territory) but because they did not eliminate the enemy’s ability to wage war conflict continues well after a year after the pronouncement of victory.

[Aggregated Combat Models; Operations Research Department; Naval Postgraduate School; Monterey, California \(2000\)](#)

This paper is on this disk and is available by Control-clicking on the above hyperlink.

This paper is an overview of current Combat Models used by U. S. military. They include:

- Regular Grid Terrain Models (FOURCE, ICOR, JTLS)
- Combat Sector Terrain Models (ATLAS, IDAGAM, VECTOR-2)
- Force Ratio Attrition Models

Chapter five covers the Lanchester Equations and attempts to modify and update the equations.

[Describing Rates of Interaction Between Multiple Autonomous Entities: An Example Using Combat Models; M. K. Lauren; Defense Technology Agency, New Zealand Defense Agency; \(2001\)](#)

This paper is on this disk and is available by Control-clicking on the above hyperlink.

Lauren writes, “This paper endeavors to show how methods such as cellular automaton models and fractal equations can replace differential equations as

methods for addressing real world problems. The origin of this work is in the area of military analysis, specifically, estimating combat losses.” He then discusses the Lanchester Equations and concludes, “... the Lanchester equations make a number of gross assumptions, in particular, that all the battlefield entities are homogenous and evenly distributed. Such an equation is virtually useless in many modern scenarios, where the battlefield is often much more dispersed and likely to exhibit spatial and temporal correlations of deployments.”

Lauren is attempting to model “Mogadishu like” scenarios and has constructed a program, MANA, as a test bed. A screen shot from MANA is below:

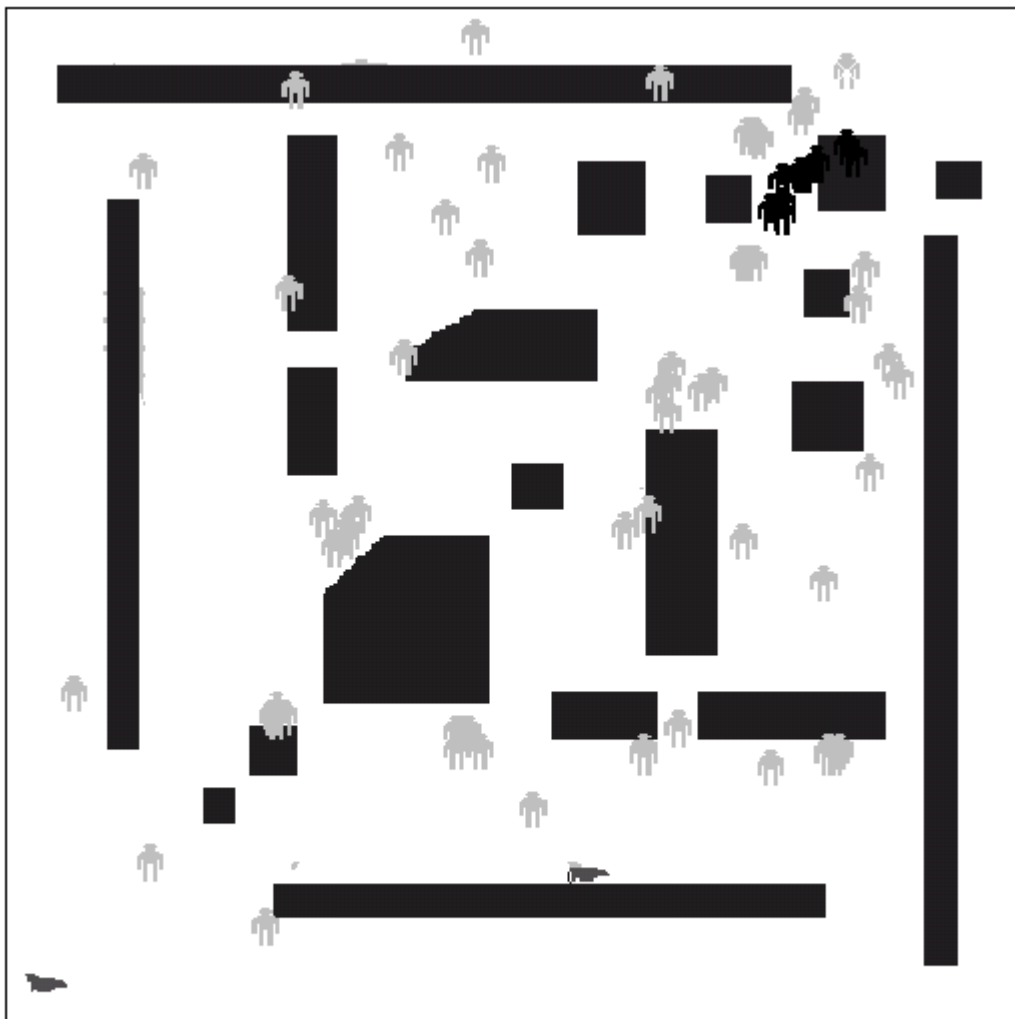


Figure 1: Screen shot of the MANA model scenario analyzed.

The Value of Information in War: Some Experimental Findings; Jan Kuylenstierna, Joacim Rydmark and Tonie Fahraeus; (No year given).

This paper is on this disk and is available by Control-clicking on the above hyperlink.

The authors conclude, "... the results show that as the absolute level of uncertainty increases, the value of having information superiority as well as the value of having superior strength decreases, whereas the value of having tempo superiority remains unaffected. Two conclusions are drawn. The first is that information superiority may be best created at lower levels of command where uncertainty is at its lowest. The second is that because uncertainty probably will continue to be a problem in war, tempo superiority may be a more viable alternative than information superiority or superior strength for winning."

In the information vacuum before the Wilderness campaign U. S. Grant was confronted by subordinate officers that were concerned about what their opponent, Robert E. Lee, was up to. Grant replied, "Oh, I am heartily tired of hearing about what Lee is going to do. Some of you always seem to think he is suddenly going to turn a double somersault, and land in our rear and on both of our flanks at the same time. Go back to your command, and try to think what we are going to do ourselves, instead of what Lee is going to do." In other words, when an army makes aggressive offensive moves (or has "tempo superiority" – a term taken from chess theory) the enemy must respond to your strategy and knowledge of the enemy's plans becomes almost irrelevant.

Arms and Artificial Intelligence: Weapons and Arms Control Applications of Advanced Computing; Edited by Allan M. Din; Oxford University Press; (1987)

This book is a collection of papers discussing the potential for the use of AI in military applications. Most of the articles cover the subject of robotic weapons though “Part III: Military and strategic implications” introduces “the strategic computing plan” and DARPA’s long range goals that eventually became BattleSpace XXI, Force XXI and the ‘digitization’ of the U. S. Army.

Digital War: A View from the Front Lines; Robert L. Bateman, Editor; Presidio Press; Novato, Ca; (1999)

This book is a collection of papers discussing implementing many of the subjects first introduced in Din’s book, “Arms and Artificial Intelligence: Weapons and Arms Control Applications of Advanced Computing” (above). The articles are primarily concerned with Command and Control, Intelligence and, to a lesser degree, training; especially of National Guard units.

Concept, Algorithm, Decision; V.V. Druzhinin, D. S. Kontorov, Moscow; (1972)

This is a fascinating book written in 1972 for the Russian military. Shortly after publication it was translated and reprinted by the U. S. Air Force. The authors, Druzhinn and Kontorov outline the basic concepts of constructing a military AI or decision making algorithm even though – not unlike Turing in “On Computing Machines” – they did not have the ability to actually write such programs.

“Chapter 5: Operational Decisions” is especially interesting and puts forth the ideas applying minimax strategies, strategies of minimum mean risk and the strategies of tolerable risk to operational decisions.

The book follows an algorithm format and does not contain any actual computer routines nor even suggests how they could be written.

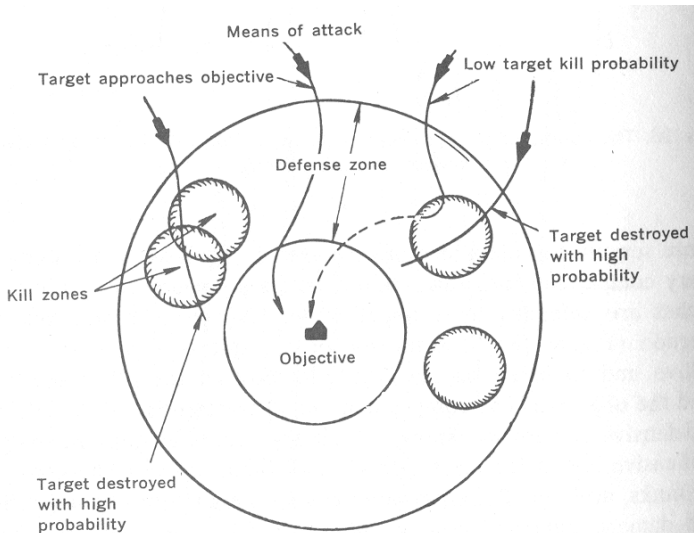


Figure 18. Diagram of a war game for a heuristic program.

The diagram (left) describes a theoretical heuristic program in which an objective, “...whose approaches are defended by a ringed system having a certain radius of destruction. The mission of one side is to penetrate to the objective and to inflict damage, and the task of the other side it to defend the objective. ...The criterion of effectiveness (price of competition) is the damage inflicted upon the objective, which is considered to be proportional

to the number of offensive systems that penetrate the defense; the price is the same for both sides with respect to magnitude and is opposite with respect to sign. The probability of destruction of offensive systems that penetrate the defense depends on basic factors, as follows:

- Increases as overlapping of the zones of destruction increases;
- Increases as the distance to the center of the zone of destruction decreases;
- Decreases as the curve of the route inside the zone of destruction increases as;
- Decreases as the number of offensive systems simultaneously located in the same zone of destruction increases.

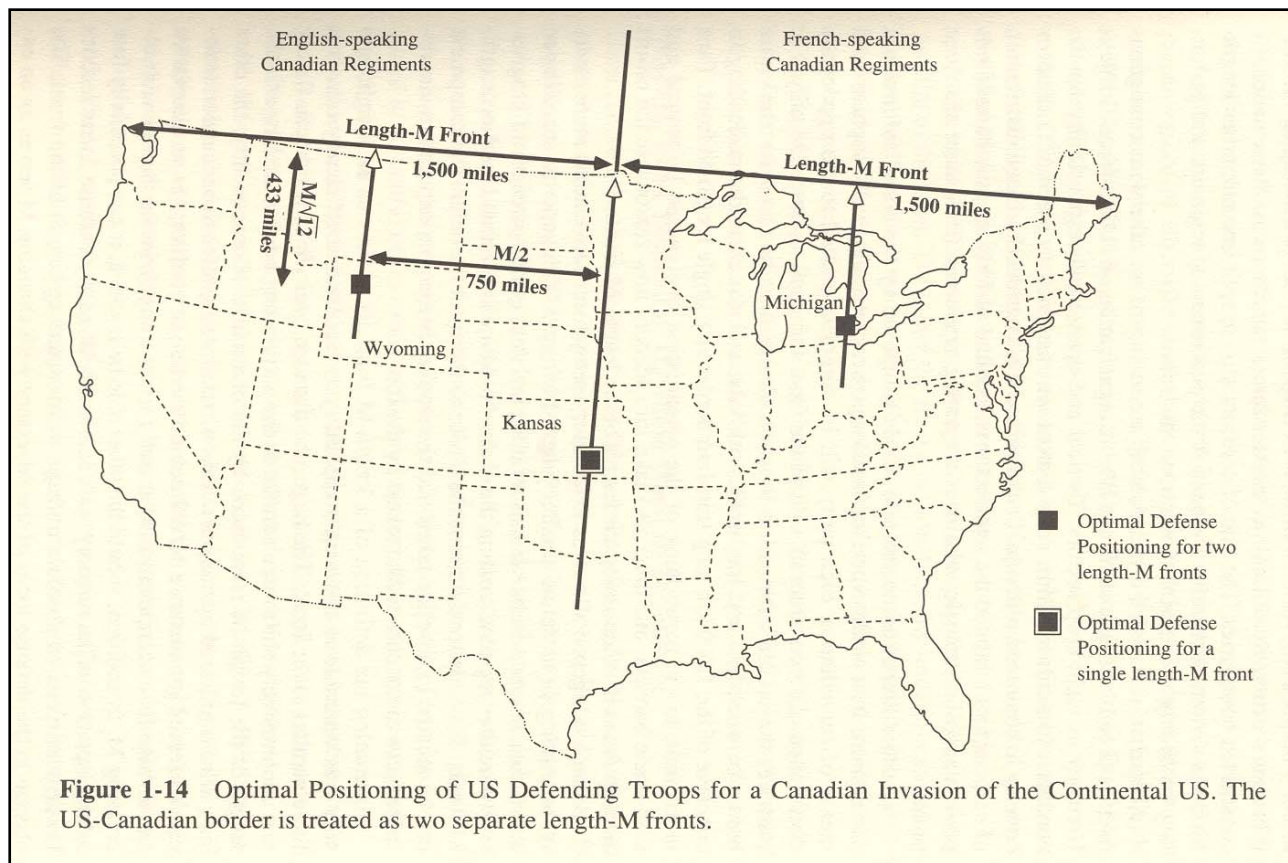
... The strategies of the attacking side are concentration of forces and maneuvering. The strategies of the defending side consist of concentrating their forces.” –pp. 106-107.

I found myself in agreement with the above passage and was surprised to discover that it paralleled my own theories outlined [above](#) (even referring to units as ‘systems’ and the concept of ‘zones of destruction’). I can only assume that further

research was not carried out on this because of the state of computer science and hardware available at this time in the Soviet Union.

Defense Positioning and Geometry; Raj Gupta; The Brookings Institution; Washington, D. C. (1993)

This book takes the Lanchester Equations to their ultimate conclusions. It presupposes that military forces are homogenous (an absurdity) and applies geometry to determine 'optimal' positioning of defensive units while completely ignoring terrain and other important variables.



This figure (from page 69) demonstrates the theoretical 'Optimal Defense Positioning' points for a Canadian Invasion of the Continental United States. Even an extremely poor military theorist would see that the Michigan peninsula is the

worst possible place to position a defensive force: it is completely cut off from sending troops to the Northeast (the Great Lakes are in the way) or to the Midwest (again the Great Lakes intervene). Gupta's algorithm also indicates that the middle of Wyoming is the key defensive position in the West. This, of course, is utter nonsense. Gupta also completely ignores the crucial road net (sadly lacking in Wyoming) which is the key to a non-static defense; as well as the intervening Rocky Mountains.

The War Game: A Critique of Military Problem Solving; Garry D. Brewer, Martin Shubik; Harvard University Press; Cambridge, Mass. (1979)

Martin Shubik, of course, is an important figure in the history of Game Theory. He is the co-author of The Shapley-Shubik Index¹⁵ used in calculations of weighted voting games (such as the Electoral College).

This book is primarily an overview of the history of wargames and also discusses the work done by the RAND Corporation (see chart below, top) and the Research Analysis Corporation (see chart below, bottom) on this subject.

These 'genealogical charts' of the history of wargames and game theory, to the best of my knowledge, are unique.

¹⁵ "The Shapley-Shubik index is the probability that i swings (or is "pivotal" in the terminology of Shapley and Shubik) if all *orderings* of players are equally likely. Thus, given a particular swing for a member, the index is the number of orderings of both the members of the coalition T_i and the players not in T_i relative to the number of orderings of the set of all players N : every reordering is counted separately. The index is the probability of a swing for the player within this probability model." - Computing Power Indices For Large Voting Games; Dennis Leech, University of Warwick <http://www2.warwick.ac.uk/fac/soc/economics/research/papers/twerpleech.pdf>

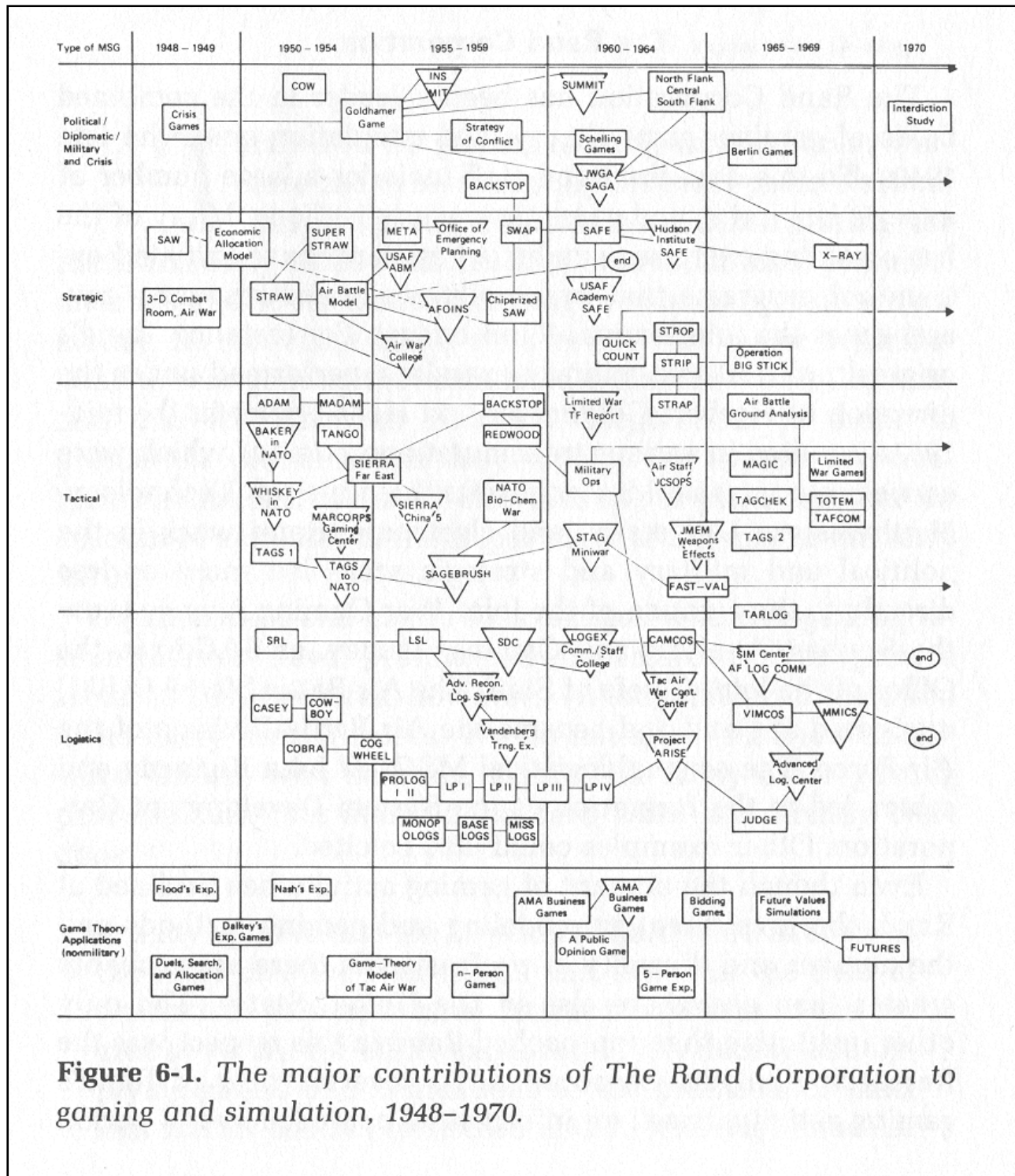
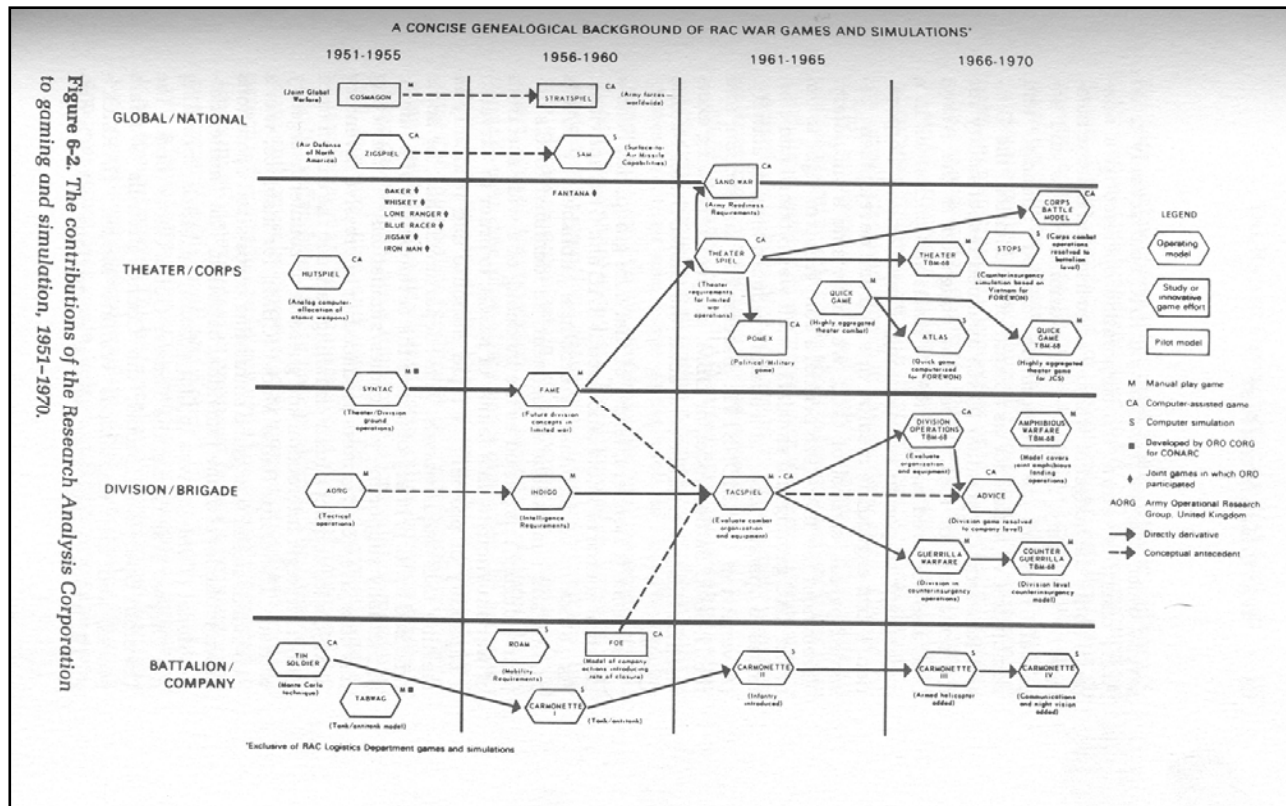


Figure 6-1. The major contributions of The Rand Corporation to gaming and simulation, 1948–1970.



Above charts are from page 60 and page 67.

Unfortunately the authors make the same dreaded turn down the valley of the Lanchester Equations which they assume must form the foundation of any future work in computer modeling.

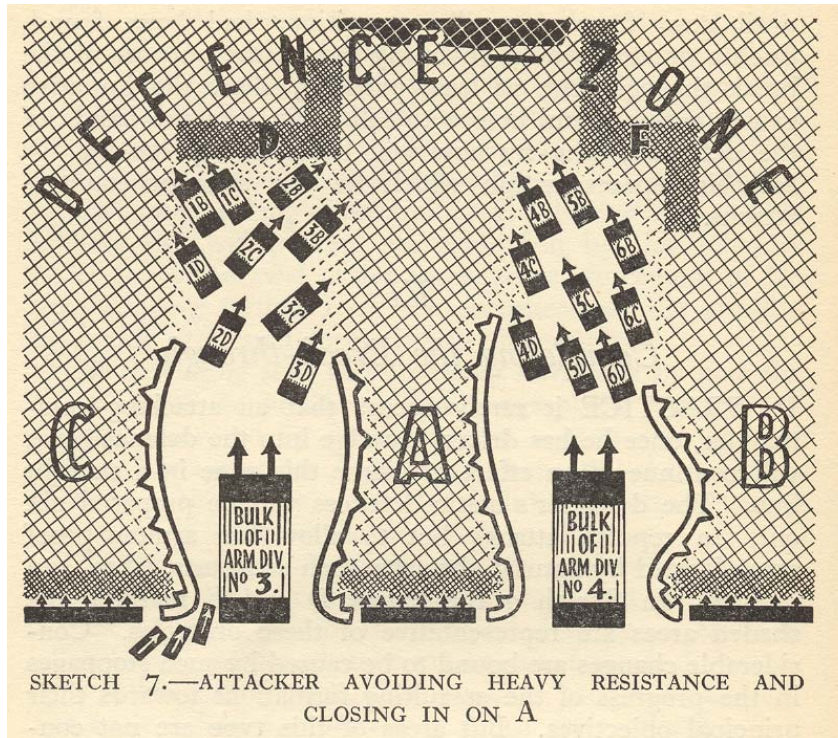
Analysis for Military Decisions: The RAND Lectures on Systems Analysis; Edited by Edward S. Quade; Rand McNally, Chicago; (1966)

This book is a collection of lectures given almost forty years ago. Computers are mentioned as a method for implementing wargames sometime in the future.

Moltke, Schlieffen and Prussian War Planning; Arden Bucholz; Berg Publishers; Oxford; (1991)

This book describes both the board wargames and operational wargames used by the Prussian General Staff in the 19th and 20th centuries. It was the Prussian General Staff's use of wargames that added an air of legitimacy to wargames and encouraged their introduction in the U. S.; especially at the Naval War College.

Landmarks of Modern Strategy; W. E. Hart; Methuen & Co. ; London; (1942)



This slim volume (only 116 pages) describes the revolution in modern strategy and tactics of the armored breakthrough (the German *blitzkrieg*).

These methods have been employed continuously since 1939 and are virtually indistinguishable from the strategy and tactics used in the current Iraq war (note the isolation and avoidance of “islands of heavy resistance”. In Iraq this caused problems with the

vulnerability of supply lines that were necessary for fueling the advancing armored columns.

Dimensions of Strategy; Edited by Jayantunja Bandyopadhyaya, Arun Kumar Banerji, Sujay Basu, Ananda Deb Mukherjee; Minerva; Calcutta, (1989)

This book is a collection of essays written by Indian theorists and obviously directed towards theory of past and future Pakistani conflicts. Game Theory is introduced as a model for bargaining and nuclear deterrence models.

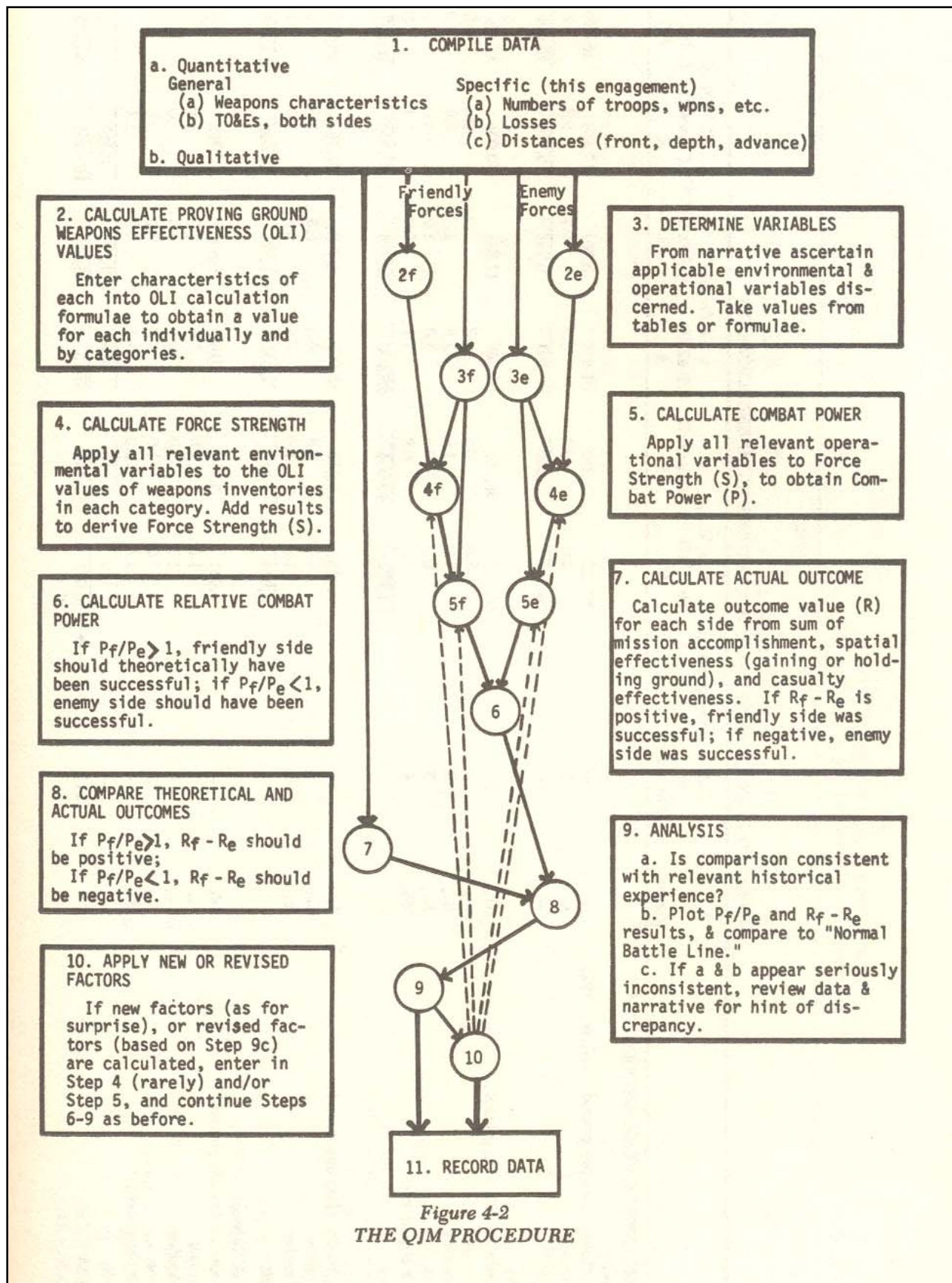
Understanding War: History and Theory of Combat; Trevor N. Dupuy; Paragon House; New York; (1987)

Numbers, Predictions & War: The Use of History to Evaluate and Predict the Outcome of Armed Conflict; Trevor N. Dupuy; Hero Books; Fairfax, Va.; (1985)

Colonel Dupuy is a bit of a legend in the wargaming and military analysis community. He is the author of the “Quantified Judgment Method of Analysis” (QJM) and the founder of The Dupuy Institute (online site here: <http://www.dupuyinstitute.org/>).

Dupuy graduated from West Point in 1938. During WWII he was assigned to Burma which, unfortunately, became something of a career cul-de-sac for a number of talented officers like Joe Stillwell. After the war he was assigned to the War Department General Staff but never rose to prominence like officers that had served in the European Theater. He was a founding member of the Harvard Defense Studies Program in the 1950s and, after retirement from active duty, became a professor of Military Science and Tactics there. He wrote numerous books on military analysis, which he was kind enough to autograph for me when we met at the U. S. Air Force Wargaming Center in May, 1993. Dupuy died in 1995.

Dupuy's QJM is a direct descendant of the Lanchester Equation (though Dupuy would argue the point; see "The QJM and the Lanchester Equations" [below](#)).



“THE QJM AND LANCHESTER’S EQUATIONS

Interestingly; there is reason to believe that, despite their totally different approaches to combat analysis the QJM and the famous Lanchester Equations are fundamentally compatible with each other.

First, let's look at a layman's explanation of the relatively simple, but mathematically sophisticated, Lanchester Equations.

In essence, the Lanchester Equations show the loss rates of two opposing sides under two general conditions of combat: (a) when one or both of the sides have only a general knowledge of the location of the other (as in a meeting engagement, or as in the case of an attacker against defenders concealed behind prepared or fortified defenses; and (b) when one or both sides have accurate information of the location of the other (as, for instance, a defender in most prepared and fortified defense situations, or two forces opposing each other on a broad, flat desert).

These two conditions of combat were expressed by the late- Frederick William Lanchester in 1914 in two sets of differential equations,; which are shown in Figure 10-1 in their very simplest formulation. The Linear Equation (or “Law”) shows the rate of change of each force with respect to-time (in other words, the effect of casualty attrition), as a constant times the product of the two opposing forces. The Square Law shows the rate of change as a constant times the strength of the opposing side—the side that has the advantage of observation. (A stands for Attacker, D for Defender.)

Figure 10-1.
THE LANCHESTER EQUATIONS IN BRIEF

Linear Law:	$dA/dt=kDA$ $dD/dt=k,AD$	Opposing sides know only general locations of targets
Square Law:	$dA/dt=KD$ $dD/dt=K'A$	Opposing sides know precise locations of targets
General Formulation	$dD/dt=CAD\gamma$ $dA/dt=C'DA\gamma$	Linear Law, $\gamma=1$; Square Law, $\gamma=0$

Some years ago Dr. Daniel Willard did a study to test the validity of the Lanchester Equations (“Lanchester as a Force in History: An Analysis of Land Battles of the Years 1618-1905”) against the best military historical database then available, a massive book called the *Kriegslexicon*, by an Austrian historian named Gaston Bodart. This is a compilation of data of some 1,500 battles stretching from the Thirty Years War, in the

early 17th Century, through the Russo-Japanese War, in the early 20th Century; it has never been translated into English. Willard decided to use this data to test his thesis that every battle is made up of a number of small combats, some of which involve Lanchester's Square Law, and some the Linear Law. Furthermore, in a data base like Bodart's, there would be such a cross section of battles that there would be some in which the Square law predominated, and some in which the Linear Law predominated. So Willard made a general formulation of the Linear and Square Laws, as shown in Figure 10-1, in which we have the Linear Law when Gamma equals 1, and the Square Law when it equals 0. He postulated that (if his reasoning was correct) by consolidating the data for Bodart's 1,500 engagements, he should end up with a mixture of Square Law and Linear Law results, so that Gamma would be somewhere between 1 and 0. Hopefully the value of Gamma might be close to the middle, some nice simple value like 0.5.

When Willard consolidated the Bodart force strength data in his computer program, he got a result between -.27 and -.87, clustering around -.5.

This led him to the conclusion that either the Lanchester Equations do not apply to historical combat, or the casualty producing power of a force increases as its size decreases; or in other words, a force grows stronger as it incurs casualties. This alternative did not impress him with its logic, and so he decided that the Lanchester Equations could not be supported by historical data.

More recently Dr. Janice Fain decided to make another attempt to relate the Lanchester Equations to historical data. She reasoned that Willard's unsatisfactory results might have been due to his data. In the first place, the Bodart data did not include any modern combat, and covered a wide range of tactics and combat circumstances. Second, the Bodart data was not necessarily reliable or verifiable from other sources. She decided to use modern war data, and also to use the most reliable data she could find—HERO's 60 Engagement Data Base of World War II combat in Italy. She also made some relatively minor refinements in Dr. Willard's mathematical methodology, but used fundamentally the same approach.

Dr. Fain's results were just as disappointing as Dr. Willard's and remarkably similar. Her results were between -.59 and -.41, also clustering around -.3. The conclusions could only be identical to Willard's.

Then Dr. Fain remembered what I had been saving for several years about the fact that force ratios are meaningless unless they represent interaction with the variables of combat. So, she went through her exercise again, but instead of using either the numerical values or the firepower values of the opposing forces to arrive at the force ratio, she took as ratios the Combat Power Potential ratios (P/P) HERO had calculated with the QJM, in which all discernible variables of combat were considered.

As the result of this second effort, Dr. Fain got a Gamma value of +.47, right in the area that she and Willard had been seeking from outset. This leads to the conclusion that the Lanchester equations provide reliable casualty rates only when combat power values for opposing forces reflect the variables of combat, as formulated in HERO's QJM.

What Dr. Fain had done, of course, was to apply the Lanchester Equations to the kind of simple conflict relationships for which Lanchester originally designed them, since the QJM ratio of P/P is, in effect, overall summation of the relative combat power of the opposing forces reflecting all of the identifiable combat variables influencing a given engagement.

This does not necessarily prove the validity either of the Lanchester Equations or of the QJMA. But it does show an interesting convergence between these two very different approaches to a representation of combat, one theoretical and one empirical. Above all, it demonstrates the significance of considering the variables of combat when attempting to analyze anything like a force ratio."

- From "Numbers, Predictions & War", pages 148-150.

TABLE 1. TERRAIN FACTORS (r)						
Terrain Characteristics	Mobility r_m	Defense Position ¹ r_d	Infantry Weapons ² r_i	Arty ³ r_{ag}	Air r_{ay}	Tanks r_{at}
1. Rugged— Heavily Wooded	0.4	1.5	0.6	0.7	0.8	0.2
2. Rugged— Mixed (or extra rugged—bare)	0.5	1.55	0.7	0.8	0.9	0.4
3. Rugged— Bare	0.6	1.45	0.8	0.9	0.95	0.5
4. Rolling— Heavily Wooded	0.6	1.35	0.8	0.8	0.9	0.6
5. Rolling— Mixed	0.8	1.3	0.9	0.9	0.95	0.8
6. Rolling— Bare	1.0	1.2	1.0	1.0	1.0	1.0
7. Flat— Heavily Wooded	0.7	1.1	0.8	0.9	0.9	0.7
8. Flat—Mixed	0.9	1.2	0.9	1.0	0.95	0.9
9. Flat—Bare, hard	1.05	1.05	1.0	1.0	1.0	1.0
10. Flat Desert	0.95	1.18	1.0	1.0	1.0	1.0
11. Rolling Dunes	0.3	1.4	1.0	1.0	1.0	0.6
12. Swamp— jungled	0.3	1.4	0.6	0.8	0.8	0.2
13. Swamp— mixed or open	0.4	1.3	0.8	0.9	0.95	0.3
14. Urban	0.7	1.4	0.8	0.9	0.9	0.7

¹ For all defense postures; Attacker is always 1.0.
² Applied to small arms, machine guns and other infantry weapons; also to antitank weapons.
³ Also applies to air defense weapons.