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War Games:
Simulating Collins' Theory of Battle Victory

Jesse B. Fletcher, Jacob Apkarian, Anthony Roberts, Kirk Lawrence, Christopher Chase-Dunn, and Robert A. Hanneman
University of California, Riverside

Collins' recent theory on battle dynamics is converted into a system of interconnected equations and simulated. Between evenly matched armies, initial advantages are shown to be difficult to overcome due to the numerous reinforcing pathways throughout the model. Morale advantages are shown to lead to quick victories, while material advantages lead to longer wars often won through attrition. A simulation of the Civil War is provided that appears to coincide with historical reality. The implications of these simulations for Collins' broader theory are briefly discussed.

Introduction

Randall Collins' (2010) recent publication in *Cliodynamics* ("A Dynamic Theory of Battle Victory and Defeat") provides a new sociological theory of how battles (and by extension, wars) are won and lost. His theory has implications for military effectiveness, geopolitics, history, and the broader study of conflict in sociology. In conjunction with his 2008 book *Violence*, this publication furthers his attempt to unify his earlier passion for conflict sociology with his later focus on emotional energy and micro-sociological interaction processes. Collins' model focuses on battles between armies on land. It has implications for sea and air battles, but these are beyond the scope of the present inquiry.

This paper adapts Collins' model of battle dynamics into a simulation model, a fully-mathematized translation of his "boxes and arrows" models, to test the theory's assumptions and assertions. The authors have worked in conjunction with Collins through personal communications to best represent the intent and meaning of his theory. In the sections below we first reprise Collins' theory. We then translate the theory into a dynamic systems simulation model. The basic behavior of the model is examined in a series of experiments, and it is applied to the case of the American Civil War. It was determined that in Collins' model of battle dynamics, morale advantages manifest themselves early in the conflict, whereas material advantages are more influential as the conflict drags on. In conclusion, we note some limitations and possible future directions for research.

Corresponding author's e-mail: sociophile@gmail.com

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Battle Dynamics

The modeling of conventional warfare has been mainly focused on Lanchester's equations (Lepingwell 1987; Speight 2001; Lucas and Turkes 2004). Lanchester's model emphasizes two components for determining battle outcomes: force size and an exogenous parameter. Specifically, in Lanchester's model, the rates of attrition are determined by the coupled equations:

$$\frac{dA}{dt} = -\beta B$$
$$\frac{dB}{dt} = -\alpha A$$

where the rate of attrition is equal to the product of an exogenous factor (fighting effectiveness, tactical exploitation, etc.) and the size of the opposing army. Here, A and B are the attrition rates of the two armies involved, and α and β are scaling factors. According to this system, the fundamental determinant of casualties is the square of each opposing armies (Lanchester 1956). This 'Square Law' of Lanchester's model provides one of the simplest solutions for battle dynamics, which explains its popularity and use (Lepingwell 1987).

Empirically, however, Lanchester's model and its 'Square Law' have found mixed support. For example, the application of Lanchester's model to data on daily casualties in the battles of Kursk and Ardennes showed support for the fundamental parameters of attrition and size of opposing force, but the functional form of this relationship (squared size of forces) was not supported (Lucas and Turkers 2004; Fricker 1998). In the case of the Incheon-Seoul Campaign, Hartley and Helmbold (1995) found similar results, but argue that the 'Square Law' is likely masked by additional factors. Given this ambiguity regarding Lanchester's model, Collins' theory of battle dynamics provides insight into additional factors that can explain the rate of attrition by including sociological elements into the study of battle dynamics.

Collins' theory of battle dynamics is, most succinctly, a theory of organizational breakdown (loss of the ability to act in a coordinated way). While he is careful to include discussions of all three of the most historically prominent theories (Biddle 2004; Malesvic 2010) of why some armies win battles and others lose (i.e. material advantage, maneuver advantage, and morale advantage), Collins is very clear on the point that it is organizational breakdown that has the most important proximate cause of battle loss. This point is derived from his 2008 work on situational violence, in which he shows that most casualties in battle, and the most decisive victories, occur after an army has suffered a disproportionate degree of organizational breakdown.

Furthermore, Collins connects organizational breakdown to emotional factors, more than to command capacity or resource advantages. He offers the famous quote by Napoleon Bonaparte who opined that morale in battle outweighed the importance of mere material resources by a factor of three to one.

This emphasis is what clearly defines Collins' theory as a *sociological* theory of battle dynamics. Social factors are the largest determinant of battle victory, not leadership or more guns. Furthermore, the largest determinant of organizational breakdown is itself determined by an imminently sociological variable: emotional energy or morale (Collins 2004).

Collins also includes another important (but frequently underemphasized) element into his theory of battle dynamics: chance. History is rife with examples of battles that would have been won *if only* a certain set of seemingly random events had not occurred (Watts 2004). This high level of sensitivity to seemingly random small events (due to accidents, weather, terrain, etc.) is an important addition.

Collins' model does not propose to be a deterministic view of how battles are won or lost, but rather provides a system of propositional statements relating the important variables and forces that influence the processes of warfare. Each of the three most important sets of factors in Collins' model (i.e. materials, morale, and chance events) will now be discussed in turn.

The Machineries of War

There is no denying the importance of having troops and weapons when going to war (van Creveld 1977). Troops and their corresponding equipment are necessary conditions of battle, and they comprise the first main causal flow of resources in Collins' theory of battle dynamics.

Material resources (i.e. troops and weapons) are provided by each society involved in the battle. These material resources must be mobilized from their point(s) of origin within each society. This process of mobilization is done through logistics, or the practical costs (time/energy) and coordination necessary to successfully bring troops and equipment to bear in a battle. Logistical loads incur costs and create 'friction' that necessarily test the efficiency, resiliency, and maneuverability of an army; some troops and equipment are inevitably lost when an army must quickly mobilize and move from one place to another.

Once troops have overcome the logistical costs of mobilization, they are on the battlefield and are capable of carrying out the next stage in the process: assault. Assault involves the utilization of the firepower of the material resources of an army to cause damage, confusion, and costs for the opposition. The effectiveness of the assault is measured first and foremost in casualties—the loss of material resources by the opposing side. Each army tries to maximize the casualties of its opponent, thereby reducing the material resources available to the opposing side and establishing a resource advantage on the battlefield.

This portion of Collins' theory resembles mainstream models utilizing Lanchester's model. However, with Collins, 'fighting effectiveness' is not an exogenous parameter and attrition is not solely determined by the sizes of forces. Collins' theory adds other important ingredients that interact with troops and equipment to produce the outcomes of battles and wars.

The Spirit of War

The 'spirit of war' has gone by many names: élan, morale, *esprit de corps*, and emotional energy (Keegan 1976). It is meant to encapsulate the emotional state, state of mind, and spiritual fortitude of the troops going to war. Morale is the term favored by Collins, and it is a widely defined term intended to imply not only the continuum of emotional states common to warfare (i.e. from confidence/enthusiasm and personal initiative to foreboding/depression and passivity), but also troop discipline and coordination. Morale is the distinctly micro-interactional element in the theory of battle dynamics, encapsulating not only emotional states, but also group cohesion and the sundry elements of small group behavior associated with that cohesion.

Morale is affected by an army's training habits, social morphology, and recent history. While these first two elements appear to be largely exogenous in Collins' theory (or at least assumed to be given at the battle's start), the latter plays a big role in the dynamic feedback properties of the model. As an army either wins or loses battles (and deals with the corresponding organizational costs incurred during this process), the army's morale is affected. Winning armies tend to be infused with positive emotional energies and greater trust in each other's abilities, boosting morale and increasing initiative. Losing armies, on the other hand, face depression, foreboding, and loss of discipline. These outcomes have important effects on the coordination of the armies' movements moving forward.

Morale's biggest effects are on an army's ability to maneuver. The greater an army's maneuverability, the more complex the movements it can make during the course of a battle and the more strategically effective it is against its enemy. If an army can effectively coordinate its movements, it can not only apply more pressure to its enemy, but can also respond more efficiently to the pressure applied *by* that enemy. Thus, maneuver encapsulates both initiative and response, a point emphasized by Collins' overarching use of the joint terms 'maneuver/counter-maneuver.'

Morale has a secondary effect on the assault effectiveness of an army on the battlefield. The intensity with which an army assaults its enemy is a function of the army's morale. As discipline and initiative increase, the firepower brought to bear on one's opponents increases. This effect is of lesser magnitude in Collins' model than the effect of material resources on assault effectiveness.

Material and emotional resources both have important effects on the outcome of battle. Both are elements that are at least partially under the control of the armies involved, and conscious efforts can be made by both sides to increase the levels and effectiveness of each of these two flows of resources.

The Fog of War

Clausewitz's (1873) famous concept of the "fog of war" is meant to denote the emergent properties of battle, and the need for battle participants to be able to adapt to the fluctuating, unquantifiable, random properties of war (Watts 2004). It has come to be synonymous with the inability of military leaders to know or predict with full certainty whether a certain maneuver or troop movement will be successful, or what event may emerge that could put all their best laid plans to waste.

Randomness in warfare can occur in many places, and can have far reaching effects. A primary site of randomness in warfare occurs in the realm of logistics. Some troops and equipment are invariably lost during the mobilization of these material resources onto the battlefield. This 'friction' may be the result of any number of uncontrollable or unforeseeable causes, such as changes in weather, impediments of terrain, lost communications, or even simple accidents. Seemingly trivial events can have far-reaching impacts on a battle, or even a war. Without the impact of randomness in battle, one would always expect a bigger and better disciplined army to succeed in warfare. As history has shown in cases like the defeat of the Spanish Armada (Martin and Parker 1999), however, simple elements like the weather can quickly and drastically shift the advantage in battle, and these random events cannot be determined or predicted beforehand.

When one combines these three elements (i.e. material resources, morale, and random events), one is able to form the foundation of Collins' model of battle dynamics. Once this foundation is laid, the remainder of the model can be fleshed out. Figure 1 provides a diagrammatic view of Collins' theory.

Beginning at the left hand side of the causal diagram, one can begin with 'Material Resources' and see the role that troops and equipment play in battle. Material resources are mobilized, incurring logistical costs, and their firepower is brought to bear on the enemy in an assault. Bypassing the downward arrow from 'Assault' to 'Organizational Breakdown' for the moment, assaults cause enemy casualties (the loss of material resources), which plays a role in battle victory or defeat. This is the prototypical causal chain of material resources in battle dynamics.

Once again beginning at the left hand side of the figure, 'Morale' influences both 'Assault' and 'Maneuver/Counter-Maneuver'. Following the lower causal pathway, maneuvers allow an army to more successfully break down the

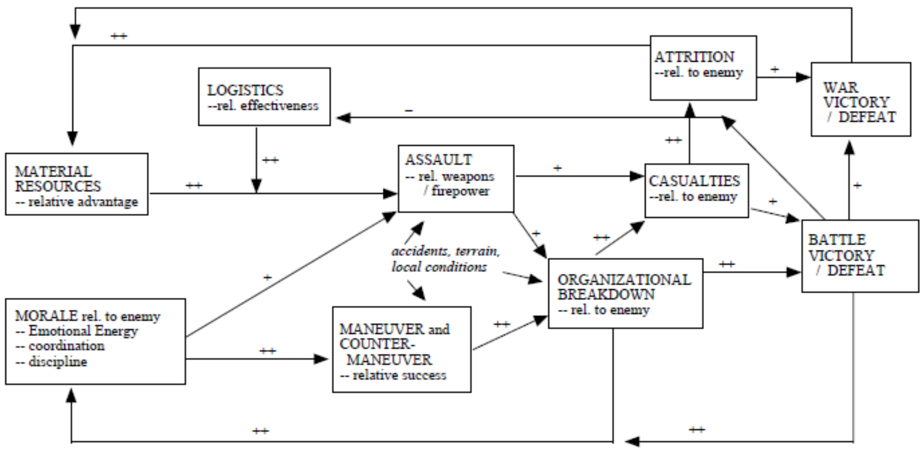

Figure 1. Collins' Model of Battle Dynamics (++ = strong causal path; + = moderate causal path).

organizational cohesion of its enemy, which then influences battle victory or defeat. This final effect is the crux of Collins' theory, and must be discussed in detail.

Organizational Breakdown

Collins' theory is explicitly a theory of organizational breakdown. As he has shown in his situational theory of violence (Collins 2008), most of an army's casualties and the most decisive battle victories/defeats occur *after an army has suffered an organizational breakdown*. Organizational cohesion allows an army to move effectively, attack effectively, and respond effectively to an enemy's movements (King 2006; Marshall 1947; Shils and Janowitz 1948). Organizational breakdown, on the other hand, increases the costs of movement, inhibits responses to an enemy's initiatives, and reduces battle effectiveness. This explicit attention to organizational efficacy is the most significant contribution to understand battle dynamics because it refocuses attention to the social capital of military organization as a fundamental factor in explaining battle dynamics.

As the model shows, both 'Assault' and 'Maneuver' influence organizational cohesion. The larger effect, however, is from maneuver. The ability to maneuver effectively gives one the ability to carry out a number of actions that can limit or reduce the organizational cohesion of one's enemy. Flanking to an enemy's weak side, surrounding an enemy and preventing retreat, cutting of logistical resupply lines to prevent the influx of material resources are all made possible by outmaneuvering one's opponent. Direct frontal assault and overwhelming firepower may also break an enemy's organizational makeup, but Collins views this as a weaker effect than effective maneuvering.

The random effects asserted by Collins to be so influential in the course of the battle literally take center stage in his model. Centered in the model between 'Assault' and 'Maneuver' is a list of random elements that influence an army's firepower, coordination, and organizational cohesion. Encapsulated by the truncated list of "accidents, terrain, and local conditions," these effects are meant to denote all such emergent and unpredictable elements arising from the context of the battle that can influence the direction and outcome of the battle itself. Clausewitzian randomness such as this is also implicitly embedded in the model in 'Logistics' and in 'Attrition.'

While Collins' theory's titular element and apparent focus is battle victory, it is clear from the model that he also includes consideration of war victory. Simply put, battle victory/defeat is an issue of the short term, and is situationally defined as skirmishes are fought. 'War Victory/Defeat,' on the other hand, encapsulates the longer issue of winning not just the battle, but the larger conflict. Presumably enough battle victories can produce a war victory, but this is not the only way to win a war. Just as war victory is the long-term equivalent of battle victory, so too is attrition the long-term equivalent of casualties. The loss of material resources (i.e. troops and equipment) on a short time scale may influence events in battle, but a long term trend of material losses may cost one the war. This long term loss of material resources is termed 'Attrition,' and has its own independent effect on war victory/defeat.[1] Last, being a dynamical feedback model, there are a number of effects that flow from the right hand side of the model back to the left. Battle victories influence both the morale of the troops as well as the logistic concerns of the armies involved. Organizational cohesion feeds back onto troop discipline and emotional energy, and attrition has clear effects on material resources. Additionally, as wars are won and lost, armies may capture equipment, land, or even troops, influencing the material resources available to the victor.

[1] A prime historical example of the effect of attrition on war victory/defeat is encapsulated in Germany's experience in Russia during World War II. As Hitler's forces extended their troops (and thus their logistical resupply lines) deeper into Russia's winter landscape, attrition of troops and equipment eventually became so great that they lost the ability to maintain the battlefront, even though they had proven their greater effectiveness on the battlefield.

The Simulation Model

Collins' theory of battle dynamics is a feedback model populated by a number of interconnected elements representing the relative strength of two armies. The relative nature of each element in the theory poses some problems for the translation of this model into a mathematical simulation, as relative levels of anything must be anchored in concrete amounts of that same thing. Therefore, the simulation of the theory of battle dynamics must involve two distinct but interrelated sub-components: (1) the simulation of concrete material and emotional resource flows (i.e. a simulation of actual armies with troops, equipment, and morale), and (2) the simulation of relative advantages of these flows and their outcomes (represented by Collins' visual model in Figure 1). Each of these two subcomponents of the simulation will now be discussed in turn.

The Armies: Materials, Men and Morale

The first subcomponent in the simulation creates each army in concrete terms, populating the army with troops and equipment, mobilizing those troops and equipment to the battlefield, and resupplying the troops and equipment from an exogenous societal source. Each army also has a flow of emotional resources (i.e. morale) that grows and declines according to the battle victories/defeats suffered by the army, and the organizational cohesion of that army. Figure 2 provides a visual representation of the army subcomponent of the model.

The operation of the material resource flow begins with the society (an exogenous stock of material resources) supplying the army with troops and equipment. During the process of mobilization some random amount of these materials is lost to what Collins' has termed the "Clausewitzian friction" of war. This is encapsulated in the 'Logistics' modifier affecting the process of material resource mobilization. Mobilized troops are then subject to attrition which reduces their numbers, a process that will be detailed in the following section. Each army also has an emotional resource flow that influences their level of morale. As is indicated by Collins' theory, morale can be influenced by battle victories and defeats, as well as by organizational breakdown. As the army loses battles or begins to breakdown more than its opponent, morale will suffer. On the other hand, morale will be boosted as they win battles or remain more organizationally cohesive than their opponents. The specific operation of each of these two factors, battle victory/defeat and organizational breakdown, will be detailed in the following section.

The Battles: Relative Warfare

The second subcomponent of the simulation recreates the battle dynamics outlined by Collins in his theory and pictured in Figure 1. Only slight

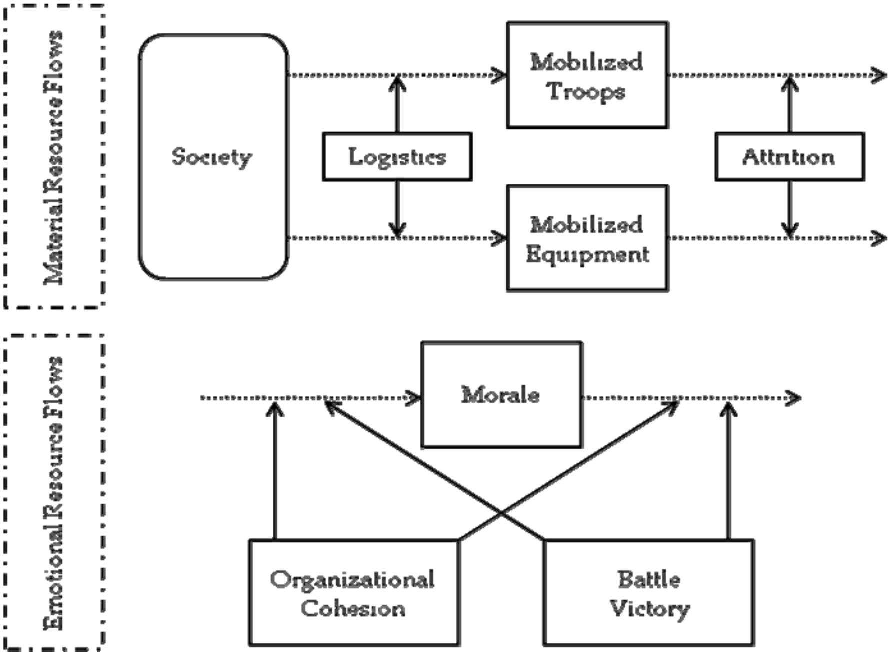

Figure 2. The Simulated Army.

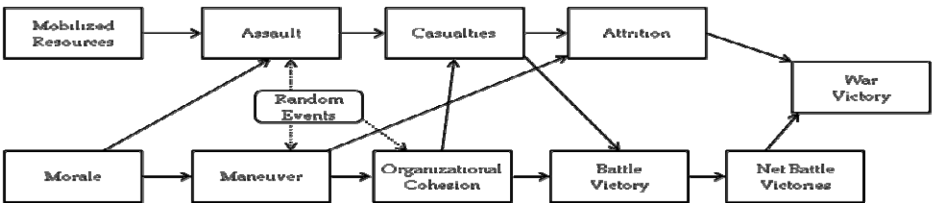

Figure 3. Battle Simulation

modifications were made to this original formulation, and the simulated elements are illustrated in Figure 3.

As was indicated by Collins in his original formulation, each element in the battle simulation is "relative." Specifically, each element is comprised of a ratio of one society's amount/level of that variable to its opponent's amount/level of that variable. For example, the 'Morale' box in Figure 3 is a ratio of one army's morale to the other army's morale. To apply arbitrary labels, if Army A is the numerator and Army B is the denominator, then any value less than 1 would imply that Army B has more morale, any value greater than one would imply that Army A has more morale, and a value of 1 would indicate that both armies have equal levels of morale. The levels of morale (as well as the amount of material resources) are determined by the first subcomponent of the simulation (i.e. the concrete simulations of each army). Notice the variable 'Organizational Breakdown' has been replaced with 'Organizational Coherence' which we are treating as the opposite of organizational breakdown. This keeps the direction of the relative variables consistent throughout the model (values greater than one always imply an advantage for Army A).

The 'Random Events' variable in the center of the diagram introduces a small amount of stochastic variation into the model at three points: Assault, Maneuver, and Organizational Coherence. Each variable after Mobilized Resources and Morale maintain their status as ratios until the point when the model reaches Battle Victory. A battle victory is not reached with every iteration of the simulation model. The simulation may run indefinitely without a battle victory ever being reached (as may be true of well supplied, evenly matched armies). Only when the appropriate conditions are met can a battle victory be achieved. A battle victory is achieved when one of two scenarios occurs. First, if it becomes true that one of the armies enjoys over twice as much organizational cohesion as its opponent, then that army will accrue a battle victory. Recall that all variables in Collins' theory are defined relatively. Thus, it does not matter how cohesive an army is in absolute terms, but rather only how cohesive it is in relation to its enemy. We have set the crucial ratio to be 2:1.[2]

But, as Collins' theory points out, an army may also win a battle through sheer physical (i.e. material) domination. In determining the crucial threshold for this form of victory, we have turned back to Napoleon's famous declaration that morale outweighs material resources in importance by a factor of 3:1. Thus, a battle victory can also be won if an army creates a 6:1 ratio of advantage in terms of casualties (i.e. 3 × the 2:1 ratio for a morale victory). In short, a battle victory is achieved when one army either 1) maintains or establishes organizational cohesion twice that of its opponent, or 2) generates six times as many casualties in its opponent as the opponent creates in it.

War victory can also be achieved through two different routes. First, it can be achieved by accruing battle victories. For this simulation, the condition has been set that if one army can accrue a total of ten net victories[3] then the war is

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[2] This is an admittedly arbitrary value, but as this standard is shared by both armies, it should not bias the model in favor of one army over another.

[3] Net Victories = (Total Battles Won – Total Battles Lost)

won. Armies may trade battle victories indefinitely without winning a war, but if a single army is compiling more victories than its opponent, the war will eventually be won.

Second, war victory can occur because of attrition. Attrition is the long-term equivalent to casualties. In this simulation, if one army can create an attrition ratio of 6:1[4] (implying that it has over the course of many battles created over 6 times the number of casualties in its opponent as it itself has suffered), then a war victory will occur due to attrition. Regardless of how a war victory occurs, through battle victory or attrition, a war victory immediately ends the simulation.

It should be noted that there are two small changes to our simulation from Collins' original formulation in Figure 1. First, logistics as a path multiplier and random force in the model has been moved from occurring between material resources and assault and now occurs in the subcomponent of the model that deals with simulating the actual armies. By the time material resources are entered into the battle dynamics simulation, they have already been mobilized and the logistical friction has been applied. This is a stylistic change made for the ease of simulation and does not change the overall operation of the model.

Second, the simulation model stops once a war victory is achieved. In Collins' model, there are feedbacks from war victory back into the model (e.g. material resources). Collins correctly states that war victories have impacts on the societies in question (as well as their armies) and thus should feedback into a comprehensive model of warfare. Our simulation, on the other hand, seeks to simulate a *single* war, and not multiple iterations of war. Thus, there are no causal feedback arrows from war victory into the model.

Results

To test the implications of Collins' theoretical model, the simulation model was run 750 times and all relevant outcome variables were recorded. Twenty five different versions of the model were tested (30 replications per condition), as important parameters were varied to allow for better understanding of the solution space of the simulation and the importance of each parameter in formulating that solution space. Simulations were run for a length of 100 time steps (Δt). This length of simulation and number of replications were sufficient for proper parameter testing of the model.[5]

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[4] This attrition threshold value was chosen to make the ratio of wars won due to attrition vs. wars won through battle victories 1:1, a model constraint suggested by Collins (personal communication).

[5] Plots of the variance of battle victories against number of trials run shows that the standard error of the results reaches its stable equilibrium at approximately N = 20

The first version of the simulation was a 'symmetric' model, or a model where the initial conditions are identical for both armies (i.e. they begin with the same material and emotional resources). Any initial advantage occurring in the symmetric model is a result of the stochastic variation introduced through logistical friction and random events. Without such variation, two identical armies could never create an advantage. However, much can be learned about the basic operation of the model simply by looking at the differences generated by a small amount of random chance. Additionally, the symmetric model will stand as a baseline against which the other variations of the model can be compared.

If one is to look for patterns in how Collinsian battle dynamics play out, one can find a relatively standard chain of events. In a simulation between two evenly-matched armies, initial advantages brought about through stochastic variation are hard to overcome. Figure 4 and 5 provide graphical representations which show the typical result of a single war between two identical armies. Figure 4 is an illustration of the material aspects of war (i.e. troops and equipment), while Figure 5 illustrates the emotional aspect of war (i.e. morale). As is clear, army 2 establishes an early advantage and maintains that advantage all the way through victory. As both armies are identical, the initial advantage must be the result of stochastic variation.

However, initial advantages are not always a guarantee of victory. Collins' model does produce battles where advantage is won and lost, and the struggle is protracted as each side vies for victory. An example of one such outcome is demonstrated in Figures 6 and 7. In this example, army 1 randomly receives a slight advantage from the stochastic variation early in the simulation, but is soon overtaken by army 2 during iterations 30 and 50, before finally regaining the advantage and eventually winning the war.

As was mentioned above, there are two mechanisms that trigger war victory in the model. One is the net number of battle victories and is driven by the lower path in Figure 3. The other is attrition, which is a function of the upper path. During the analysis of the symmetric model it was observed that on average, the duration of wars determined by attrition ($\mu = 37.8\ \Delta t$, $\sigma = 11.8$) is significantly longer ($p < 0.10$) than wars determined by cumulated battle victories ($\mu = 30.9\ \Delta t$, $\sigma = 8.0$). This implies that the path to war victory driven by morale (lower path) leads to quicker war victories than the path driven by material resources.

While pitting two identical opponents against one another may yield important information about the basic operation of Collins' theory, it is not sufficient in parsing out the finer implications of how the model operates. To

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runs. N = 30 runs was carried out to guarantee stable results. The tests varying the stochastic random events variable were run for 200 time steps due to the fact that wars were not always completed in 100 iterations for smaller values of this variable.

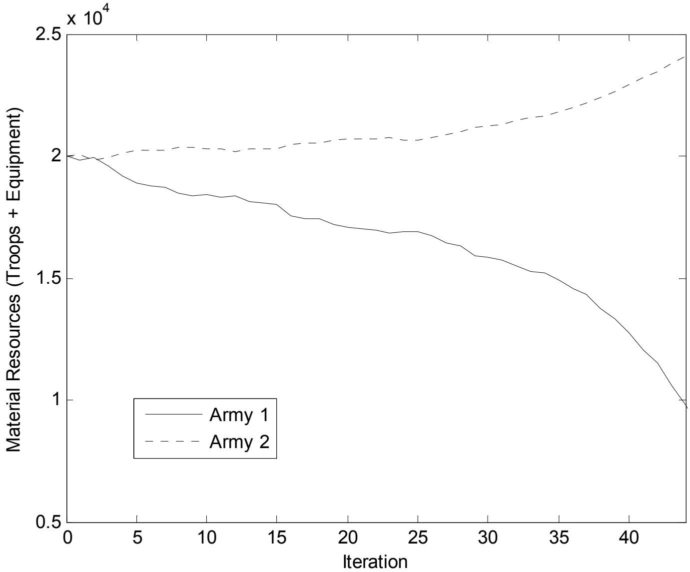

Figure 4. Initial Advantage Maintained: Material Resources.

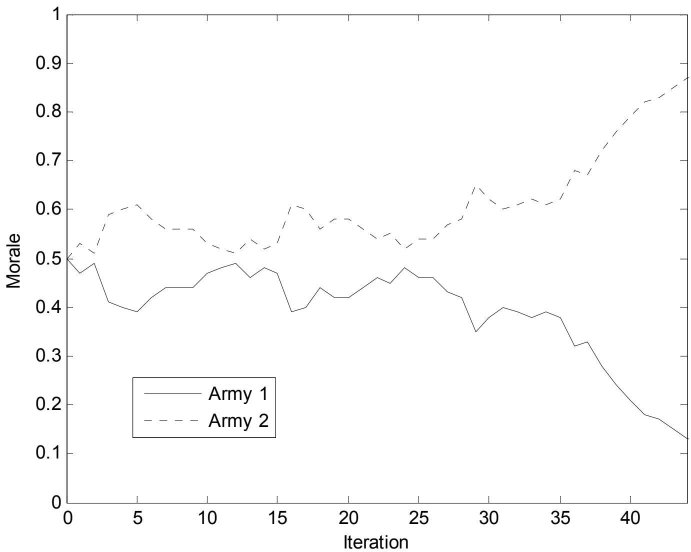

Figure 5. Initial Advantage Maintained: Morale

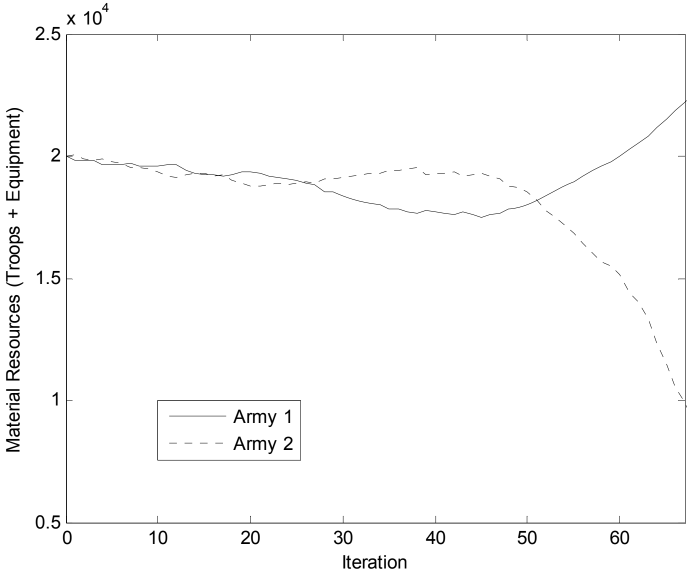

Figure 6. The Struggle for Advantage: Material Resources.

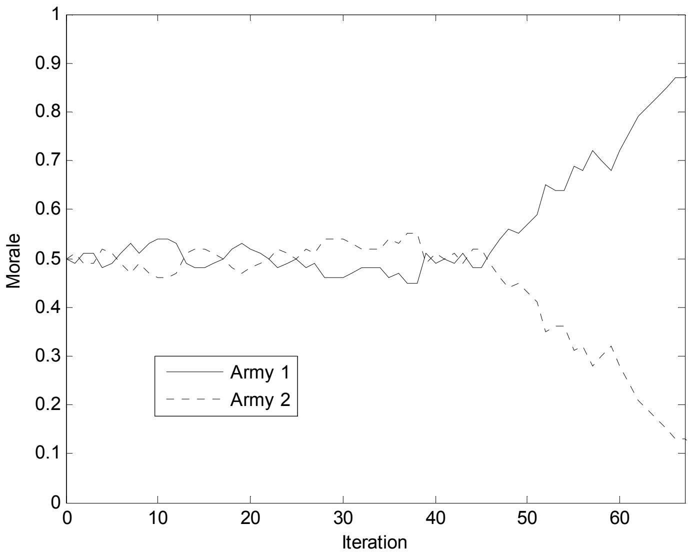

Figure 7. The Struggle for Advantage: Morale.

do this, one must vary the crucial parameters in the model and measure the model's sensitivity to these varied conditions. In pursuit of this, four parameters were varied: (a) initial material levels, (b) initial morale levels, (c) supply rates, and (d) the magnitude of the random events variable. Taken together, these additional models comprise what we term the 'biased' simulations of Collins' model.

For the first three biased simulation models, one of the two armies is given an advantage (initial materials, initial morale, or supply rate), which is gradually increased to see how the parameter in question influences the outcome variables. The outcome variables of interest for these tests are the probability of winning a war[6] given the advantage, and the average length of wars. Under all three circumstances, the advantaged army's probability of winning the war grows logistically toward unity[7]. Interestingly, the probability of winning a war grows faster for initial material advantages than for morale and supply rate advantages. For all three types of advantage, the duration of wars generally decreased with advantage.

The other set of biased simulations varies the random events (i.e. stochastic noise) variable. As the magnitude of the random events variable increases, the noise in the system grows. The outcome variable of interest here is average war length. When there are no random effects in the symmetric model, no one wins, and war length is infinite because neither army can get an advantage. However, as noise is introduced, at some point one side gets a slight advantage that feeds back and amplifies the advantage leading to victory (unless a series of random events reverses the trend). By varying the magnitude of the noise in the system, it was discovered that the stronger the noise, the shorter the wars. The duration of wars decays exponentially with increasing noise magnitude.

To further test the implications each parameter has on the overall operation of the model, linear modeling statistics were carried out to test the relative strength each variable has in determining the outcome of the simulated battles. There were 300 simulations included in the linear modeling tests, covering the range of variation across all variables of interest. Random-intercept panel regressions were used to correct for the autocorrelation between cases that occur within the same simulation, and are preferable to time-naïve regressions because the passage of time is not only controlled for, but can be included as a predictor in the model. Battle victory is considered a dichotomous outcome at each time point (0 = no battle victory recorded; 1 = battle victory), and thus the regression is carried out assuming the Bernoulli family of outcome distributions with the logistic link function. Table 1 provides the results of a

[6] Probability of winning a war is measured as the proportion of total war victories for the set of tests of a given condition.

[7] Plots and tables of the biased simulation results can be found in Appendix B: Parameter Tests.

Table 1. Multivariate Random Intercept Panel Logistic Regressions (N = 300 simulations). Outcome variable: Battle Victory. All Predictor Variables are Standardized (Mean = 0; SD = 1).

Predictor Variables	*Coeff. (SE)*	*Sign.*
Time	–0.33 (0.28)	NS
Casualties†	2.43 (0.42)	***
Organizational Breakdown†	20.36 (1.22)	***
Time × Casualties	1.17 (0.42)	**
Time × Organizational Breakdown	0.17 (1.01)	NS
Intercept	–5.65 (0.35)	***

** $p < 0.01$; *** $p < 0.001$, NS = not significant

†Variable is measured as the absolute value of the natural log of (Army 1/Army 2).

multivariate random-intercept panel logistic regression predicting battle victory.

Each predictor variable has been standardized, allowing coefficients to be compared in terms of their relative impact on the outcome variable; greater deviations from zero indicate strength. Positive coefficients indicate a positive relationship with the outcome variable (battle victory), while negative coefficients indicate a negative relationship.

When comparing the two variables that have a direct effect on battle victory, it is clear that organizational breakdown has the much larger effect (b = 20.4; $p < 0.001$) on battle victory, being nearly an order of magnitude more powerful than the direct effect of casualties (b = 2.4; $p < 0.001$). However, the interaction effect between time and casualties is also significant (b = 1.2; $p < 0.01$), implying that for each iteration that passes, the effect of casualties on the outcome of the battle increases by 1.2. Simple arithmetic reveals that after approximately 15 iterations of the simulation, the effect of casualties is equal to that of organizational breakdown in determining battle victory ($2.4 + (15 \times 1.2) = 20.4$). This provides further support for the observational evidence provided earlier that morale seems to provide strong boosts to battle effectiveness during the early stages of the conflict, while material advantages and overwhelming force pay dividends in the longer run. Time showed no direct effect on battle victory outcomes, and the interaction between time and organizational breakdown was not significant.

Two additional biased models were run. In this final set of simulations, advantages weren't given to just one army or another, but different types of advantages were given to each army. Given the information gathered from the parameter tests described above, it was decided that morale advantages would be 'pitted against' the two forms of material advantages: initial advantages (a larger standing army), or cumulative advantages (a larger resupply rate). Thus, army 1 was always given a morale advantage (2 × the morale at the start of war), while army 2 was given one of two material advantages (3 × the materials at the start of the war, or 3 × the resupply rate). These values were chosen because they seem to hold verisimilitude as loose proxies for the advantages held by the South and the North in the American Civil War, respectively. Here is a quote from Dr. Collins in his original formulation of the theory of battle dynamics:

> Material resource superiority can take account of maneuver by persisting longer and forcing a war of attrition. This was the strategy of General Grant in the US Civil War, in which the North had over three times the resources of the South, while the South had more trained officers (initially) and better knowledge of the local terrain, which resulted in better maneuver and élan. (2010:4–5).

While no specific metric for the morale advantage of the South was given, a 2 × morale advantage was shown in the sensitivity testing to be quite a robust advantage, and thus was chosen. These two final simulations were run to stand as proxies for the conflict that Collins himself turned to most frequently in his theory of battle dynamics: the American Civil War.

Historical Example: The North vs. the South in the Civil War

According to our simulation, the broad outlines of the conflict between the North and the South can be captured by the variables Collins offers in his theory. In fact, many of the examples used by Collins in outlining his theoretical concepts come from the Civil War, making it a prime candidate for simulation.

When army 1 (i.e. 'the South') is given the 2 × morale advantage, and army 2 (i.e. 'the North') is given its 3 × materials or resupply advantage, both simulations of the civil war (i.e. an initial material advantage and an ongoing resupply advantage) behave similarly. In both cases, the longer the war, the more likely army 2 (the North) will win. The morale advantage of the South manifests itself through quick battle victories at the start of the engagement. If enough of these quick victories can be achieved, the South wins the war, usually within the first 15–20 iterations. If, on the other hand, the war lasts longer than this transition point, then the North invariably wins. This observational supposition can be tested by carrying out paired student t-tests to test for significant differences between the two outcomes. These tests were carried out, and wars in which the South won are significantly shorter ($\mu = 14.5$ Δt, $\sigma = 5.5$) than wars in which the North won ($\mu = 35.4\ \Delta t$, $\sigma = 16$; $p < 0.001$).

In short, when simulating the American Civil War using Collinsian battle dynamics, the longer the duration of the war, the more likely the North will win, regardless of how one defines material advantage.

The mechanism for winning wars turned out to be related to the victor as well. Though the South tended to win most of its wars by battle victory (63 percent), the North only won wars by attrition. In both models, all war victories produced by the North were wars of attrition. Knowing that wars of attrition tend to be longer in the symmetric model, it is not surprising that Southern war victories were on average much shorter than Northern ones.

Quantitatively, the two versions of the civil war simulation are not equivalent. Specifically, the ratio of North to South victories is widely divergent across the two models. When the North is given only initial material advantages (i.e. 3 × the troops and equipment at the start of the war), it is able to win the war only 26.7 percent of the time. When the North is given a persistent resupply advantage (i.e. 3 × the exogenous resupply rate throughout the simulation), the North is able to win the war 46.7 percent of the time. While neither scenario has the North winning the Civil War a majority of the time, it appears that the increased resupply rate is a more powerful material advantage than simply fielding a larger army at the start of the war. Historically, the North did enjoy an ongoing resupply advantage relative to the South, due both to its superior production capacity, and its ability to enforce harbor blockades on Southern cities that prevented the South from being resupplied by European countries interested in the raw materials of the region (Wise 1991).

Discussion

In testing the symmetric model, it was shown that initial advantages are difficult (but not impossible) to overcome, due to the number of reinforcing pathways that flow through the model. Slight advantages soon turn to overwhelming dominance as each iteration further reinforces the direction and magnitude of the difference between the two sides. But, even the slight stochastic variation included in this model can occasionally turn the tide and avoid such runaway outcomes, showing that through his emphasis on uncertainty ("the fog of war"), Collins' model is able to avoid the trap of predetermined outcomes.

Each of the biased models provided an indication of how different initial conditions affect the overall behavior of the model. Unsurprisingly, increasing morale or materials advantage (both initial materials and supply rate) increases the odds of winning the war. It was also found that the greater the advantage given, the shorter the war. Due to the feedback in the model, advantages tend to be amplified unless stochastic events undermine this advantage. Oddly, the probability of war victory increases at a faster rate if initial material advantage is increased rather than if morale or supply advantage is increased. This appears to undermine Collins' claim that organizational breakdown and ultimately morale are the key factors driving battle dynamics in his model. However, more detailed statistical analysis determined that organizational breakdown is a much stronger predictor of battle victory than casualties for early stages of conflict. As conflicts drags on, casualties and ultimately material advantages begin to dominate the dynamics.

Exploration of the random events variable that introduced noise into the system showed that by increasing the magnitude of noise, wars became increasingly shorter. Again, this is likely related to the positive feedback built into the model. The magnitude of the random events variable directly determines the magnitude of change in advantage due to random events. Larger shifts in advantage are ultimately harder to overcome and amplified at a faster rate. This, in turn, shortens the length of wars.

Our simulations of the Civil War provide the most interesting look at the implications and power of Collins' theory. Interestingly, the model does not usually replicate the historical results of the Civil War. At best, under the conditions implied by historical circumstance and the writings of Collins, the outcome of the Civil War seems to be roughly equivalent to a coin flip, with each side having approximately equal odds of winning the war (Ransom 2005).

One possible explanation for this discrepancy between our model and historical fact might be the misspecification of causal factors of war victory. In context of the Civil War, the political will of the Lincoln administration to maintain the North's campaign against the South during the initial phases of the war was a significant factor behind the North's victory (Martel 2007). This is especially important given the relative material advantage of the North, while the South maintained better organizational capacity and morale. Subsequent models should include political will as an important cause of war victory.[8]

However, some of the insights of our simulation are in line with history; specifically the implication that material advantage needs time to overtake significant morale disadvantage. It was demonstrated that wars won by attrition in our model tend to take longer than wars won by battle victory. It was also shown that battle victory is determined by morale advantage in early stages and by material advantage in later stages. This implies that if one army has a morale advantage while the other has a material advantage, then the one with the morale advantage needs to press its advantage early on in the war, so

[8] Collins' model of battles focuses on the morale of the soldiers, but the morale of the larger society is also an important variable that has consequences for warfare outcomes. Following Ibn Khaldun there is an important modeling literature on the importance of social solidarity in competition among societies (e.g. Turchin 2003).

that it might accumulate enough battle victories to ultimately succeed and win the war. Our Civil War example demonstrated that this is indeed the case.

Historically, it seems well accepted that the South was better organized and could maneuver more effectively, while the North had material advantages. This combination of factors led to the South's dominance at the beginning of the war (whereby Lee's superior maneuverability and organizational cohesion gave him an important edge), but over time the factors of attrition and the increasing dominance of the North's ability to resupply the battlefield with fresh soldiers and weapons eventually won them the war. Interestingly, these same dynamics are witnessed when one inputs the appropriate initial values into Collins' model.

To provide the clearest comparison of historical fact with our simulated outcomes, it is illustrative to look at the two side-by-side. Table 2 shows the largest and most influential battles of the Civil War (based on both the number of casualties and strategic relevance) and shows which were victories for the North, for the South, or were deemed inconclusive.

A map of these real victories over time, beginning with the first major battle (1st Bull Run) and ending with the final Civil War battle (Appomattox), can be compared to a map of one of our Civil War simulations that begins at the first battle victory and ends with the victory by the North. The simulation chosen was one of the civil war tests included in the results discussed above, and is typical of results gained when the North wins the simulated war. Figure 8

Table 2. Key American Civil War Battles (ABPP 2011; McPherson 2005).

		Casualties		
Date	*Battle(s)*	*South*	*North*	*Victor*
July, 1861	First Bull Run	1,750	2,950	South
April, 1862	Shiloh	10,699	13,047	North
June, 1862	Seven Days	20,000	16,000	South
August, 1862	Second Bull Run	9,197	16,054	South
September, 1862	Antietam	13,724	12,410	Inconclusive
September, 1862	Stones River	11,739	12,906	Inconclusive
May, 1863	Chancellorsville	12,821	17,278	South
May, 1863	Vicksburg	9,091	10,142	North
July, 1863	Gettysburg	28,063	23,049	North
September, 1863	Chickamauga	18,454	16,170	South
May, 1864	Spotsylvania	12,000	18,000	Inconclusive
May, 1864	Wilderness	11,400	18,400	Inconclusive
November, 1864	Sherman's march	1,000	2,100	North
April, 1865	Appomattox	unknown	unknown	North

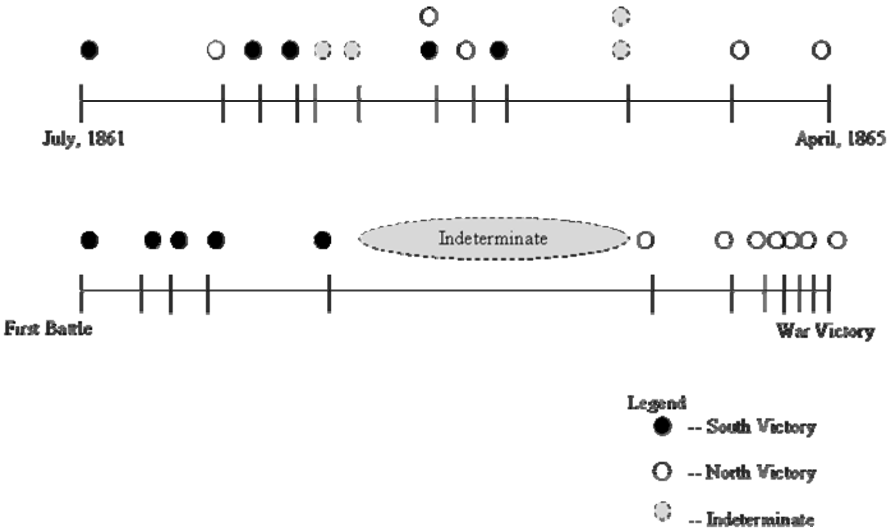

Figure 8. Battle Victories in the American Civil War vs. Battle Victories in Civil War Simulation

provides the visual comparison of the actual civil war results with our simulation.

As is clear, the two battle maps share some striking similarities. In both cases, the South shows clear dominance in the first third of the war, winning 75 percent (3 out of 4) of the major battles in the Civil War and 100 percent (5 out of 5) of the battles in the simulation. Then, both simulations enter a period where neither army is truly dominant. This is represented in the Civil War by a series of inconclusive battles and an even-split between battles won by the North and battles won by the South. While 'inconclusive' battles cannot occur in the simulation, the simulation does go through an extended stretch where neither army is able to win a battle, and both struggle for dominance over the other. Eventually, the North achieves stable dominance in both historical fact and in the simulation, winning a string of victories and eventually the war.

The isomorphism between the historical and simulated results are striking, and encouraging for the overall verisimilitude of Collins' work. The implications of his theory seem abundantly clear: the effects of morale, discipline, and emotional effervescence are powerful and can determine the outcome of a war *if they are capitalized upon quickly*. A better organized, more emotionally energized fighting force can press early advantages and break the will and discipline of a larger enemy, but must accomplish this feat quickly. If too much time passes without a decisive victory, the materials of war may persevere and achieve victory through sheer force or attrition. Collinsian battle dynamics are premised upon the short-term efficacy of morale and the long-term efficacy of materials.

Conclusions

Collins' model of battle dynamics is powerful in its ability to incorporate three important aspects of war into a cohesive and dynamic model: material factors, emotional factors, and random/emergent factors. Rather than focusing on one to the exclusion of the others, Collins does well to integrate all three and explicitly show how each influences the other. This simulation has attempted to highlight how Collins' model operates in practice, and detail the implications of his logic.

There are limitations that remain both with the theoretical model and our simulation. Given the results of our simulation of the civil war, one cannot help but wonder if perhaps the morale/maneuver/organizational breakdown causal chain is given too much weight in Collins' theory. In our simulation of the Civil War, overwhelming material advantages have trouble overcoming even somewhat modest morale advantages. While a more robust resupply rate does seem to level the playing field somewhat, even an understaffed and under-supported army may be victorious if their morale is high and the war does not drag on. Some consideration may be given to balancing both the theory and the simulation to give less weight to morale in the overall operation of the model.

In regards to the simulation model, a number of additional variables must be incorporated in moving forward. First, the issue of land and space must be made explicit. As it stands, these armies are fighting in virtual space, rather than on battlefields. While the issue of logistics is included, it is disconnected from any sort of issues related to land, such as the length of supply chains, or the ability to scavenge off the land. Given the importance of such issues in the Civil War (such as Sherman's march to the sea, or the sudden and dramatic shift of fortune for Lee once he entered Pennsylvania), it becomes clear that spatial location is an important variable to make explicit in the simulations. It may also be reasonable to suppose that morale dynamics differ depending on where a battle is fought. A loss in enemy territory may be less consequential than a loss in one's homeland and the home-field advantage in warfare is partly due to knowing the territory and partly due to the boost in morale that comes when soldiers are defending their own land against an invading force.

Additionally, Collins' theory provides a rubric for how to account for technological differences between the two armies, an addition that should be made to the existing simulation model. This factor seems of special importance in the modern theatre of war, where it is not uncommon to witness technologically advanced armies pitted against small groups or even individuals with crudely made weapons and explosives.

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