Human Behavior Representation Using the RAND Will to Fight Model

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ABSTRACT

Since at least 1997, work has been ongoing to fill the human behavior representation (HBR) gap in military simulations (Hutson, 1997; Cornwell et al., 2003; Silverman et al., 2006; Johns, 2007). The work done within the artificial intelligence community to represent behaviors has an even longer pedigree. In 2018, the Army Modeling and Simulation Office formally recognized the HBR gap, initializing an effort to reduce it. Prior to that, RAND was commissioned by the US Army to develop a method to analyze and account for the will to fight of partner nations in support of operations. The RAND National Will to Fight and Will to Fight reports (2018) describe the development of a model and method of analyzing the construct of will within a military context. The Will to Fight model has evolved from a report, to a 28mm miniatures style game. From that evolution a computational model was developed and tested in both NetLogo and IWARS, prior to initializing development and integration of the model into the constructive OneSAF simulation. This paper describes the development of the Will to Fight model and the instantiation of the game as well as our progress on the development of the referent software implementation for the model to be provided to the US Army. As of January 2019, modeling and initial coding preparations are underway. Implementation and initial testing in IWARS and OneSAF are being conducted through 2019. Assessment of the process will be iterative with observation and participation of AMSO, PEO-STRI, and other U.S. Army stakeholders. The current one-year effort will conclude in January 2020 with the goal of a working Will to Fight agent- and unit-level model suitable for full testing and iterative improvement and modification in official U.S. Army simulations. RAND will transfer software implementation of the Will to Fight model to the U.S. Army in 2020 according to the OneSAF user agreement.

ABOUT THE AUTHORS

LTC Glenn Hodges PhD, is an Assistant Professor and Deputy Director of the Modeling, Virtual Environments, and Simulation (MOVES) Institute at the Naval Postgraduate School. His research is in the area of cyber ecology, the study of humans and their interactions within blended natural/technology environments. LTC Hodges is currently the Project Manager for the Army HBR effort.

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Henry Hargrove is a computational scientist working for the RAND corporation. He currently is the lead software developer working on the referent implementation of the Will to Fight Model.

Dr. Aaron Frank is an information scientist specializing in the development of analytic tradecraft and decision-support tools for assessing complex national security issues. His interests include uncertainty, the philosophy and history of science, decision making, and the way in which models mediate between data and theory in order to understand individual choices and collective action.

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HISTORICAL BACKGROUND OF HUMAN BEHAVIOR REPRESENTATION (HBR)

The following historical information is taken from the National Research Council (1997 & 1998) as a stage setter for the discussion of the implementation of the RAND Will to Fight model. In 1996, the Defense Modeling and Simulation Office (DMSO) requested that the National Academy of Sciences/National Research Council conduct a study of the state of the art in human behavior representation as it applied to military simulations. The phrase human behavior representation has been used by the defense modeling and simulation community to refer to models of human behavior or performance that need to be represented in military simulations. During the first phase of an 18-month study, the panel conducted research into the scientific literature on human behavior and attended workshops sponsored by DMSO, where military contractors provided information on their efforts to model human behavior in a variety of military simulations. In the final 10 months of the study the panel investigated 11 different models, which the report describes as 'integrative architectures' as well as the literature on the human capacities of decision making, situational awareness, planning, and multi-tasking. The panel acknowledged that an integrative model of the human was necessary but did not go so far as to recommend converging the multiple constructs that support the modeling of human behavior into a single integrative architecture (National Research Council, 1997, pp. 51). They emphasized that adopting modular structures would allow for easier interoperability among multiple models. In the final report executive summary the panel stated that "*The modeling of cognition and action by individuals and groups is quite possibly the most difficult task humans have yet undertaken* (National Research Council, 1997, pp 8.) and furthermore, based on the work that the panel executed they were convinced that 1) human behavior representation is essential to the successful applications in both wargaming and distributed interactive simulation; 2) current models of human behavior can be improved by transferring what is already known in the behavioral science, social science, cognitive science, and human performance modeling communities; and 3) great additional progress can be expected through the funding of new research and the application of existing research in areas the panel explored" (National Research Council, 1997, pp. 9).

FAST FORWARD

The Army has evolved its simulation programs over time as requirements have changed. Many of the recommendations stated in the National Research Council reports have been addressed since 1997. However, the requirement that soldier and unit entities act more human-like has not been an area of much improvement or effort. This became evident to one of the authors during his tenure working for the Human Dimension Division (HDD) in the former Army Capabilities Integration Center (ARCIC). At that time, HDD supported the Future Warfare Division and Joint Army Experimentation Division of ARCIC as they developed and executed the Chief of Staff of the Army's annual wargame. We noted during one of many after action reviews that the scenarios and simulations used to drive the game needed higher fidelity human behavior models in order to provide a more realistic picture of soldier performance on the future battlefield. This suggestion was dismissed and, in our estimation, has resulted in several pronouncements by the Chief about future human performance that are not supported by past or present scientific research. Troubled by this situation, research was initiated at the Naval Postgraduate School to determine the extent that realistic human behaviors had been developed and implemented into simulation and what it might take to improve the Army's current capabilities.

Army simulation leaders recognize the problem and they seek to remedy it with integrated research, experimentation, and development. With direct support from the Human Behavior Representation (HBR) Working Group, the Army Modeling and Simulation Office (AMSO) engaged RAND to integrate the military unit Will to Fight model into OneSAF. This work is ongoing in mid-2019, and is scheduled to be completed by early 2020. Our objective is to integrate an empirically-derived, analysis-driven, broad-scope human behavioral model into the OneSAF simulation, and then to turn this work over as a minimally viable product to the OneSAF team at PEO-STRI for further development and practical use. In order to help integrate the Will to Fight model with existing and parallel work on physiological and psychological modeling and simulation, RAND is working closely with several Army programs and offices, including the Soldier Lethality Task Force, The Soldier Center at Natick, and others. All of these models and modules will eventually work together in some form to provide a reasonably realistic yet logically transparent human agent in OneSAF.

Many disciplines work to better understand human beings and model their cognitive, physical, and social systems (e.g. Artificial Intelligence and Machine Learning, Psychology, Anthropology, Kinesiology, Engineering). The National Academy of Sciences has been chartered to study the human being in the context of the military on several occasions (National Research Council, 1990, 1997, 1998). Decades of work have been executed researching and developing artificial intelligence capabilities to build smart entities and model human cognition and behavior (Silverman et al., 2006a, Sun, 2008). From our perspective, most of this work has been done to try and perfect the representation of intelligence with a secondary outcome of realistic behaviors and few of these models has ever been fully implemented in an Army simulation of record.

THE GAP: HUMAN BEHAVIOR IN SIMULATED FORCE-ON-FORCE COMBAT

Any effort to represent human behavior will tend to fall into one of two categories. The first category focuses on completeness (richness) of the representation. This is the category where a model developer attempts to capture all of the details from the literature dealing with humans. This tends to result in extremely complex models that are computationally intractable at all but the smallest of scales (Silverman et al., 2006b). The second category is one that attempts to follow the law of parsimony where the modeler abstracts away much of the human detail, which results in a representation that decision-makers do not trust. Since all models are idealized, the goal is to conceive and develop a human behavior representation that is both reasonable and parsimonious so as to be trustworthy.

An assessment of 62 military and commercial tabletop games and computer simulations showed that the military simulation community has not kept pace with commercial peers when it comes to human behavior representation. On the commercial side, computer games like *Close Combat* aptly represent a basic set of human characteristics in soldiers. Soldiers feel fear, they are pinned by incoming fire, sometimes they disobey orders when the orders seem nonsensical, and sometimes they flee. In contrast, nearly all of the simulations used by the U.S. military, from CARMONETTE in the 1960s through the most advanced modern examples like JCATS, COMBAT XXI, and OneSAF, represent humans as super soldiers (Connable, et al., 2018). In 2015 our colleagues at the Army Research Laboratories quoted a U.S. Army Soldier's observation about individual agents (soldiers) in OneSAF: "[They were] Super Soldiers who could stand face to face with a Shark-nado, shed only tears of joy, needed no rest or sleep, and effectively executed tasks after being in [full chemical protective gear] for the duration of the exercise" (McDonnell, 2015).

While HBR is lacking across military simulations, the RAND team did not invent the idea of adding human factors into simulated combat. In many respects the present work stands on the shoulders of groundbreaking and mostly unsung pioneers in the military simulation community. Their work is primarily—and, arguably, unfairly—captured in obscure journals, conference papers, and technical military reports. Some work is aptly recorded in full-length books, but most of these dense and technically focused analyses are not accessible to the leaders who sponsor military simulation work. Examples include the ground-up human behavioral modeling in EINSTein from the Center for Naval Analyses; work that Paul J. Bross and company did with JWARS in 2004; excellent work by the Australian simulation community on programs like MANA, and more recent efforts on OneSAF by ARL and on COMBAT XXI by LtCol. Byron Harder USMC (Spear & Baines, 2009; Connable et al., 2018). Despite all of this good work, human behavior is mostly absent in modern force-on-force combat simulation in the U.S. military.

BUILDING THE WILL TO FIGHT MODELS

In 2017, the Army G-3/5/7 funded RAND to build two models of "will to fight," a term that effectively encompasses the human dynamic of war. Understanding will to fight requires an examination of the factors that influence it. In this complex accounting, will to fight analyses consider the impact of materiel quality and capability on confidence in battle: How much does it help to have the best tanks, planes, and rifles, and how much does it hurt when materiel quality is poor, or quantity is insufficient? Will to fight also encompasses all of the difficult-to-assess cultural and psychological intangibles that are so critical to combat outcomes, including identity, esprit de corps, leadership, integrity, ideology, and cohesion.

RAND's military unit model is designed to help structure analysis to understand the will to fight of formations from squad to division level, and also for entire military services. For this model, will to fight is defined as *the disposition and decision to fight, act, or persevere as needed*. The second, national model focuses on the factors that influence the will to fight of senior political decision-makers. Both models incorporate the difficult-to-understand but critical cultural factors that so often elude military analysis. For example, both models consider the influence of popular support for a military conflict, and both models assess economic motivations and fears, but they focus analysis in different directions: one down to the organization or unit, the other up and in to the political center. Our simulation work has focused on the military unit Will to Fight model.

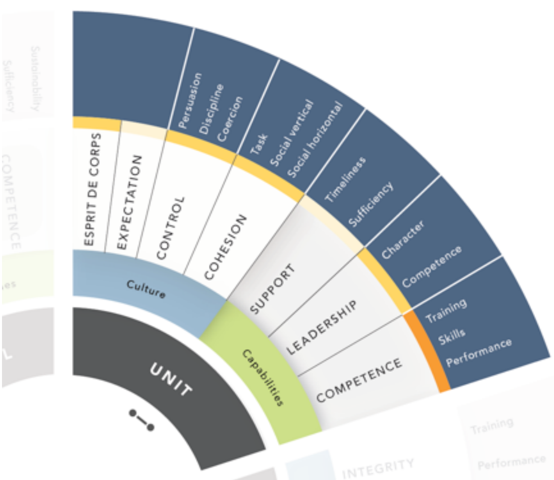

Figure 1 shows a zoomed-in slice of the Will to Fight model. Each of the factors is grouped together as a cultural influence or as a capability. Examples at the unit level include cohesion and esprit de corps as cultural factors, and leadership and competence as capabilities. RAND's report—*Will to Fight: Analyzing, Modeling, and Simulating the Will to Fight of Military Units*—describes all of these factors and provides the empirical basis for including them as key influencers on will to fight (Connable et al., 2018).

Intelligence analysts and military advisors are encouraged to modify and apply the model to help structure analysis and assessments of both adversary and allied or partnered military units. How likely are they to fight in a given circumstance? Where are their strong points and critical vulnerabilities? For adversaries, what can we do to weaken their will to fight?

Figure 1. The RAND Military Unit Will to Fight Model (Source: RAND RR-2341-A, *Will to Fight*)

Since will to fight cannot be easily quantified or distilled into a formula, it is sometimes hard to translate for the literal world of military analysis. Given this challenge, most assessments of combat effectiveness—the forecasted ability of a unit to fight and win in combat—default to summing and comparing physical assets or practical, quantifiable human actions like training time. For example, many analyses of a prospective Russian-NATO war in Europe tend to ignore critical questions, including but not limited to: (1) Are all Russian forces the same, or are some more likely to fight—and fight well—than others? (2) Can Russian will to fight be eroded or broken, thereby shortening a war or perhaps preventing it in the first place?

Military simulation offers a tangible way to help translate complex human factors into literal, quantifiable, and visible entities that tend to be more digestible than long narratives about culture, identity, leadership values, cohesion, and esprit de corps. ***As long as users understand that the numbers in simulation are analytic proxies, then simulation of human factors can be represented safely and effectively.*** The trick in using simulation to effectively represent human behavior is to ground the proxy data (notionally, something like "Soldier #3 has 14.2 will to fight") in real-world, empirical analysis that recognizes the limits of quantification.

THE JOURNEY FROM CONCRETE TO COMPUTATIONAL

In 2017-2018, with help from colleagues at the Army's Natick Soldier Center, the RAND team first applied an extant combat psychological model to the Army's Infantry Warrior Simulation (IWARS). Dr. Steven Silver developed this model for Microsoft and Atomic Games in the 1990s to help integrate human behavior into *Close Combat*. While they did not ingest the whole model due to its complexity, they did apply its general theories: If a soldier is shot at, and if his friends are wounded or killed, then he will experience fear and react to that fear based on his psychological profile and combat experience. Silver's model applies a trait-state approach in which soldiers enter combat with certain traits—aggressiveness, intelligence, and even humor—and then experiences create fluctuations in those states as combat unfolds. Experiments with the Silver Model in IWARS established the first step towards a grounded, empirical argument for incorporating human behavior into force-on-force combat simulation. To study this argument, we proposed the following simple, but important hypothesis for initial experimentation:

> H^1: Comparative analysis of automated computer-simulated force-on-force combat using identical programs and scenarios will show that applying a will-to-fight behavioral modification model will always—to varying degrees—change agent behavior and overall combat results.

Unsurprisingly, 7,840 runs across multiple scenarios in two experiments demonstrated that adding human behavior to military force-on-force combat simulation always changes combat results from the baseline "super soldier" event (Connable et al., 2018). Table 1 shows results from the first series of the third simulation experiment using the Silver model in basic Blue-on-Red, face-to-face combat with varying terrain. In each case the odds of victory changed when human behavior was added to the scenario. *No fewer than one in ten soldiers fled combat. Kill ratios fluctuated as psychological state changes led to delays in firing and shifts in fire superiority.*

Table 1. Sample Results from RAND IWARS Experiment 3, Series 1

Scenario *With* Versus *Without* the Silver Model (CPM)	Odds Ratio to Blue Loss	% Change to Blue Fleeing	% Change to Blue Hesitating	% Change to Red Average KIA	% Change to Blue Average KIA
Blue Cover, Red Weak	2.06	24.3	4.3	2.0	3.7
Blue Cover, Red Equal	1.64	23.9	4.5	–2.5	6.3
Blue Red Equal	0.89	16.3	3.4	–6.5	–4.8
Platoon	1.37	11.6	6.6	–2.5	0.9

(Source: RAND RR-2341-A, Chapter 3)

One set of experiments does not settle the issue of the value of HBR in simulation. Some simulations have narrow, technical purposes that cannot afford, and that would not benefit from additional human-like behavior. But these initial experiments do raise important and perhaps troubling questions for designers and consumers of force-on-force combat simulations. ***If the general purpose of force-on-force simulations is to help understand the likely outcomes of prospective combat; and if super-soldier simulations are skewed by at least 10% (or as we show, ~20%, ~30%, and in a few cases ~60%) due to lack of generally-representative human behavior; then these simulated combat events may be misleading senior military leaders.*** Simulation events are often laden with caveats to prevent leaders from extrapolating results too far into the real world. But these caveats cannot prevent leaders from learning the wrong lessons from our work. If H^1, above, is consistently proven with additional simulation experiments, then the community must address what will be a known and glaring gap that has potential real-world consequences.

THE IMPLEMENTATION PROCESS

Human behavior representation has not found an anchor in contemporary simulation in great part due to the perception that existing human behavior models are too "squishy," too unpredictable, and not sufficiently grounded in proven science. With this challenge in mind, this project is building a OneSAF HBR module grounded in the Will-to-Fight model that is, in turn, derived from a 9-part, multi-method research effort and represented in over 200 pages of research findings. The research team added four additional steps into the typical model-to-sim loop: (1) a structured analytic tool to develop tailored will-to-fight "scores" for each side; (2) tabletop gaming to help test out and refine the transition of factors, variables, and rules from model to simulation; (3) incorporation of a proven psychological model to add reasonable, parameterized variation for each agent; and (4) a proven social science model for group behavior.

Building from the Will-to-Fight model and the analysis from the Will-to-Fight tool, the RAND team designed and tested the model and analysis using a tabletop game. The game simulates battles between the Iraqi Army and the Islamic State in the Iraqi city of Mosul in 2014 and in 2016-2017. The game represents individual soldiers as agents at approximately a 1/50 scale (28mm). Its purpose is to help test and modify the representation of will to fight at the soldier level before the expensive and time-consuming process of coding begins. In addition to providing a sandbox for the team to rapidly revise rules, the manual game also enables direct engagement by researchers with relevant operational experience who can help refine the application of the model to the scenario context.

The research team is building empiricism in layers by integrating the Will to Fight model—which itself is informed by the literature on psychology and sociology—with broadly-accepted psychological and sociological models. At the agent level the OneSAF Will-to-Fight module will include a parameterized version of the standard Five Factor personality model. This model is grounded in decades of literature and it is the most widely used model for psychological analysis and testing in both civilian and military medicine. At the unit level the OneSAF module will incorporate a sociological cohesion model that represents vertical and horizontal cohesion, as well as task cohesion. These three elements of cohesion are widely understood in contemporary literature to represent the ways in which bonds form (or do not form) within a military unit.

Today the team is working on implementing the gaming rules from the tabletop games into computational prototypes that will ultimately transition into OneSAF. The majority of these rules regarding individual combat behavior have been implemented in a prototype for IWARS as an initial proof of concept to test computational viability and alternative representational schemes that would have downstream implications regarding computational expense, i.e. memory, processing, for large-scale populations of simulated combatants. Additional prototyping has been developed within Netlogo for exploring group dynamics associated with unit behavior and cohesion dynamics associated with command and social networks within military forces. As the psychological, group, and combat dynamics associated with will to fight are being developed as separate but interacting conceptual and software modules, the initial minimally viable product for this research phase is deliberately designed to be extended by allowing future research to modify or substitute component models with new components that rewire agent attributes in new ways, or introduce new internal representations of agent attributes at the individual and group levels to keep pace with relevant social and psychological research.

INTEGRATING SOCIAL INTERACTION

The current implementation of group dynamics in the Will to Fight model is based on social network influence theory (Friedkin 1990, Friedkin & Johnsen 2014). The selection of social network influence theory as an initial group effects model was based on theoretical and technical features of the model and its history of applications in the study and prediction of beliefs in small groups. As a theoretical construct, the social network influence model provides a set of generalized rules regarding interpersonal influence that is sensitive to specific structural configurations of networks and the extent to which individuals balance confidence in their own beliefs and the opinions of those around them. From the perspective of will to fight, the disposition of soldiers is then characterized by their innate psychological characteristics and the disposition of others within their social groups—that may include others within physical proximity as well as peers and leaders that provide social support. This initial formulation assumes fixed network structures, with link structures and weights being parameterized according to parameter values that represent analytic assessments of social, vertical, and horizontal cohesion. The introduction of task cohesion as an alternative source will be modeled through the development and sustainment of shared mental models and problem-solving strategies within groups. Whereas social, vertical, and horizontal cohesion are theorized as network positions that affect the flows of disposition and support between individuals and groups, task cohesion rests upon the development of common cognitive processes associated with situational understanding, problem solving, and task execution that enables effective collective behavior by military forces. Therefore, the modeling of task cohesion requires an alternative set of parameters and computational mechanisms to include within the larger computational Will to Fight model.

The technical benefits of the social network influence model are derived from the simplicity of the model in mathematical terms, and the fact the model is deterministic given a specific set of agents. Given the challenges associated with incorporating many different lines of research and theoretical reasoning about will to fight, minimizing the sources of stochastic variation provides multiple benefits to developers and analysts during this early phase of designing and building a minimally viable product. Depending upon analytic results, the desire for increased internal complexity of agents, and evolving theoretical and empirical research trends and findings, the social network influence model may be substituted with alternative models that simulate the relationships that group structures have on individual, agent-level disposition. An example of an alternative, dynamic model of interpersonal influence related to the diffusion of fear and panic is the Agent Zero framework (Epstein, 2014)

The group dynamics model, implemented and tested in the NetLogo simulation environment as a Java-based extension for portability into OneSAF uses the standard form of the social network influence model as depicted in Equation X below:

Equation X:

$$\boldsymbol{y_i^{t+1} = a_{ii}\sum_{j=1}^{n} w_{ij}y_j^{(t)} + (1 - a_{ii})y_i^{(1)}}$$

In Equation X, the disposition of agent *i* at future time t+1 is the left-hand side y_i^{t+1}. Each agent's future disposition is given by the weight that each agent places on the disposition of others a_{ii} in its network and the weight it places on its initial disposition $(1 - a_{ii})y_i^{(1)}$. The effects of each member *j* in *i*'s social network is the weighted average of *j*'s disposition multiplied by its weighted influence on agent *i*, $w_{ij}y_j^{(t)}$. The total influence weights of all members of agent *i*'s social network, w_{ij}, sum to 1, which includes all members of the population n, excluding oneself, *i*. Likewise, dispositional values, *y*, and weights of internal vs. network weights, *a* are on the interval [0, 1]. The social network influence model is simultaneously sensitive to individual values denoted by each agent's initial disposition, the extent to which they are anchored on that value, the network structure and dispositions of other group members, and the relative weight each agent assigns to aligning their disposition with others.

BUILDING OUT BEHAVIOR

Agent-based modeling allows the creation and simultaneous execution of multiple routines that represent the mental and physical processes that human soldiers voluntarily and involuntarily consider as they act. Using IWARS as the simulation development platform has allowed prototype testing and tuning of the rulesets developed for the 28mm game before implementation into a more comprehensive simulation. The strengths of IWARS include its programming simplicity (evaluations typically obtain as true or false), the graphical display of routines, and unique naming of evaluation 'boxes' all of which eases runtime verification. However, IWARS has limitations in how complex the evaluative expressions can become and the scripting required to enable inter-agent relationships is not straight forward. Figure 3 shows the IWARS *Mission Builder* interface and the current Will to Fight (WtF) engine.

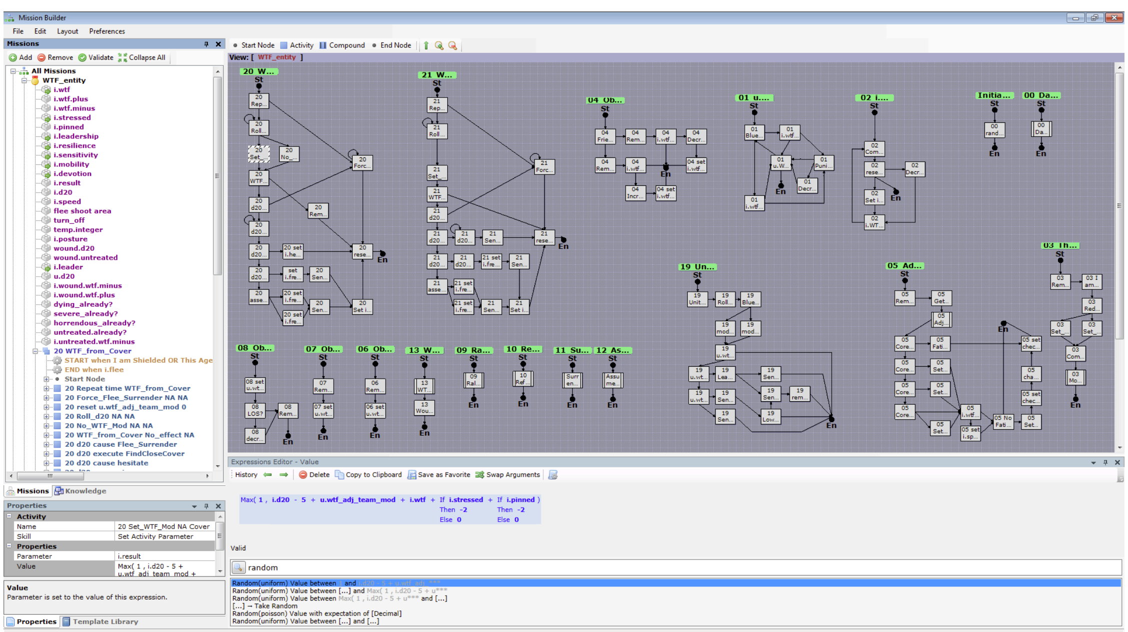

Figure 3. Infantry Warrior Simulation (IWARS) Mission Builder Interface with Will to Fight Engine

(Source: RAND screenshot from IWARS Version 5.1.2 developed by AMSAA and Technology Solutions Experts, Inc.)

Using IWARS before implementing into OneSAF helps identify tailoring that is required when converting rulesets from the tabletop game to autonomous simulation, accommodations for enhanced features that simulation offers (such as simulation tick updates to physiological models or physics-based combat adjudication), and challenges that arise when layering multiple routines. Our strategy for a successful software implementation has three parts: detailed specification, runtime verification, and tuning.

First, we identified specific triggers or predicates that lead to departures in expected behavior by using the specifications from the 28mm tabletop game. Table 2 summarizes the 28mm ruleset and then breaks out which predicates, sometimes evaluated with additional chance, cause which outcomes. **Bolded** items are implemented in version 0.65 of the IWARS Will to Fight engine. These items were selected based on their applicability to Battle Drill 2A and feasibility of coding in the IWARS logic engine. Items marked with a Y are implemented as written in the ruleset but transformed to simulation tick execution vice turn based. Items marked with an M are modified as follows: a) uses IWARS suppression state, b) uses IWARS physiological model, c) excludes unit cohesion and competence factors. Items marked with an N are not implemented for the following reasons: 1) feasible but trimmed to reduce complexity, 2) not in Battle Drill 2A, 3) uses existing IWARS combat adjudication that does not allow runtime performance degrades, 4) uses IWARS physiological model. Outcomes with an * manifest as actions that the agent takes. Unit level of execution is only conducted by a designated leader which follows a succession tree. Marksmanship includes geometry computations present in the 28 mm game.

Table 2. Summary of 28mm Rules, What WtF Factors act as Predicates and What Outcomes Result

			28 mm predicates									28 mm outcomes										
Level of Execution	28 mm Rule	Implemented into IWARS	Individual WTF	Unit WTF	Fatigue[4]	Marksmanship[3]	Leadership	Resilience	Sensitivity	Devotion	Cohesion	**Individual WTF**	**Unit WTF**	**Fatigue**	**Hesitation ***	**Freeze ***	**Refusal ***	**Flee or Surrender ***	**Find Cover ***	Combat Adjudication	Movement	Other
Individual	**No Cover**	**Y**	X												**X**	**X**	**X**	**X**	**X**			
	From Cover	**Y**	X												**X**	**X**	**X**	**X**				
	Near Miss	**M[a]**	X					X				**X**			**X**	**X**			**X**			
	Individual Casualty	**M[a]**	X					X				**X**			**X**	**X**			**X**			
	Sprint, Shuffle, Enter, Stairs	**M[b]**			X																X	
	Burst Fire/Blast Casualty	N[1]	X					X				X			X	X			X			
	Atrocity	N[2]	X						X			X										
	Civilian killed	N[2]	X						X			X										
	Aimed Rifle, Burst, Hand-to-Hand	N[3]	X			X																
	First Aid	N[1,2]			X																	X
	Rest	N[4]												X								
	Communicate to Civilian	N[2]																				X
	Blast Vehicle Damage	N[2]																				X
	Advisor Killed	N[2]											X									
Unit	**Rally Unit**	**Y**	X	X								**X**										
	Failure	**Y**					X	X				**X**										
	Unit WTF on Individual WTF	**M[c]**		X			X				X	**X**					**X**	**X**				X
	Rally Individual	N[1]					X	X					X									
Game Mechanics	PSYOPS	N[2]						X	X	X		X										
	Heavy Weapons Actions	N[2]						X	X	X		X										
	Advisors designating indirect fires	N[2]	X			X														X		
	Vehicles	N[2]	X			X														X		
	PSYOP attack	N[2]								X		X										
	MILDEC	N[2]																		X		
	Communicate to Civilian	N[2]																		X		
	IED	N[2]																				X
	Sniper fire	N[2]																		X		

Predicate values are stored in *Knowledge Parameters* known uniquely to each agent with default decay times, which is the time period where knowledge is designated as stale (5 second default). Outcomes are caused by routines and are either continuously evaluated with a constant cycle time or are triggered by a known set of conditions.

Outcomes that manifest as actions are:

- Hesitate: Inserts a 5 second pause when re-firing a weapon. Resets to 0 during each cognitive cycle. Conversion from a turn-based mechanic to simulation tick required establishing process cycles that limit how often routines may execute. Cognitive delay represents the internal thought process of the agent, set as 5 + random (uniform) 0…10 seconds. The variation represents fluid intelligence (Cattel, 1971). Similarly, process delay is set as 30 seconds with the same variation and represents the decision-making cycle of the agent. This does not apply when the entity is fleeing and is triggered by the individual will to fight check. There exist two routines for individual will to fight checks, either from cover (when using a shield or in prone posture) or from no cover (crouching or standing posture). The routine path is generally the same except for thresholds and magnitudes of outcomes that are slightly larger for the no cover routine.
- Freeze: Prevents execution of weapon firing or movement routines. Based on events, can be established up to a maximum of 3 but is not cumulative. Decrements by one during each cognitive cycle. When a freeze is observed by another agents, temporary individual will to fight modifications occur. This is triggered by the individual will to fight check.
- Refusal: Same as freeze except this is triggered by a unit will to fight check.
- Flee or Surrender: Causes the agent to stop executing offensive and defensive actions and instead flees to a waypoint while sending return area fire. Surrender occurs when an agent is proximal to an OPFOR agent. As an example of an IWARS limitation, although the surrender state is recorded, IWARS lacks the complexity to shift RoE for a surrendering agent and accept surrender. This outcome is triggered by the individual will to fight check.
- Find Cover: Causes agent to search for, move to, and use nearby shields. IWARS uses stochastic shield generation according to a specified density and generation area. To avoid obfuscation caused by this, 10 discrete shield areas (100 m^2) are placed between the two forces with sufficient density to reasonably ensure there is a shield that can be used by a nearby agent. If none are available, posture changes to prone. This is triggered by the individual will to fight check, near misses, and individual casualty.

ENTITY BEHAVIOR WITHOUT THE WILL TO FIGHT ENGINE RUNNING

A simplified Battle Drill 2A (React to Contact) was used as the baseline scenario for initial testing. Without the Will to Fight Engine running, the blue squad marches toward the red squad in a wedge formation. Red initial contact forces blue elements to go prone. Blue fireteam 1 (FT1) then approaches the front line while blue FT2 flanks along a perimeter path. At T+5 minutes, both blue fireteams alternately bound towards red, targeting the highest threat when aware of one or laying down suppressive fire in the initial red area. At T+6 minutes, red bounds towards the initial blue area with the same shooting doctrine. The scenario ends at T+15 minutes. A constant seed is used to allow deterministic comparisons. The Will to Fight engine will only be added for blue with the data collection plan including agent known individual will to fight, unit will to fight, duration of hesitation(s), duration of freeze(s), and will to fight triggers/outcomes.

RESULTS WITH WILL TO FIGHT ENGINE RUNNING

The addition of each routine adds some compute time for each of 9 agents in the blue force, and scalability will pose challenges as the scenario is ramped up to the brigade level. Scalability aside, just the interconnectedness of the routines, with multiple generated conditions that may interrupt, resume, restart or end routines, creates complex behaviors that necessitate rigorous programming verification. Challenges that have already been encountered include overwriting knowledge parameters out of sequence, unwanted termination or continuous looping of routines based on generated conditions, attempted running of multiple routines due to simultaneous receipt of triggers from more than one agent, and cascade effects. As examples, Figure 5 (left) shows the unit Will to Fight routine, conducted by a designated leader, that can cause unit wide unit and individual will to fight semi-permanent modifications, freezes, leader replacement (due to failure to rally), and surrender.

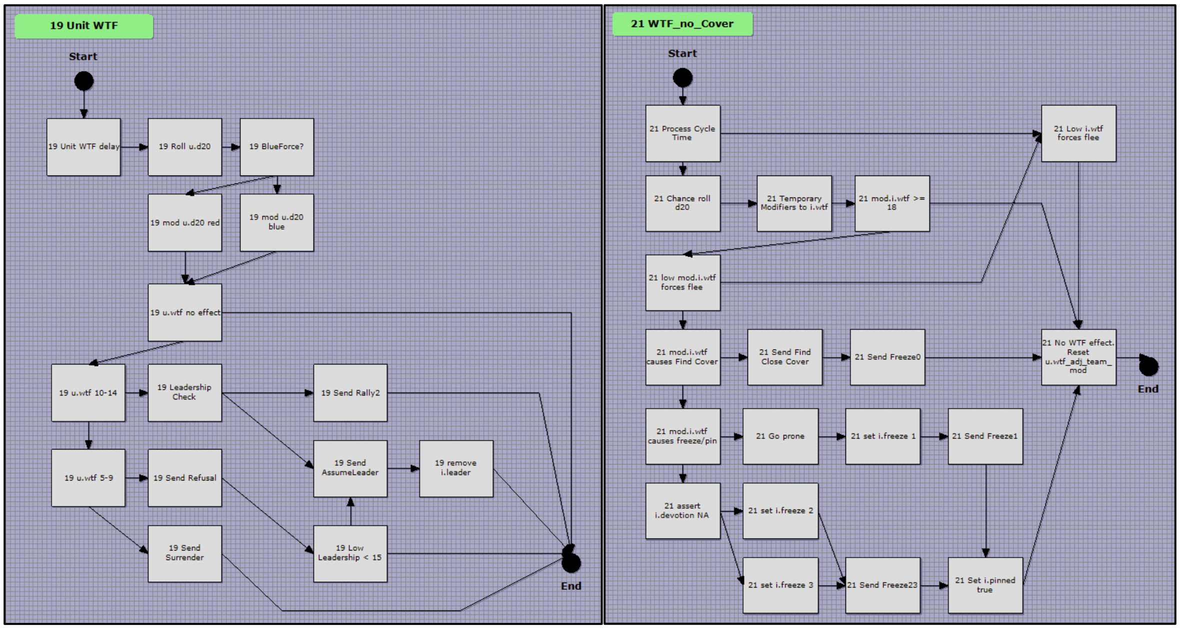

Figure 5. Will to Fight Routines for Unit Adjudication and Individual "no-cover" Adjudication
(Source: RAND screenshot from IWARS Version 5.1.2)

Figure 5 (right) shows the individual will to fight with no cover routine, conducted by every agent, that can cause the find close cover action, individual freezing, or the flee action. In turn, friendly agents that observe certain behaviors, such as freezing, also cause temporary modifications to their will to fight adjudication. At this stage, these apparently complex outcomes are not due to emergent group behavior but rather several individual behaviors that interact out of sequence; we believe this is appropriate given how a real human's will to fight is affected by both endogenous and exogenous factors.

Once the ruleset specification is implemented and programming logic verified, significant tuning will be required for each scenario where the Will to Fight engine is applied. This is normally part of the validation process, where simulation outcomes are compared to real-world benchmarks and simulation parameters are adjusted for authenticity. Unfortunately, little empirical data exists that measures human performance while quantitatively measuring endogenous and exogenous factors. We intend to partner with other research efforts, led by Army Futures Command, and incorporate human research results like those from the MASTRE project into this step.

Figure 6 provides a glimpse of how will to fight factors could dynamically change throughout the simulation allowing for a quantitative analysis of run results. While unit will to fight does not change for any agent, individual will to fight dips and restores near the end of the run likely due to friendly and OPFOR casualties. Several cycles of freezing are seen, the largest peak indicating that at least 3 members of Fireteam 2 are frozen at the same time. By holding the randomization seed constant, Will to Fight parameters (individual will to fight, resilience, sensitivity, etc.) can be varied with other conditions remaining the same such that the influence of that specific parameter can be understood, tuned if necessary, and then tested in a stochastic scenario for significance. This entire process will be repeated for OneSAF in a constructive setup with some notable differences. Because OneSAF allows the Java software coding of complex behaviors, has the ability to incorporate performance degrades during runtime, and allows more integration between existing behavior models (such as movement, weapon firing, etc.), more sophisticated evaluative logic and sociological network modeling will be possible. With that advanced functionality, additional challenges in software integration are likely as is the possible need for existing behavior models to be modified to accept will to fight interaction.

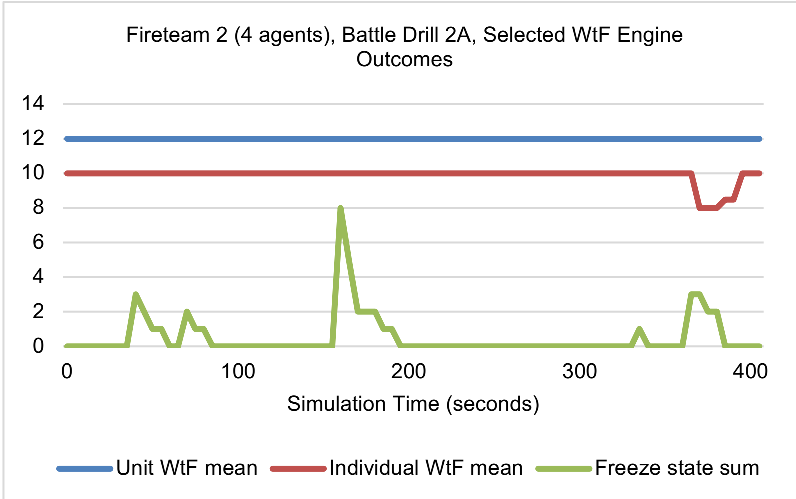

Figure 6. Dynamic will to fight Parameter Changes during Preliminary Simulation runns
(Source: RAND analysis)

NEXT STEPS

Implementation and tuning of the computational Will to Fight model as a baseline of human behavior representation in simulation continues as this paper is being written. As previously indicated, the project deliverable is a minimally viable product that will be integrated into the OneSAF simulation. The authors are continuing to pursue additional modules to be integrated into the human behavior representation such as DREEMS. DREEMS is the dynamic representation for evaluating the effect of moderators and stress on performance. This work is a SIBR funded by the Soldier Center developed by Charles River Analytics. We believe that there will be extreme goodness in the integration of DREEMS with the Will to Fight model in the HBR space. Additionally, discussion is underway to formalize HBR governance and leadership for the Army in the Combat Capabilities Development Command of the Army Futures Command. The current vision includes both executive and technical boards to guide the research and development of HBR.

ACKNOWLEDGEMENTS

The authors would like to thank the Army Modeling and Simulation office for supporting this research and everyone who participated in the human behavior representation working group activities.

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