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TOWARD BETTER MANAGEMENT OF POTENTIALLY HOSTILE CROWDS

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ABSTRACT

The U.S. Capitol protest and siege in January 2021 provides a vivid demonstration of the challenges posed by managing potentially hostile crowds. Individuals in these crowds are organized into identity groups. Crowd participants' emotions, beliefs, objectives and group affiliations are dynamic. Security forces managing such crowds are tasked with the weighty decisions of tactical rules-of-engagement and choice of weapons. We have developed an agent-based simulation modeling the detailed psychological and behavioral dynamics of individuals and groups in a potentially hostile crowd. This crowd is modeled as actively engaging with security forces that protect a compound. The user can specify crowd attributes, choose diverse non-lethal weapons and rules-of-engagement, watch the event play out, and see the impacts on key outcomes of crowd attitudes and actions. We present our prototype simulation and initial experimental results. We then discuss our future plans for this research.

1 INTRODUCTION

The U.S. Capitol protest and subsequent breach in January 2021 provides a vivid demonstration of the significant role social identity dynamics play in volatile crowd situations. The evidence indicates that several extreme organizations and salient social identity groups arrived with the intention of breaching the Capitol (McDonald and Hymes 2021). Others in the crowd, initially intending only to protest, also stormed and breached the Capitol, helping to overwhelm the Capitol police force (Hoerst 2021). Yet most protesters did not take part in the violence; thousands were at the protest but only several hundred stormed the capitol. During the breach, reactions of the security forces included use of a number of non-lethal weapons and tactics as well as a documented instance of lethal force.

The January events at the U.S. Capitol provide a domestic security example of common situations faced by military and security forces. Peacekeepers also encounter unstable, confused, or hostile crowds from opposing social identity groups, and they use a variety of non-lethal approaches to reduce the likelihood of violence. Humanitarian assistance organizations and the security forces protecting them likewise encounter potentially hostile crowds, especially during disasters. How do social identity dynamics and real-time events influence crowd behavior in potentially hostile situations? In turn, how can the composition or behavior of security forces influence the crowd's level of hostility? Individual case studies cannot provide generalizable answers to these questions. By simulating crowd scenarios, including security force size and composition, the set of weapons and tactics used by the force members, and the nature, composition and intentions of the crowd, we can identify weapon choice and rules of engagement that are more likely to produce desired results for crowd management.

Over the last several years, our group at the Naval Postgraduate School developed a comprehensive simulation that explicitly models these situations. We emphasize the social identity dynamics of people and groups that have potential to form a hostile crowd, along with physical, psychological and social aspects of these individuals. The physical context for the model is an urban area consisting of a compound and the surrounding buildings and roads, where a crowd of individuals engage in various behaviors and security forces patrol and protect the compound using a range of less-lethal weapons and tactical rules of engagement. In this paper we describe the main components of our completed prototype simulation, the Workbench for refining Rules of Engagement against Crowd Hostiles (WRENCH version 4.0). We further present sample results from a data farming experiment and analysis that demonstrate the potential for this simulation, then discuss future developments. Data farming, in significant contrast with data mining, is a technique for prospectively generating or growing data by running large-scale simulation experiments with efficient combinations of input settings, also called design points (Sanchez and Sanchez 2017).

2 WRENCH DESCRIPTION

The eventual goal of our WRENCH simulation is to inform the development of rules of engagement for security forces that better control crowd behavior without negative repercussions, using the least amount of force. Our immediate goal is to identify potential effects of different security approaches, providing a testbed to explore possibilities. The purpose is not to predict specific outcomes, but to identify ranges of effects that are likely to occur. The crowds of concern to the security forces are composed of civilians, not opposing military or criminal personnel, resulting in challenging policy choices for authorities to maintain control. Empirical research published in psychology and social movement literatures informed the model components we used to model social and individual identities, as well as individual motivators, attitudes, and emotions. We then integrated these components into a conceptual metamodel, which was then coded to form the WRENCH computer simulation model.

The initial application of WRENCH concerned the incorporation of non-lethal weapons in the force continuum, addressing how selection of weapons and tactical rules of engagement affect crowd response. The goal is to effectively deescalate potentially volatile situations while maintaining force legitimacy. Development of WRENCH has been primarily funded by the U.S. Joint Intermediate Force Capabilities Office (JIFCO, the former Joint Non-Lethal Weapons Directorate).

WRENCH is a stochastic agent-based simulation model programmed in NetLogo 6.1. (NetLogo is a free, open-source agent-based simulation modeling platform (Wilensky 1999); version 6.1 was released in 2019.) WRENCH is therefore a bottom-up model, where each agent's internal construction informs their responses to interactions with other agents and the environment, and those interactions then inform the agents internal states. The model incorporates empirically derived principles to drive behaviors, which then aggregate within the social and spatial constraints of the model. A typical model within WRENCH covers a specific geographic area that includes detailed geographic features such as roads and buildings drawn from GIS data. Each individual has their own demographic characteristics, emotions, needs, experiences, perceptions, intentions, and behaviors, and can have a social identity group (SIG) identification. Each SIG in the model has constituents, needs, intentions, and possibly a higher level SIG identification. Each member of the security force is also modeled separately, including their own intentions, behaviors, perception of threats, and roles within the force structure. The available less-lethal weapons, tactical rules of engagement, overall force relationship with the population, and other details are also explicitly modeled. At present the SIG identity of the security forces is modeled as their static command hierarchy, unlike the dynamic SIG identities among the crowd.

In WRENCH, people move around the geographic area while security forces patrol and guard the compound to maintain security. People who have increasing anger, unmet needs, or hostile intentions may develop hostile behavior toward the forces. Once the security forces perceive hostile behavior among the population, the forces engage the threat according to the rules of engagement and force continuum options specified for the scenario. The non-lethal force continuum options range from low severity (e.g., verbal warnings, acoustic hail and laser dazzler devices) to high severity (e.g. tasers). When crowd hostilities have abated, security forces resume their guard and patrol behaviors to maintain security. Current scenarios run with a 1-second time-step and cover a relatively small geographic area.

In the following sections we give an overview of several key aspects of WRENCH.

2.1 Modeling of Individuals and Groups in the Crowd

In WRENCH, individuals in the civilian population are modeled as having two primary components: a physical, behavioral component (Person agent), and a mind, emotions component (Identity agent). Identity agents are also used to model social identity groups (SIGs). Overall, individual identity agents and SIG identity agents have the same design and variables, but influences on these variables differ. Thus we use the distinguishing terms *individual* and *SIG* to specify each where needed. Variables within each agent are updated based on the values of multiple influencing variables. Updates for some agent variables (e.g. fear, anger changes prompted by immediate stimuli) are made every time step with no delay. Other variable updates, such as those that represent the results of conscious decisions, occur at longer intervals. And some updates are time-delayed, such as fear and anger responses to weapons impacts that were reported to a person by other SIG members, rather than personally witnessed or experienced. Most variable influence relationships use deterministic formulas, whereas decision intervals, time delays, and some aspects of movement have stochastic elements.

2.1.1 Identity Modeling for Individuals and Social Identity Groups

All identity agents have variables representing their emotions, attitudes, intentions and objective, and they can identify with a higher SIG. In this section we describe the main constructs of identity agents and what influences these constructs. Psychological and sociological literature informed the design and functionality of these agents. Supporting information is provided as space allows. Further information is available from the authors.

2.1.1.1 Fear, Anger, Illegitimacy, and Hostility

At the most basic level, identities are modeled with the emotions of fear and anger, and a belief regarding the legitimacy or illegitimacy of the security forces. Individuals' emotions and beliefs about legitimacy change in part due to perceived mismatch between the severity level of a weapon deployed by the forces and the hostility of those impacted by the weapon. For example, if the deployed weapon was perceived as somewhat too severe, it immediately arouses anger; if it is perceived to be dangerously severe, it immediately arouses fear. Impacts that are seen as lenient also affect fear and anger, but to a lesser degree. WRENCH models other details pertaining to anger and fear, such as social contagion and dissipation of emotions over time, and the additional fear of mothers protecting their children. It also models complexity around weapons impacts (whether experienced, witnessed, or heard about from a fellow SIG member) along with an individual's perception of another's emotions, distinct from the other's actual emotions. In addition to contributing to fear and anger, perceived weapon severity mismatch is interpreted as injustice. Such perceptions of injustice drive an individual's perception of the security forces' legitimacy. Finally, an identity's hostility level or hostile intent is driven by their anger, fear, and beliefs about force legitimacy. While hostility level does not fully determine behavior, it does contribute to behavior.

These constructs and dynamics are supported by our conceptual literature review. Emotion is thought to result from experience (pain, pleasure, physical change, observations) and cognition (interpreting what we feel and observe). The cognitive process that triggers emotion can be conscious or unconscious. When something changes, people can experience immediate flashes of emotion, and these emotions create action readiness (Frijda 1986) that may lead to behavior change. Anger can contribute to aggression, since individuals often confront the cause of their anger. While usually believed to cause people to flee, fear can also lead to aggression, particularly when conflict appears unavoidable (Spanovic et al. 2010).

The model includes factors that people use to decide if security forces are just and legitimate, two linked but distinct determinations that directly affect crowd-security force interactions. Perceptions of injustice have historically been powerful motivators for protest, both violent and non-violent (Goodwin et al. 2001). The greater the perceived justice, the greater the likelihood that people will view the security forces as legitimate and cooperate accordingly (Tyler 2011). People arrive to crowds with a pre-existing idea whether security forces are legitimate; this is initially an external variable. Baseline belief in security force legitimacy leads people to believe that the security forces have a right to exercise power (Tyler 2006), so security forces perceived to be legitimate are less likely to need force or threats as deterrents (Schulhofer et al. 2011). For example, police perceived to behave in accord with accepted moral standards are afforded greater legitimacy and their directives are more likely to be followed (Jackson et al. 2012). In contrast, security forces that demonstrate procedural injustice, whether through disrespectful behavior or unfair decision-making “erode the extent to which citizens value the police as group authorities, as well as the subsequent identification they have with the set of rules that legal authorities enforce. This leads individuals to question whether the authorities are in a position to dictate proper conduct." (Jackson et al. 2012).

2.1.1.2 Needs

Identities are modeled as having personal satisfaction levels of each of three types of needs, reflecting work by Maslow (1943), Herzberg (1964), and others (e.g., Alderfer 1969). These include physical/safety needs (represented in our model as being status), social and esteem needs (represented as belonging status), and self-actualization needs (represented as becoming status). The being status indicates extent to which an identity has what it needs for basic survival. For an individual identity this represents the survival needs of the associated person, but for a SIG it represents the resources the group itself needs in order to survive. A low being status (or high being need) will drive an individual identity to acquire resources from others or protect what they have. The belonging status indicates extent of perceived belonging with others who have a shared belief in colleagues’ willingness to share sacrificially. A low belonging status (and thus high need for belonging) may motivate the identity to change how they relate to one or more other identities. The becoming status indicates belief of the identity in themselves as one who offers or is worthy of nurture (has or receives compassion). A low becoming status (high becoming need) can prompt an identity to seek nurturance from a SIG, offer to join with another identity to create a SIG so that they are nurtured, or, if a SIG themselves, invite another identity to become a constituent member.

2.1.1.3 Objective and Intentions

Each identity has an overarching objective and specific intention. The objective is influenced by the identity’s attributes and changing levels of fear, hostility, illegitimacy beliefs, and being status. If the identity is a member of a SIG, their objective is influenced by the group (SIG) objective. Each identity begins with a particular objective such as “protest”, “attack”, or “stay-safe”, or just go about their own business (“none”). A complex set of rules governs the changing of an identity’s objective, but an objective does not change quickly or frequently. While an individual’s hostility and fear generally align logically with the identity’s objective, and the individual identity’s objective with the person’s behavior, this alignment is not forced; objectives and intentions are not driven by emotion alone. For example, an identity with the objective of “attack” may not necessarily be extremely angry.

An identity’s objective drives their intention. For an individual identity, this resulting intention is the primary driver of the associated person’s behavior. For example, a “protest” identity objective results in a “converge” identity intention, so the associated person then approaches the target of the protest (usually a compound gate) and mills about at a distance specified in the intention (based on other identity variables). An “attack” identity objective will motivate a “converge” identity intention at a distance of zero, meaning the associated person will charge the gate entry point and, once they reach it, try to get past the guard and enter the compound.

2.1.1.4 Social Identity Group Dynamics

Any identity, individual or SIG, can be a member of a ‘higher’ SIG. Whenever a WRENCH scenario is populated with a new set of individuals, all babies and children are automatically placed into a family SIG with a mother. (Each mother can have one baby 'in-arms', and any number of additional children with them.) All other SIGs are created dynamically during a simulation run, based on the emotions, needs, and objectives of the identities. For example, if an individual in a crowd becomes very fearful, that individual identity may join a SIG or create a SIG with similar people nearby (Spanovic et al. 2010). If an identity finds that their objective differs from the objective of their higher SIG, and the individual's emotions are highly inconsistent with the SIG's objective, that person may leave the SIG. If a SIG is left with only one constituent, the SIG dissolves. Only family SIGs are not dynamic (so babies and children never leave their mother, and the mother never leaves them).

These constructs and dynamics are supported by social identity theory. People categorize themselves as belonging to particular groups, view in-groups favorably, and view out-groups unfavorably. Social identities are compelling, even if the individuals in the group do not know each other (Kou and Gui 2014; Hopkins et al. 2016; Novelli et al. 2013). People have stable social identities, and new identities arise from "shared problems, shared goals, perceptions of vulnerability, and collapse of previous group boundaries" (Ntontis et al. 2018). The idea of discrimination is built into social identity theory: identification with a group creates social prejudice that can justify negative or even violent intergroup actions. In social movement theory, this perspective is called collective identity (Klandermans 2002).

Social identity theory was developed further, mainly by Drury and Reicher (2000), into the elaborated social identity model for crowd behavior. Directly contrary to old theories, it is not the loss of identity that characterizes a crowd but the joining of people into their shared social identities or into a new social identity that is crucial to crowd dynamics (Neville and Reicher 2011). Crowds are built from many smaller groups, and interactions with authorities often reflect in- versus out-group perspectives. Changes in social identity are key to crowd actions (Stott et al. 2017). A shared collective identity underlies crowd behavior and reactions to events and to other groups. Likewise, social identity underpins the spread of particular crowd tactics, such as violence, and the communication of emotions. Both the individual and the changing social identities must be modeled as dynamic (Edmonds 1997; McPhail 2006).

As an example of identity dynamism, Drury and Reicher (2000) analyzed a case of altered behavioral norms and social identities in the midst of a protest against road expansion. As the police violated participants' expectations of police behavior, turning from neutrality and respect to unfair and illegitimate treatment in participants' eyes, the crowd responded with normative and identity changes. Norms against violence altered, and identities shifted from protesters to activists. Simply put, crowd participants became radicalized from outrage at security forces' treatment of them. When they felt the police were no longer treating them with respect, they felt free to reciprocate that lack of respect toward the police.

2.1.2 Person Modeling for Individuals

In WRENCH, a person agent has been designed to model the physical component of an individual, functioning primarily as a conduit where the objective and intentions of the individual identity are acted out in the physical environment, and the effects of the physical environment are translated into effects on the individual identity. The environmental factors that affect a person's individual identity include proximity to danger, the displayed hostility of those nearby, and the impacts of weapons. People agents also respond to the physical environment, particularly roads, patrol cars, buildings, and other people. People also observe others and are observed by others. They particularly pay attention to the hostile intention of others in proximity, as they perceive it. Through observation of others, people deduce a range of likely hostile intentions of each person around them, and then, when reacting, convert that perceived range into an assumed value. These are termed cognized-intent (range) and assumed intent (value) of the person being observed.

A person acts out their intentions through movement. A "disperse" intention will cause a person to run away from a perceived threat. A "converge" objective will cause a person to move toward whatever agent or location is indicated in the intention, which also signals how far away they want to remain from the target. A person who has no particular intention wanders about, pausing occasionally at buildings to represent “window-shopping” type behavior. The actual movement of a person is also governed by many additional details to add fidelity, such as navigating around buildings or along roads, maintaining personal space, and maintaining distance from people of other ethnicities, as desired.

The people are also the agents who directly experience or witness the impacts of the weapons being deployed by the security forces. The impact of weapons, experienced or witnessed, affects anger and fear levels. If the impact of the weapon is severe and damaging to the individual, it can affect the identity’s being needs. People retain a memory of recent weapons impacts, which contributes to the individual’s beliefs about security forces legitimacy. Such recently remembered weapon effects can also be communicated socially to the other individuals in their SIG, enabling the modeling of ‘rumored’ impacts.

Most events have deterministic effects on people and groups, including effects on physical well-being, emotion, cognition, hostility level, and behavior. For example, if the impact of a weapon causes pain, the individual’s physical well-being status decreases proportional to the level of pain. The person’s decrease in well-being will then affect the associated individual identity’s emotional state, such that heavily diminished well-being increases fear or anger. The increased fear or anger may interact with environmental factors to trigger subsequent behaviors. For example, increasing fear may lead crowd members to flee, but only in the absence of others from their social identity group. If members of their social identity group are present, the increased negative emotion heightens their solidarity with the group. In addition, objectives are contagious among group members, while anger can be contagious to others in spatial proximity. These relationships among variables are based on published empirical research.

2.2 Modeling of Security Forces

Physical security force agents include a compound squad, patrolling squads and a command structure. The compound guard squad is represented as a SIG with soldiers (DIs) along with a squad leader soldier as the constituents. Patrolling squads are similarly represented as SIGs but include a vehicle that assumes a dedicated driver who is also the squad leader, along with several soldiers (DIs). The squad SIGs are all part of the higher Command SIG. At present, force identity agents’ objectives and behavior are driven solely by the mission; they are not influenced by personal emotions or beliefs. Future versions of WRENCH will incorporate personal identity characteristics of individual security force members. This will allow for direct representation of more complicated concepts such as force’s “will to fight” (Connable et al. 2018) and identification with groups participating in the crowd.

The security forces are in either a general patrol state or a general defend state, according to the intentions of the Command SIG. During a general patrol state, patrol squad DIs remain on their squad vehicle while it drives about the road network on patrol, and the compound guards stand watch at the gates. Once an imminent threat manifests, Command will switch to defense mode and dispatch the patrolling squads to fortify the compound gates. When a squad vehicle arrives near their designated compound gate, it will come to a halt and the DIs will dismount and run to the gate, positioning themselves alongside the compound DI to help defend the compound.

When defending the compound, soldiers are continually assessing the hostilities of the people in sight. DI agents observe the people, deducing a range of likely hostile intentions of each person and converting that into an assumed value. While the cognized-intent of a person is ‘seen’ similarly by people and DIs, they have different assumed-intent interpretations of that cognized intent range. There are several possible user-specified methods a DI may use to determine an assumed intent from a cognized intent.

In order to defend the compound, DIs will use the available less-lethal intermediate force capability (IFC) weapons according to the user-specified tactical rules of engagement (ROEs). The Forces are allowed to use the set of IFCs specified by the user through the "IFC Selection and Display" screen within WRENCH. The weapons information used in WRENCH was provided by JIFCO. Along with descriptive information, each IFC weapon in the database has a designated range of use, intended type of target (Single-Personnel, Multi-Personnel, Vehicle, etc.), severity level, impact breadth, and impact duration. The severity level of each weapon is operationalized as its ‘coerciveness’ and assigned an associated level in a continuum: Psych 1, 2, or 3, or Pain 1, 2 or 3. Each of these severity levels is then aligned with a perceived hostility level to determine which severity level of weapon would be deemed as fair and appropriate for each hostility level.

The "ROE Selection and Display" GUI screen allows the user to decide which sample ROE ruleset the forces should follow when engaging people in the crowd, or the user can design their own ROE ruleset. Each ROE ruleset specifies what focus area is to be scanned (“All”, “Near”, “Middle” or “Far” distances as specified by model parameters), what hostility levels are to be targeted, what type of target is to be engaged (hostile individuals, hostile clusters of people, or dense clusters of people to disperse).

3 WRENCH EXPERIMENTATION

Once completed, we conducted a large-scale data farming experiment with the WRENCH 4.0 prototype, testing 21 variables of interest using a Second Order Nearly Orthogonal-and-Balanced (NOAB) design (MacCalman et al. 2017) with 140 design points and 30 replications of each. This efficient, space-filling experimental design allowed us to efficiently test the 21 variables, some discrete and some continuous, at many levels. Table 1 summarizes the 21 factors and their respective levels or ranges.

Table 1: Experiment factor description.

Factor Number	Factor name	Factor type	Values if Categorical	Low	High
1	People-Force Relation	categorical	{Trusting, Cautious, Fearful}		
2	Force-People Relation	categorical	{Nurturing, Cautious, Repressive}		
3	SiegeCompound?	categorical	{true 0 penetrators, true 1 penetrator, false}		
4	ROE	categorical	{"Disperse(Near-to-Far)" "Disperse(Far-to-Near)" "QuellAll" "ReactAll" "GraduatedApproach" "RingsApproach" "RingsApproachByThreat" "MixedCritRings" "MixedCritRingsByThreat"}		
5	HierMult	discrete		1	5
6	SIGCongregateThresh	discrete		0	5
7	FiringRate	discrete	{60,30,20,15,12,10,6}	6	60
8	EmotionDecayFactor	discrete		0.90	1.00
9	RumRedFact	discrete		0.00	1.00
10	WitRedFact	discrete		0.00	1.00
11	ImpRedFact	discrete		0.00	1.00
12	MomIncFact	discrete		0.00	1.00
13	IllegThresh	discrete		0.00	1.00
14	FearFactor	continuous		0.02	0.30
15	AngerFactor	continuous		0.02	0.30
16	DecDel	continuous		5	20
17	EthnicTolerance	continuous		0	100
18	Lethal Range	continuous		1	60
19	MemoryForWeaponImpacts	continuous		1	60
20	JNDthresh	continuous		0.00	0.25
21	IllegFactor	continuous		0.0002	0.0020

The use of such an efficient design was critical, since a full-factorial design would be prohibitive in terms of high time and processing requirements. Due to space constraints we cannot provide a detailed description of each factor here, but the factors and ranges were selected to cast a wide net across a number of factors of interest and their allowable ranges. The end user is most likely to vary the inputs that correspond to tactics and the operating environment rather than test the parameter levels we’ve included in this experiment. Since model development is still in progress, our primary goal for this experiment was to support verification and validation activities by assessing the sensitivity of results to key model parameters. Consequently, our presentation of this experiment and analysis should be viewed as a demonstration of the types of insights this model can provide rather than providing insights for policy at this stage of development. As the model matures and validity is increased, analysis will address more specific operational and policy questions.

We used JMP Pro 15 to analyze the results of this experiment, a commercially available and widely used statistical software package (SAS 2020). The amount of analysis that can be performed on the resulting data set is vast, so here we present a small subset of the analyses we performed. We first examined the correlations between eight different output metrics of interest, presented in Figure 1 via a color map. This provided several insights. First, the total number of social identity groups (SIGs) formed is positively correlated with the final average fear level of the individuals (individual identities). Second, the average number of times a psych weapon is deployed, rather than a physically painful or disabling weapon, is negatively correlated with the final average hostility level of the individuals. In other words, fear is correlated with the formation of identity groups, and less severe weapons are correlated with lower hostility.

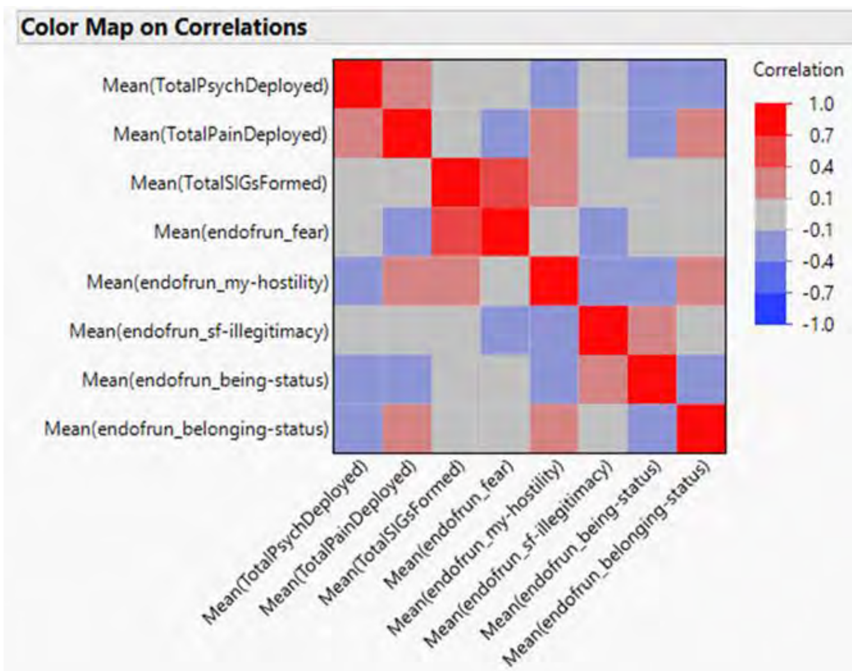

Figure 1: Color map plot of correlations.

We then fit ordinary least squares regression models as well as nonparametric partition trees to key metrics. Of note is that a single partition tree with highest explanatory power can be overly sensitive to the data, so a common practice is to complement this with fitting a bootstrap forest that fits many hundreds or thousands of individual trees, each time holding out a subset of variables or observations, and averaging results across them. From the bootstrap forest, we obtain the column contributions of each factor on the metric of interest. Using this method we developed the sum of squares (SS) contributions of all of the factors, for each of six output metrics (the mean end-of-run values for fear, anger, hostility, sf-illegitimacy, being-status, and belonging-status). For each of the output metrics, we found that all factors had a non-zero level of contribution, providing good evidence that the model design has an appropriate level of interconnectedness among model constructs.

Using this type of analysis, if we discover that one or two factors dominate the others, this is valuable information. Knowing which parameters the model is most sensitive to can focus efforts for further data collection and validation. For example, for the mean end-of-run hostility metric, the most explanatory factor by far was the Witness Reduction Factor (WitRedFact), explaining almost 26% of the variation in response. This is a factor by which the 'felt' impact of a weapon is reduced when it is witnessed as compared to when it is experienced. The high influence of this factor initially seemed surprising, but when we recognize that a single experienced impact may be witnessed by a large number of people, the high influence of this factor seems to be reasonable. Gaining this insight during the development process indicates the importance of reviewing available literature in pursuit of a realistic value to use for this factor.

We can also use the information gained from this type of analysis to drive graphical exploration. For example, both partition trees and regression can indicate when an interaction effect exists between factors. We typically restrict our attention to two- and three-way interactions, as higher order interactions tend to occur less frequently and can also be difficult to explain. When analyzing the average of the total number of times higher severity pain weapons were deployed during each run as a function of the experiment factors, an interaction between Firing Rate, Illegitimacy Threshold (IllegThresh), and Rules of Engagement (ROE) rule-set was discovered. In Figure 2, we isolate the interaction between Firing Rate and ROE, with the lower end of the Illegitimacy Threshold data selected. When firing rate is low (left half of the plot), we observe that choice of ROE rule-set does not have a large effect, but when firing rate is high (right half of plot), the corresponding ROE can be seen to have a much greater effect, which is an interesting outcome. Upon further reflection we can see that, while we may not have been able to predict this outcome, it does make sense that differences in results based on ROEs would be enhanced when a higher firing rate is used, and this provides evidence that the model is functioning well.

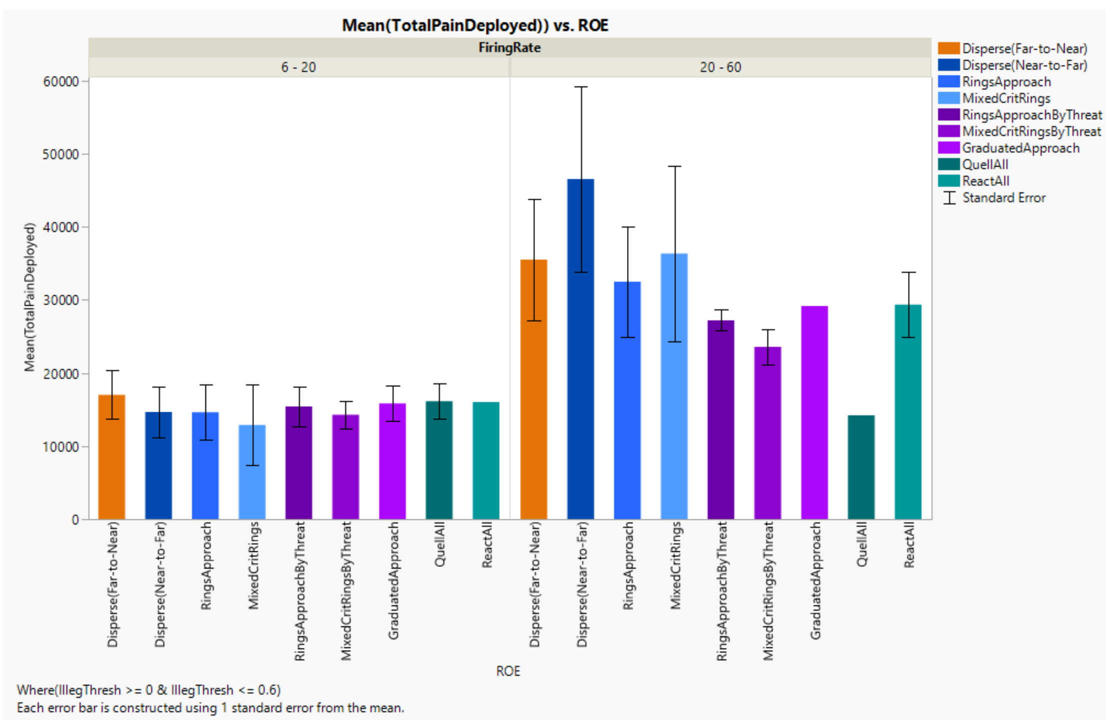

Figure 2: Average TotalPainDeployed (severe weapons) as a function of ROE and FiringRate.

We also conducted time series analysis to assess how key metrics changed over the course of the many simulation runs, as well as how the time series were influenced by experiment factors. Just as we fit metamodels to the end-of-run data, we can also generate summary measures of the time series and fit metamodels to those. Summary measures may include the range of the time series, directionality if monotonically increasing or decreasing, values at chosen time points (such as before or after a key event occurs in the simulation), magnitude and trend during specific time periods, or more complex measures.

Additionally, we used functional data analysis to treat the entire time series curve as the response, instead of using summary measure(s). A description of further analysis is available upon request.

The data farming experiment and analysis on WRENCH 4.0 demonstrates that, even in a prototype form, WRENCH is capable of complex modeling that produces sensible and interesting results. It also gives a glimpse into how powerful data farming experiments and analyses can be. Advanced, complex agent based modeling and data farming methodology is a powerful combination. Used together, they lead to more useful and credible analysis, and also enable model improvements at a pace and efficacy that may otherwise not be possible. We have thus far used data farming in an exploratory manner to support verification and model tuning, but we will move in the direction of more focused studies with future model releases.

4 WRENCH VERIFICATION AND VALIDATION EFFORTS

WRENCH 4.0 is a completed prototype, but verification and validation efforts are still underway and model improvements are also planned. Verification efforts have included a line-by-line review of the code, assessing code functionality against comments in the code from prior programmers. Testing has been performed on various sub-sections of code and error-checking routines have been incorporated in many areas of code. Further verification tests are also being designed, along with data farming experiments that can help verify functionality of complex aspects of the code.

Regarding model validity, we have made every effort to ensure that our conceptual model aligned with the real operational environment, and further efforts to improve model validity are still underway. Detailed information about needs, emotions, social identities, and effects of trust toward security forces was drawn from published articles. These processes have been researched at a level that gives us reasonable surety about the direction and general magnitude of causal relations. Early results from experimentation show reasonable correlations between security behaviors and the levels of fear and hostility in the crowd. Insights from our extensive literature reviews of psychological and social literature continue to be incorporated into the conceptual metamodel and the WRENCH code. More extensive literature reviews of other simulation models that represent engagements between crowds and security forces are planned.

Following development of parameters based on empirical research, we will continue to use data farming to examine effects of a wide range of potential parameter values on outcomes. These experiments will also help improve validity by exposing any inconsistencies in results. Meetings are also planned with subject matter experts for further data farming experiments and face validation activities. Empirical research on the immediate physiological and psychological effects of non-lethal weapons is less advanced, so we expect to improve the accuracy of the model as ongoing research clarifies effects of non-lethal weapons on targets.

We have not yet attempted to validate the model against real-world crowd events. To address this, we are working on a series of case studies. One aspect of the future validation process will be comparison of hostility levels predicted by the model against observed hostility in actual crowd situations. Another will be the extent to which crowd movement in the simulation follows patterns that parallel movement in actual crowds. Opportunities for external validation of the model are limited by the small number and high context-dependence of hostile-crowd events, so we expect to validate against averages and ranges of behavior rather than risking over-calibration to a small set of cases.

5 SUMMARY AND FUTURE DIRECTIONS

WRENCH 4.0 is a unique, powerful platform to explore the effects of using different Force configurations, sets of available Intermediate Force Capabilities, and Rules of Engagement in the management of potentially hostile crowds. WRENCH can be interactive, allowing the user to watch the effects of using different IFCs and ROEs on crowds with different configurations. Some parameters can also be changed as the simulation is running to see the immediate effects. WRENCH could therefore be used to enhance training of security forces in preparation for using IFCs in this type of operational environment.

Many details about the crowd can be specified, such as overall population characteristics and identity group configurations, as well as the overall relationship between Force and Crowd. WRENCH can be parameterized to model a wide variety of hostile crowd behaviors, as well as defensive force strategies and technologies for managing that hostility. WRENCH can also be used to do large-scale experimentation to determine which parameters have the most impact on outcomes, and what IFC and ROE selections lead to the best outcomes. WRENCH can be used for what-if modeling in support of decision-making about specific intermediate force capabilities technology used to manage hostile crowds, which is of particular interest to the Joint Intermediate Force Capabilities Office.

Work is underway to advance WRENCH in several ways: coding more detail regarding the internal functioning of people and identities to incorporate more of what has been found in the extensive literature reviews just completed; enhancing the physical and emotional responses to impacts of each different type of intermediate force capability; adding in the use of crude weapons by crowd members; and explicitly incorporating trust between identities within and across groups. Other efforts to improve the validity of WRENCH are also underway.

WRENCH can help develop policy in a number of additional areas. The compound defense scenario can be customized to model domestic, peacekeeping, or humanitarian situations in which security forces must manage potentially hostile crowds. The user interfaces within the simulation can be enhanced and expanded, and teaching materials could be designed to teach potential operational and strategic implications of tactical decisions regarding use of various intermediate force capabilities and rules of engagement. Social networks and social media use can be incorporated to enhance the modeling of interpersonal and intergroup communications, self-organization, and larger-scale mobilization. With the explicit incorporation of the complexities of psychology, sociology, and military operations, the potential for WRENCH is vast.

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REFERENCES

Alderfer, C. P. 1969. “An empirical test of a new theory of human needs”. *Organizational Behavior and Human Performance* 4(2):142–75.

Connable, B., M. J. McNerney, W. Marcellino, A. Frank, H. Hargrove, M. N. Posard, S. R. Zimmerman, N. Lander, J. J. Castillo, and J. Sladden. 2018. *Will to Fight: Analyzing, Modeling, and Simulating the Will to Fight of Military Units*. Santa Monica: RAND Corporation. https://www.rand.org/pubs/research_reports/RR2341.html, accessed 19th June 2021.

Drury, J. and S. Reicher. 2000. “Collective Action and Psychological Change: The Emergence of New Social Identities”. *British Journal of Social Psychology* 39(4):579–604.

Edmonds, B. 1997. “Modeling Socially Intelligent Agents”. *Applied Artificial Intelligence* 12(7–8):677–99.

Frijda, N. H., P. Kuipers, and E. ter Schure. 1989. “Relations among emotion, appraisal, and emotional action readiness”. *Journal of Personality and Social Psychology* 57:212–228.

Goodwin, J., J. M. Jasper, and F. Polletta, eds. 2001. *Passionate Politics: Emotions and Social Movements*. Chicago: University of Chicago Press.

Herzberg, F. 1964. "The Motivation-Hygiene Concept and Problems of Manpower". *Personnel Administration* 27:3–7.

Hoerst, C. 2021. “The Role of Collective Psychological Empowerment in the Capitol Insurrection.” Crowds and Identities: John Drury’s Research Group blog, February 26. https://blogs.sussex.ac.uk/crowdsidentities/2021/02/26/the-role-of-collective-psychological-empowerment-in-the-capitol-insurrection/, accessed 14th April 2021.

Hopkins, N., S. D. Reicher, S. S. Khan, S. Tewari, N. Srinivasan, and C. Stevenson. 2016. “Explaining Effervescence: Investigating the Relationship between Shared Social Identity and Positive Experience in Crowds”. *Cognition and Emotion* 30(1):20–32.

Jackson, J., B. Bradford, M. Hough, A. Myhil, P. Quinton and T. Tyler. 2012. “Why do people comply with the law? Legitimacy and the Influence of Legal Institutions”. *British Journal of Criminology* 52(6):1051–1071.

Klandermans, B. 2002. “How Group Identification Helps to Overcome the Dilemma of Collective Action.” *American Behavioral Scientist* 45(5):887–900.

Kou, Y. and X. Gui. 2014. "Playing with Strangers: Understanding Temporary Teams in League of Legends". In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-Human Interaction in Play*, 161–169. New York: Association for Computing Machinery.

MacCalman, A., H. Vieira, and T. Lucas. 2017. "Second Order Nearly Orthogonal Latin Hypercubes for Exploring Complex Stochastic Simulations". *Journal of Simulation* 11(2):137-150.

Maslow, A. 1943. "A theory of human motivation". *Psychological Review* 50(4):370-396.

McDonald, C. and C. Hymes. 2021. "'We Have a Plan:' New Proud Boys Indictment Says Group Leaders Used Radios and Encrypted Chats to Coordinate." CBS News, March 20. https://www.cbsnews.com/news/proud-boys-capitol-riot-coordination-indictment/, accessed 15th April 2021.

McPhail, C. 2006. "The Crowd and Collective Behavior: Bringing Symbolic Interaction Back In". *Symbolic Interaction* 29(4):433–64.

Neville, F. and S. Reicher. 2011. "The Experience of Collective Participation: Shared Identity, Relatedness and Emotionality". *Contemporary Social Science* 6(3):377–96.

Novelli, D., J. Drury, S. Reicher, and C. Stott. 2013. "Crowdedness Mediates the Effect of Social Identification on Positive Emotion in a Crowd: A Survey of Two Crowd Events". *PLOS ONE* 8(11).

Ntontis, E., J. Drury, R. Amlôt, G. J. Rubin, and R. Williams. 2018. "Emergent Social Identities in a Flood: Implications for Community Psychosocial Resilience". *Journal of Community & Applied Social Psychology* 28(1):3–14.

Sanchez, S. M. and P. J. Sanchez. 2017. "Better big data via data farming experiments". In *Advances in Modeling and Simulation—Seminal Research from 50 Years of Winter Simulation Conferences*, eds. A. Tolk, J. Fowler, G. Shao, and E. Yücesan, 159–179. Cham, Switzerland: Springer International Publishing.

Schulhofer, S., T. Tyler, and A. Huq. 2011. "American Policing at a Crossroads: Unsustainable Policies and the Procedural Justice Alternative". *Journal of Criminal Law and Criminology* 101:335-75.

Stott, C., J. Drury, and S. Reicher. 2017. "On the Role of a Social Identity Analysis in Articulating Structure and Collective Action: The 2011 Riots in Tottenham and Hackney". *The British Journal of Criminology* 57(4):964–81.

Spanovic, M., B. Lickel, T. F. Denson, and N. Petrovic. 2010. "Fear and anger as predicters of motivation for intergroup aggression: Evidence from Serbi and Republika Srpska". *Group Processes & Intergroup Relations* 13(6):725–739.

Sullivan-Toole, H., and E. Tricomi. 2015. "Fairness and Inequity Aversion". *Brain Mapping: An Encyclopedic Reference* 3:3-8.

Tyler, T. R. 2006. "Psychological perspectives on legitimacy and legitimation". *Annual Review of Psychology* 57:375-400.

Tyler, T. R. 2011. "Trust and legitimacy: Policing in the USA and Europe". *European Journal of Criminology* 8:254-66.

Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

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