Human Behavior Modeling of Crowds: Coding Individuals and Social Influences

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Abstract. Crowds are one of the most challenging forums for human behavior modeling. Models generally model either the individual or the group. But human behavior is neither solely individual nor do people always act as a unified group. A model must account for both levels without reducing decision-making to either. We use the concept of social identity to model individuals variously affected by their group identities, identities are dynamic within the crowd event. We incorporate social scientific insights in an agent-based model using NetLogo to create people who can join with others or leave the group, depending on their senses of just treatment by the security forces and their safety concerns. Running the model in different settings, and varying the expectations and objectives of people, resulted in changed groupings and participants within the crowd along lines expected by social science. Our goal is to test diverse rules of engagement to determine the least possibility of civilian harm and backlash.

Keywords: Crowds, modeling, social identity, agent-based, security forces, rules of engagement

1 Introduction

Crowds are one of the most challenging forums for human behavior modeling, a context that has eluded both social scientists and modelers due to the numerous influences on individual behavior [25]. Both fields of study have largely been unable to successfully combine the diverse facets of behavioral decision-making in large groups. For long crowds were conceptualized as either an aggregation of individuals all acting on their own individual interests, physically co-located but without considering the influence of that context, or alternatively as an unruly and uncontrollable group, bent toward violence and acting as a single unit. The latter is the conceptualization of Le Bon, generally dominating fields from sociology to journalism [19]. Political science as a discipline has mainly settled on individual rationality, the opposite of Le Bon, forthrightly declaring all actions as intending to maximize individual utility, whatever that may be. It is the individual who acts, and analysis remains on this individual level, posing an inherent problem for understanding collective action [20].

Combining the individual and the social in a dynamic context is strikingly difficult. It entails both a deep knowledge of social science and complex modeling using diverse

levels of identification. Our model leverages in-depth social scientific research on human behavior derived from the varying levels of analysis: group, individual, and interactions between those. We draw upon the latest literature in psychology, social psychology, sociology, and social movement studies, among others. We include the dynamic conditions under which individuals join, separate from the group, or alter their relevant felt identities from one level to another.

2 Individuals in Crowds: Insights from the Literature

We use the concept of social identity to link the self with relevant others. Social identity refers to how the individual thinks of themselves as belonging to particular groups or categories in society [7]. We focus on identity because the change from an individual orientation to a social "we" framework is part and parcel of the transition to collective action [11]. Individuals hold numerous social identities, some more relevant or salient than others.

Social identity theory is simple and far-reaching, indicating that people categorize themselves as belonging to a group and subsequently see that group favorably while out-groups are viewed in negative terms. Belonging in a general sense is a human need; people seek social identities, even if they do not previously know the individualism [13]. Motivation for social identity represents a balance between the desire for inclusion and similarity to others, versus a desire for distinction or positive differentiation. The idea of discrimination, along even arbitrary group lines, is built into social identity: just belonging to a group, no matter how meaningless or arbitrary the assignment, creates a positive prejudice toward that in-group. The two identities, collective or group and personal, are not separate in a strict sense but intertwined.

Social identity is related to many if not most pertinent crowd outcomes; it is the variable that explains most behavior in crowd and group settings, particularly if the strength of the social identity or salience, is added. Social identity determines when a psychological crowd exists – a grouping with a minimal common sense of unity – versus a gathering of individuals. The salience of a person's social identity colors their expectations of others and their receptivity to information [17] [11]. It determines the individuals who band together under conditions of both threat or fear and of help and support [15]. Social identities are implicated in norms, the spread of violence, emotional contagion, ideas of fairness or legitimacy, memories of intergroup conflict particularly with security forces, and sustaining commitment to the group [22] [10] [23].

2.1 Dynamism within a crowd and group size

Crowds are composed of smaller groups of people who arrive and leave together, even in an overall unified crowd [18]. They come with a set of norms, expectations, and attitudes toward other social groups in the crowd and toward the security forces. However, crowds are dynamic, and this is what makes them challenging to model. Allegiances, social identities, and their attendant norms can change due to the level of threat (fear) [6] [8] and the need to help fellow group members (prosocial feelings) [9].

Two key changes are important to outcomes between security forces and crowds: the sense of legitimacy or fairness of the security forces and the size of the crowd and groups within it. Much of the social identity literature on crowds is focused on participants' ideas of how the authorities should act during this crowd event. As such, we include legitimacy beliefs about the security forces at the start of the run (these can vary by social group). The legitimacy variable refers to the social group's attitude toward the authorities and security forces, their belief in the security forces' ability to act within the behavior the group believes to be just [21]. Violating this perception has been responsible for a large amount of violence in group settings [25]. While the goal of security forces is generally to disperse the crowd, often the opposite result occurs. A sense of threat among participants can escalate violence and confrontation.

We include numerous other inputs into our model, coding individuals by demography, type of setting and starting hostility, among others. All these inputs are closely derived from social scientific conclusions. We then examine outputs that have been shown to alter the course of a crowd event or to change the participants, their norms, and their ideas about the authorities over the long term.

We know that crowd size and how the crowd divides itself are important to outcomes. These are both important in themselves, as measures of crowd dispersal, and as indicators of fundamental changes to social identities and their norms among the crowd. Diffusing people and social tension is often the desired outcome for crowd control. However, dispersing many participants does not equal de-escalation. On the contrary, small groups are often the ones responsible for violence and the expansion of norms to include confrontation.

One typical scenario along these lines is for crowd participants who are caretakers of children (usually women), risk-averse, influential social group members with norms of non-violence, or less salient social identity holders to leave, allowing the dominant social norms to alter toward more violence [5]. The departing groups often are the actors exerting a restraining influence on crowds. Their absence has been correlated with violence and the end of a non-violent protest strategy [4] [3].

Security force actions that trespass social group norms of fairness can generate larger social identities focused on opposition, spurring escalation by transforming the dominant social identities. If some participants leave and others join into a larger group, this indicates that a new identity arises, usually from a sense of shared threat [1]. Common threat will unite disparate groups, generating a large group that then moves to a different social identity. The more fear, the more people will draw closer to each other.

Larger groups unified in opposition can escalate the confrontation more than the original crowd. Numbers affirm to the individual that they are more powerful than they originally thought, and a sense of hope, of community power, comes with belonging to the group. Large groups contribute to a stronger, more empowered sense of social identity, leading the members to believe they are in the right and have social backing [26]. People are drawn to such positive personal feelings. This positive outlook generates more sustained involvement in a movement [24] [2] [14] [23].

3 Our Crowd Model

To tackle the problem of modeling potentially hostile crowds we chose to use the agent-based simulation modeling method. Agent based simulation modeling is a bottom-up modeling approach where the individual agents within the model are independent decision makers. These independent agents interact with each other and their environment, and adjust their behavior and decision-making accordingly. In an agent-based environment, the crowd behavior emerges as a result of the actions and interactions of the individual agents. Agent based simulation modeling can also include random or stochastic elements to simulate reality more accurately. Overall, it is the best simulation method for modeling complex human behavior and interactions.

We model crowds in the context of interactions with security force members in an urban environment where the crowd has the potential to become hostile and attack a compound being secured by the forces. Our simulation model is called WRENCH (Workbench for refining Rules of Engagement against Crowd Hostiles). The conceptual metamodel underlying WRENCH has been developed based on extensive social science research. We then coded the model into NetLogo 6.1, a leading agent-based simulation modeling environment.

3.1 WRENCH

WRENCH explicitly models individual people and their social identity groups, along with security force members, as independent agents. These agents interact in a physical environment which is constructed using imported GIS data. The security force uses intermediate force capabilities (IFCs) as well as lethal capabilities. IFCs are weapons that are intended to be non-lethal but can cause unintended deaths as well. If hostilities arise, the security force members employ a user-specified set of weapon capabilities (various IFCs and lethal) according to user-specified rules of engagement (ROEs) to manage the crowd hostilities.

Individuals within WRENCH are modeled using two types of agents that are inextricably linked. The Person agent represents the physical body of an individual in the population. This agent moves and interacts with the environment and other people, and as such may witnesses or experience the impacts of weapons. The Identity agent represents the cognitive and emotional aspects of the individual. Each identity agent has an overarching objective, fear and anger emotions, beliefs about the legitimacy of the security force, needs, intended level of hostility, and specific behavioral intention. As the simulation progresses each individual's identity takes in input from their person agent's state and interactions with others and the environment and updates their state variables through a complex web of influences simulating psychological and cognitive processing over time.

The behavior of each person is then driven by their personal identity's overarching objective, specific behavioral intention, and extreme fear. In addition, people stay with their group (and children with their parent), avoid buildings, maintain personal space when not motivated to violate it, and witness and experience weapon impacts. A group leader will also stay with a group member if they are injured and cannot move, simulating helping behavior.

The Identity agent construct is also used to represent social identity groups (SIGs). Identities associated with people are *level-0* identities. When multiple level-0 identities join into a group, a new *level-1* identity is created. Two or more identities at any level can unify to form a larger next-higher-level SIG, allowing groups of any size to form dynamically. When a SIG joins a higher-level SIG it does not dissolve into the larger SIG; rather, the joining SIG, with its characteristics and member relationships, is maintained within the larger SIG. Using the identity agent construct to model SIGs allows a SIG to be more than merely the sum of its members. In WRENCH, when a SIG is first created it takes on the characteristics of the members, but as the characteristics of the constituent members evolve over time the SIG's characteristics evolve more slowly; change in a group takes time. The higher the SIG level, the slower the evolution as the changes in the lowest-level individual constituents propagate up through the SIG hierarchy.

There are several reasons why people may choose to group together with others; the two we include in our model are fear and love. A SIG is born-in-fear when an identity's fear level, or change in fear level, is quite high such that they are motivated to join with a same-level identity near them that shares their objective as well as other characteristics. If the identity to group with is already in a SIG, the fearful identity joins that SIG; otherwise, a new born-in-fear SIG is formed. A born-in-love SIG is created based on an identity's desire to nurture an identity that is very needy or being treated unfairly, that isn't already in a SIG. If the identity seeking to nurture is in a SIG, the needy identity joins it; otherwise, a new born-in-love SIG is created.

An identity in a SIG may also choose to leave the SIG. This can happen when an identity's objective is different from the SIG's objective, but also requires further motivation to leave as well. The most common reason an individual will leave a SIG is in the case of a mother whose objective has changed to "StaySafe" in the face of security force use of weapons. If the SIG she is in has the objective to "Protest" or "Attack" she will leave the SIG to get her children to safety. In other cases if the identity's emotional, cognitive, or hostility levels are so divergent from what could sensibly support the SIG's objective, the identity will choose to leave the SIG; otherwise the member will change their objective to match the SIG's. If a departing SIG member leaves only one member, the SIG itself will dissolve if not itself a member of a higher level SIG.

With regard to the population, there are many different ways we can specify the characteristics of the people. We develop populations with different demographics based on their purpose for being there (a primary occupation of "Market", "Labor", Protest"), and this also informs the objectives and emotions among the people. We can also assign different initial hostility levels of the population along with other characteristics size and composition of family groups, desired personal space, identity driver of social groups, and overall relationship with the security force. Family SIGs and some social SIGs are generated within the population at the start of a run, whereas born-in-love and born-in-fear SIGs form dynamically over time.

The current mission scenario is compound defense, where the security force is charged with maintaining security at the compound and patrolling the surrounding area. The compound squad includes the gate guards and the patrolling squads are in vehicles that drive along the roadways. If the compound is compromised or hostilities near a guard reach a threatening level the compound squad will start engaging with the crowd. Once the compound squad begins defending the compound the patrolling squads are

dispatched to join the guards and aid in the defense of the compound. The force members engage the crowd with an available level of force that best aligns with the perceived hostility level of the person or cluster of people being targeted, according to the specified ROEs. The response of each person to a deployed weapon influences the force's perception of that person's level of hostility, and how the force members interpret this data can be changed as well.

A variety of IFCs are included in the model, such as flash-bang devices, blunt-trauma devices, acoustic devices, and several others. Effects of different IFCs vary both in characteristics of their effects on people and in the severity of their effects. For the severity level continuum of the IFCs we categorize weapons as having a primarily psychological effect or inflict physical pain, with three levels of psych severity used and three levels of pain severity. Higher-severity pain weapons can also cause accidental death, particularly when someone has been hit by more than one weapon impact. Research to inform the modeling of the IFCs included manufacturer's information, weapons effects research, and video records of engagements. The various ROEs specify how a security force member assesses threats, how they choose which threat to target, and how they choose which among the available IFCs and lethal weapons to use on the target.

3.2 Experiment

We conducted a data farming experiment with WRENCH 5.1 using a Second Order Nearly Orthogonal-and-Balanced (NOAB) experiment design [16]. We generated 100 design points, running 30 replications of each design point for 30 simulated minutes each. This efficient, space-filling experimental design allowed us to efficiently test the factors, some categorical and some continuous, at many levels. In this experiment, we included two factors that pertain to the population characteristics. The first is the primary occupation of the population, which we tested at the Market level and at the Protest level. A market population includes more children, and therefore more family groups are created at the beginning of a Market run than for a Protest run. Some people in a Market population are created with the objective to protest but most are created with no specific objective so that they wander through the area pausing at buildings to shop. In the Protest population all people are created with the objective to protest, so they head toward the compound and intend to remain in that area. Objectives can change during the simulation, depending on a person's interaction with people around them, force activity witnessed or experienced, and their SIG if in a SIG. The second factor pertaining to the people is the people-force relationship (People-Force_Relation). People can initially be fearful, cautious, or trusting of the security force. The people-force relationship factor determines the population's initial levels of fear and legitimacy beliefs.

We also included in the experiment three factors that pertain to the security force characteristics. The security force has a parameter somewhat similar to the people-force relationship called the force-people relationship (Force-People_Relation). This parameter governs how the security force perceives the behaviors of the population. The force can be nurturing, cautious, or repressive towards the population; when the forces repressive they assume the worst about the perceived behavior of each person. When the forces are nurturing they assume the best about the perceived behavior of each person,

and when they are cautious they take the middle-ground assumption. The security force has two additional parameters that describe which tactical ROE ruleset they are operating under, and which IFC(s) they have available to use.

3.3 Results

WRENCH can produce a wealth of output data during each simulation run. For this analysis we have selected a few population output variables to focus on. For the people in the population, we look at the change in the number of individuals with the objective to Protest or to Attack (delta_Protest, delta_Attack). For measures of social identity dynamics we look at the change in the total number of individuals that are in groups (delta_Total_in_Groups), and the largest group that formed during the run (Max(Largest SIG Size). The data for these metrics was then averaged across all replications in each design point. We used JMP Pro 16 to analyze the results of this experiment, a commercially available and widely used statistical software package (SAS 2021). 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.

Here we will present insights from our analysis using partition trees to explore the effects of experimental factors on certain output metrics of interest. When generating the partition trees we separated out the market case and the protest case due to very different characteristics of the population. For example, in the protest case all people begin with the objective of protesting, so any change in the number of protesters will be a reduction, while in the Market population there are very few protesters in the beginning so the number of protesters almost always increases. If the Protest and Market population results were averaged together these negative and positive results would mostly cancel out leading to a false observation of little change to the number of protesters under different factor levels. When generating the partition trees, we stopped splitting when the increase in R^2 with more splits became marginal.

First, in the partition tree for the change in the number of protesters in the Market population case ($R^2 = 0.846$), we find that the Force-People_Relation is the first split, having the most explanatory power for the change in protesters (Fig. 1). We that a Repressive security force leads to a greater increase in protesters. And when the force is Repressive and uses one of three different subsets of IFCs there is an average increase of over 35 protesters, effectively escalating the situation. In these runs there were 134 people, so this is quite an increase. The corresponding partition tree for a Protest population ($R^2 = 0.779$) shows the largest decrease in protesters occurred, an average reduction of 56.1 protesters, when the force was Repressive and one of three different sets of IFCs were used, effectively deescalating the situation. This leads to two insights. First, the force stance toward the people is very important for managing both Market and Protest populations but has an opposite effect on escalation early in a confrontation. Second, the choice of IFCs matters in both Market and Protest populations, with some IFCs leading to better outcomes in both (more de-escalation in a Protest population and less escalation in a Market population).

The partition tree for the change in the number of attackers in a Protest population showed a very small R^2 value ($R^2 = 0.258$), but the partition tree for the change in the number of attackers in a Market population ($R^2 = 0.839$) shows results similar to the change in the number of protesters: the largest increase occurs when the force is

Repressive, under much of the same IFC subsets. With these factor values the average increase in the number of attackers is 4.31. Since each attacker is much more of a threat than each protester, this is a significant result.

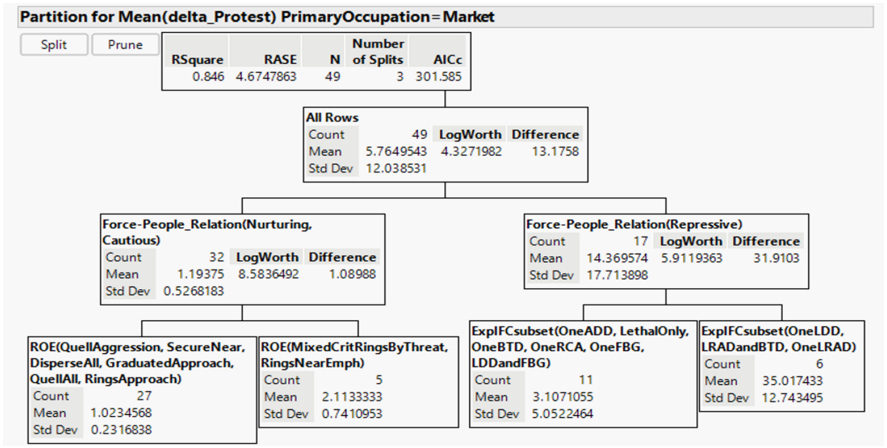

Fig. 1. Partition tree for change of number of protesters in a Market population.

We also generated partition trees for the delta_Total_in_Groups and the Max (Largest SIG Size) metrics and found some insights there as well (Fig. 2). In the delta_Total_in_Groups partition trees (Protest $R^2 = 0.789$, Market $R^2 = 0.790$) we find that a Repressive force leads to more people leaving groups, but in the Protest population the IFCs then make the biggest difference, leading to an average of 15.9 fewer in groups, while in the market population the ROE then drives the largest average drop of 16.9 people in groups. For the Max (Largest SIG Size) metric the partition tree ($R^2 = 0.732$) shows little difference in max group size for the Market population across factor values, but for the Protest population partition tree ($R^2 = 0.741$) the largest group is more than three times the average starting group size in the Protest population (within just 30 minutes of simulated time). This highest average increase occurs with a repressive force using certain subsets of IFCs. These results show that, for a Protest population, a repressive security force leads to fewer, larger groups.

4 Insights and Future Directions

The change in protester numbers showed that the force stance toward the people is important for managing both Market and Protest populations, but has an opposite effect on escalation early in a confrontation. It also showed that the choice of IFCs matters in both Market and Protest populations, with some IFCs leading to less escalation in both populations (more de-escalation in a Protest population and less escalation in a Market population). Results also showed that for a Market population the greatest increase in attackers occurs when the force is Repressive, under much of the same IFC subsets that drove the increase of protesters. This aligns with social science literature asserting that expectations and senses of fairness will guide behavior, causing an increase in confrontation when those are violated. We can conclude that a heavy show of force against

hostile people, when most of the surrounding people are not behaving in a confrontational manner, has the potential to cause a significant escalation of the situation in a short amount of time (within 30 minutes of simulated time). In a population focused on protesting, a repressive security force leads to fewer, larger groups within the crowd, which could have significant security implications. Larger groups indicate the formation of a new, empowered social identity. The consequences for confrontation will vary with the context and subsequent security force actions.

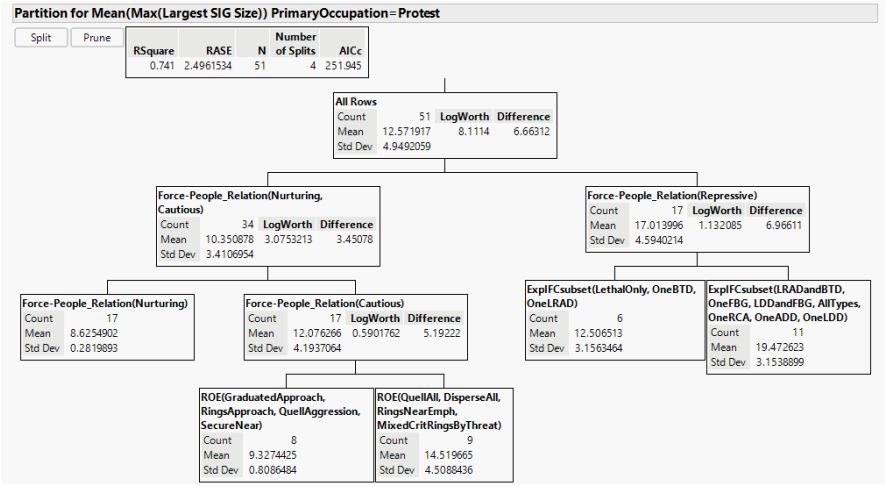

Fig. 2. Partition tree for the largest SIG size in a Protest population

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