Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir

Research Article
DOI: 10.22067/JSTINP.2022.76299.1009
JSTINP 2022; Vol. 1, No. 1

Simulating Crowd Behavior Using Artificial Potential Fields: An Agent-Based Simulation Approach

Seyed Morteza Hozhabrossadati[a]*

[a] *Department of Business Management, Toos Institute of Higher Education, Mashhad, Iran.*

How to cite this article

Hozhabrossadati, S.M., 2022. Simulating Crowd Behavior Using Artificial Potential Fields: An Agent-Based Simulation Approach. *Journal of Systems Thinking in Practice, 1*(1), pp. 49-71. doi: 10.22067/JSTINP.2022.76299.1009.
URL: https://jstinp.um.ac.ir/article_42613.html.

A B S T R A C T

This paper presents an associate agent-based model (ABM) of the rebellions where protesters and mobs move in a crowd and try to reach valuable sites while cops settled in front of sites to safeguard them and use obstacles to disperse them. This paper aims to show how people during a protest decide and steer to get their target, such as valuable buildings. To simulate the protest and entities, we employ agent-based modeling, which provides a flexible tool for assessing scenarios. Our paper uses steering behavior techniques to simulate the higher cognitive process of rebellions and police at the microscopic level. It considers the special characteristics of protesters' behavior, like avoiding obstacle collision relating to perceived hardship and grievance. The artificial potential field is used to show the movement of people. The projected model consists of 4 forms of agents; policemen, protesters, mobs, and facilities that give an acceptable framework for future studies.

Keywords

Behavioral Operations Research, Simulation, Artificial Potential Field, Crowd Steering Behavior, Agent-Based Modeling.

Article history

Received: 2022-04-18
Accepted: 2022-07-06
Published (Online): 2022-07-16

Number of Figures: 8 **Number of Tables: 4** **Number of Pages: 22** **Number of References: 56**

****Corresponding author:***
Email: smh2sadat@yahoo.com

1. Introduction

Civil violence, dispensed as a signal of defiance against a central authority or between opposing teams, has been utilized in the context of recent society to explain associated actions of violation. That's manifested in numerous forms and categorized according to the character, the severity of the conflict, and conjointly degree of involvement (Quek et al., 2006). These vary from little-scale riots and protest to giant-scale revolutions like ethnic wars. Researchers are seeking to interpret the most reasons and effects from numerous views. In most cases, riots occur once giant, hostile teams of individuals gather and perform property destruction and often fight with police. United Nations agencies are deployed to manage the gang. Within social conflict theory (McLellan, 1971), many researchers take into account unrest because of the results of instability in the socio-economic atmosphere (Situngkir, 2004). With accordance to Pires and Crooks (2017), they can be as results of a spread of social and political grievances, like inequality (Jackman, 2002), lack of resources (Auyero & Moran, 2007), or the unfair treatment of civilians by authorities (Stark, 1972). We can notice studies concerning riots at intervals in many disciplines, as well as social science (e.g., Tucker et al., 1999), military operations (McKenzie et al., 2004), and physics (Pabjan & Pekalski, 2007).

Crowd Control is some actions that apply force to prevent or disperse an outsized, hostile group. Organization to control crowds includes team members, formations, and instrumentation. Generally dispersing a riot involves the employment, or threat to use, violence. Studying the great motion of individuals dynamics affects a large variety of applications together with behavioral sciences, escape designing, stampedes, event organization, and controlling crowds (Kirkland & Maciejewski, 2003).

Police operations to manage crowds may be a complicated, culturally specific method (Wise & Cheng, 2016), and officers have to have several decussate responsibilities. Programs for managing riots are with success used with a spread of samples as well as community members, school students, prisoners, internal organ patients, abusive spouses, and showing emotion disturbed or disabled young people (Brondolo et al., 1994; Friedman et al., 1984; Gerlock, 1997; Kellner & Bry, 1999; Holbrook, 1997; Miranda & Presentacion, 2000; Brondolo et al., 2003, Makowsky & rubin, 2013; moro, 2016). Conversely, very little attention has been paid to formulating their behavior and additionally deciding, utilizing the abstraction information in creating agent-based models of the protests. It has been argued that this is often a very important, however unnoticed, space, particularly with the rising urban population and youth bulge (NIC, 2012).

The relative analysis literature presents astonishingly few empirical studies of the effectiveness of violence management through knowing offensive behavior against valuable places (Pires & Crooks, 2017). In this case, protesters aim to overcome the building to point out their ability to follow requests.

If we think about riots as agents, the methods they use to manage interactions with the general public will have specific and measurable consequences. Perez and Muir (1996) believe that if community members are dissatisfied with their interactions with the police, they will complain against some officers to the police department's inspection unit. The speed at that civilian's file complaints against enforcement workers is thought to be one marker of a department's effectiveness in coaching, personnel choice, and oversight (Perez & Muir, 1996). As a human being may be a complicated creature, studying lots of citizenries is definitely very sophisticated. Once humans create teams, their interactions become an important part of cluster behavior. In several cases, individuality gets lost, and collective behavior comes on the scene. The linguistics underlying the motion of crowds must be studied extensively to achieve realistic behavior in virtual ones. Therefore, crowd simulation analysis has benefited from the psychology literature (Durupınar, 2010).

From a governmental perspective, business for reconciliation can be valid and intelligible. Several researchers (e.g., Fielding, 2005; Adang et al., 2010) have advocated that investment in peaceful and robust relationships between policemen and citizens will prevent such escalated conflict. Moreover, in several countries, it is acknowledged that the link between police and citizens is ongoing, and cooperation with them is significant and inevitable for police duties (Tyler and Huo, 2002; Skogan, 2005). Different policing strategies, like community-oriented policing (Weisburd and Braga, 2006; Friedmann, 1992), problem-oriented (Goldstein, 1979), and reassurance policing (Fielding and Innes, 2006; Fleming, 2005) advocate making, securing, and keeping appropriate citizen and police relationships (Stronks and Adang, 2015).

Police ought to think about many aspects. Fast mobilization of spare officers to handle the case is significantly important. Delay in reaching the destination might permit the violent crowd to realize such momentum that may be tough to prevent. A spare range of officers should be waiting in reserve at the point of the area. Keep citizens off the streets within the space affected. Do not permit mobs to congregate; keep everybody moving. Innocent bystanders around disorder might be over-excited by their own emotions and acquire concern into members of the mob. Avoid close fighting at the maximum amount possible. Finally, the less force employed in restoring order can cause lasting peace. Any unreasonable act of violence or viciousness by the officers could flip the emotions of the spectators toward the rioters.

We have projected the model with the addition of dissimilar agents. These agents are applied to perform numerous maneuvers for interacting beneath totally different rules. This text focuses on the planning and development of Multi-Agents to check the microscopic behavioral dynamics of civil violence. Agents are sculpturesque from multidisciplinary views, and methods evolve via co-evolution and learning. The agent moves around and attempts to reach the target (e.g., valuable sites) through offensive actions. The projected model results reveal fascinating emergent phenomena and patterns of agent steering behavior and autonomous behavioral development.

The idea is based on Epstein (2002) about civil violence. The results set up micro-macro interconnections among the attributes of warfare and present new insights into the wealthy dynamics that get up from unrest. Epstein (2002) modeled civil violence in a decentralized uprising against a central authority and collective violence between two hostile ethnic groups. An agent-based approach is used and brings out outstanding features of agitator behavior through simple empirical rules and equations of engagement in the microscopic interaction between them. In that model, police and rioters move randomly around, which is considered as one of its limitations. In this paper, we aim to introduce agent movement toward a specific target (e.g., valuable sites) by applying artificial potential field. We are interested in the modeling of human agents belonging to an explicit group in which the members are in a well-defined formation. Specifically, we have used the steering behaviors framework to develop a simple model of civil violence for police as guardians of valuable places.

The organization of this paper is as follows: section 2 presents a short review of existing works in the literature. Section 3 introduces the model specifications. Section 4 presents a brief explanation of agent-based simulation, and in section 5, our proposed framework with computational agent-based simulation is presented, while section 6 concludes the paper with an overview and some suggestions for future works.

2. Previous studies

Different types of empirical simulations have been carried out over the years to model complex dynamic systems in different disciplines (Goh et al., 2006). The simulation of human behavior from the earliest days of computer graphics research has been studied. The first thing is focusing on animal behavior, but a lot of recent work has been done about human behavior. In addition, techniques are proposed to simulate a group of individuals as a single entity and consider each individual in the population separately. Reynolds (1987) carried out the first work, which popularized the whole field. He introduced a simulation of a herd of birds. The main point he introduced was that each bird is treated individually. A combination of every bird that follows a set of standard rules leads to flocking behavior for the entire group. Each bird had three main bases: going to other birds trying to match the speed of the boat around, and preventing collisions (Rymill & Dodgson, 2005).

Moreover, the MANA model (Yiu et al., 2002) proposed an extension to Epstein's model by introducing specific movement strategies aimed at correcting the completely randomized movement of factors. Also, Situngkir (2004) utilized empirical formulation for modeling the phenomenon of massive conflict by invoking its analogy with the macro-micro link in Sociological Theory.

Bandini et al. (2004) used cellular automata and autonomous agents to model the pedestrian population based on the so-called cellular agent approach. The simulation of individual aspects, such as selective ones, was modeled using the ABM approach, while physical aspects like information transfer, understanding, and movement are solved using local rules based on cellular automata. This combination provides a model which can be used for analyzing back-and-forth scenarios. It involves complex abilities to reach an agreement among the agents and to join and leave the groups of delegates who have agreed. A cellular agent approach to simulating pedestrians is used in a subway station scenario (Bandini et al. 2009) and pedestrians visiting a museum (Bandini et al. 2004).

Goh et al. (2006) improved Epstein's model of civic unrest between two groups. Agents such as the Epstein model can be silenced, activated, or imprisoned, and active opposition agents can murder the agent. Their work suggests describing population agents consist of some improvement in relation to Epstein's: 1) the tendency of revolting is expressed in terms of two attributes, grievance G and greed G_r and a time factor T_f weighting them 2) the steering is with accordance to specified strategies, which are improved by evolutionary learning; 3) the net risk modeling consists of a deterrence term including the maximum prison term. Their model offers a more realistic description of Epstein's movements and operating jails, including the effects of learning and memory on the characteristics of the agents.

Ronald et al. (2007) model pedestrian crowds using a BDI agent approach. They apply this approach to simulate audience behavior at the stadium, where visitors' attractions are available.

 DOI: 10.22067/JSTINP.2022.76299.1009

Pedestrians are autonomous agents with a lot of information about the environment and their own, such as attractive locations, the impact of their activities on the environment, and the things that need to be done on failures. Also, agents can communicate directly with each other.

Ballinas-Hernández et al. (2011) define a model of nomadic populations using ideas from the field of the kinetic theory of living systems, besides computational agents. Their work supports quantitative characterization of the function of agents supports a neglected issue in ABM models through kinetic parameters. Flow and activity algebra graphs for both groups, continuous homogeneous passersby, and heterogeneous pedestrian groups are presented regarding their desire to achieve their goals.

Kim and Hanneman (2011) introduced a model of employee protest that supported Epstein's model that comes with 2 necessary factors best known from psychological science research: 1) the grievance is defined in terms of relative deprivation (RD theory ensuing from wage inequality) and 2) cluster identity effects. The advantages of the model square measure the introduction of sound principles from psychological science and grievance modeling, risk aversion, and peer effects. However, the model additionally shares necessary limitations (homogeneity of the surroundings, Impractical Movement of the agents, etc.).

Davies et al. (2013) introduced a model for the London riots in 2011 based on three elements: 1) a contagion model for participation decision making; 2) a model for choosing the site and a model to show the interaction between rioters and police. Their model tried to understand the patterns of riot behavior besides the allocation of officers to neutralize similar events. The model uses statistical descriptions and simulation and incorporates data on deprivation based on official reports. The environment includes a list of residential sites and j retail shops in London where the riots occurred. In step: 1) one agent in the residential area decides to participate riot based on its deprivation and function of the attractiveness to riot, which is a function of the distance between its retail site and residential area, the floor space, and the deterrence expected at j; 2) if the agent decides to riot, it chooses the retail area to go, based on his utility that takes into account the distance between two places, (the deterrence depends on the expected number of officers at the chosen rioting site) and 3) rioter interacts with the officers and maybe prisoned with probability P (Lemos et al.,2013).

Niemann et al. (2021) studied the behavior of the ABM process on a long-time scale. They showed that, under certain conditions, the transfer operator approach allows us to bridge the gap between the path-wise results for large populations on finite timescales, i.e., the SDE limit model, and approaches built to study dynamical behavior on long time scales like large deviation theory. They provided a rigorous analysis of rare events, including the associated asymptotic rates on timescales that scale exponentially with the population size. They demonstrated that it is possible to reveal metastable structures and timescales of rare events of the ABM process by finite-length trajectories of the SDE process for large enough populations.

In this work, a complete specification of the goals and actions of the system entities is needed to modify the execution of possible schedules; conjointly, we tend to propose the choice creating of police and rebellions in the case of an attack on a special site that guardians should protect.

3. Advantages of ABM in riot studies

Riots occur when the social context leads to significant levels of grievance in a large proportion of the population and raises the level of internal conflict within the society. People become aware of the riot through several sources, and the decision to join it can be contagious. In the early stage of assembly, the crowd may behave peacefully, or part of them may decide to engage in a violent confrontation with officers. Depending on the depth of the social conflict and the grievance level, the riot may last more or repeat cyclically, which in turn changes the social context (Lemos et al., 2013).

Given the challenges imposed by the crowds, Modeling and Simulation techniques, in particular, Agent-Based modeling (ABM), are widely used to study the complex interactions of individual people in a crowd beside the emergence of group behavior Bonabeau, 2002; Laclavík et al. 2012; Hu et al., 2012). Agent-based modeling enables to study of the consequences of actions that protesters and officers may carry out in protest management (Hu et al., 2012).

We have two components of bounded rationality: bounded information and bounded computing power. Global information and infinite computational power do not exist for agents, and they use local information to make use of simple rules (Epstein, 1999).

The ABM is especially powerful in representing spatially distributed systems of heterogeneous autonomous actors with bounded information and computing capacity who interact locally.

Individuals are modeled as intelligent agents with specific attributes and can make a decision independently based on decision rules. Modeling the decision-making process of humans is important for designing the decision rules (park et al., 2015). The explanation mentioned above shows that we should employ agent-based simulation to know the nature of human behavior in civil violence.

4. The proposed framework

In an agent-based model, an agent represents any unit that can behave like a person or vehicle that can exist in the same simulation. The surroundings may include spatial spaces such as streets or social spaces that define relationships between agents, influence and constrain their behaviors, and are known as the simulation's environment (wise and Cheng, 2016). In the agent-based computational model presented in this paper, four types of agents interact; protesters, mobs, policemen, and facilities. Protesters are members of a population who act against a central authority and decide whether or not to rebel against the government based on their degree of economic and political grievance shown by aggression (park et al., 2015). It is an agent whose aggression level is normal by default. It can be influenced by either a mob agent or a guardian; when it is influenced by a nearby mob, its aggression level increases and follows the mob, damaging properties together. When nearby police influence it, its aggression level goes down from normal to good, making it non-violent. Also, Mobs are the other kind of members with a higher degree of grievance. It is an agent whose aggression level is always high and who tends to damage properties such as breaking store-front windows and burning cars. It influences nearby protest agents to increase their aggression level. It has a behavior of going to its destination, such as valuable sites. The people must not pass critical areas, so policemen arrest them as soon as they enter the alert area.

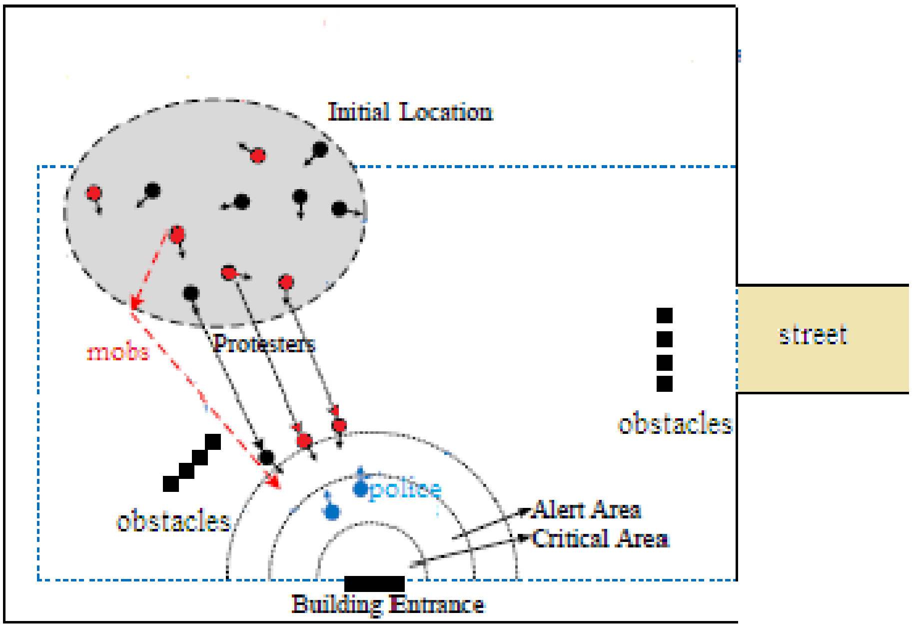

Figure 1. Depicted scenario

Policemen are the forces belonging to the central authority who should suppress any rebellion by showing off their power by locating in appropriate situations (for surpassing protesters) and arresting mobs. Facilities are places such as state-building, which must be protected from attack.

Figure 2 shows a plan of the procedures that lead to social changes. As per this, a tactile boost causes a conduct response that relies upon the individual points and is looked over many social choices with the target of utility expansion. Be that as it may since an operator is utilized to the circumstances he is regularly stood up to, the response is typically rather programmed and controlled by his experience of which one will be the best (Helbing and Molnar, 1998).

We simplify the thought process to consider a single choice, whereby an agent must make a single decision by considering a series of options. Protesters and mobs wander and try to close to facility agents for conquering. According to Zhong (2014), whenever an agent receives a stimulus, the mental process is broken down further into a sensing phase, an assessment phase, and a decision phase.

Sensing phase: In this phase, the decision-maker perceives environment features and discovers alternative options. For example, when people are going toward targets, the perceived information can be the distance to each target, driving, and repulsive factors (attraction of target and presence of policemen). Different targets are alternative options for the same decision (i.e., which target to choose).

Assessment phase: The subsequent stage is to evaluate every variation alternative. This stage is the most significant and complex part of the basic leadership process. Whether an elective alternative is great or not is subject to the particular setting and different physical, social and mental variables. We can respect the way toward surveying an elective alternative A_i as a capacity that maps apparent highlights to reward esteem.

Decision phase: Given those mentioned above, this stage essentially picks the best choice, for example, the alternative with the biggest reward. In view of the above presumptions of the basic leadership process, structuring choice standards for a specialist-based group model is a procedure of finding the relating prize capacities (Zhong, 2014), which could be different in various cases.

After making the decision, a reaction will occur. It is, therefore, possible to put the rules of pedestrian behavior into an equation of motion.

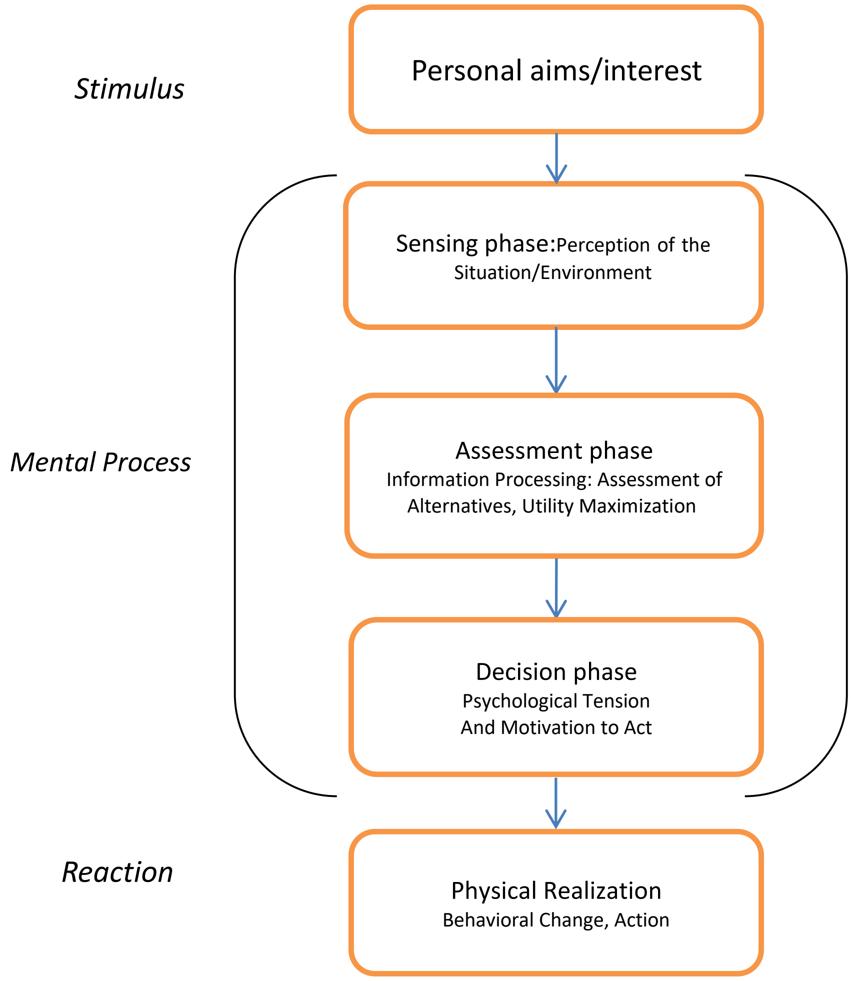

Figure 2. Schematic representation of processes leading to behavioral change

In the following, we propose the computational behavior of agents during a riot to reach target sites.

4.1. Protests and mobs

The features of each agent are described in detail, beginning with the citizen agents (protests and mobs) specification because their specifications are similar, excluding parameters. As in Epstein (2002), social grievance shows the motivation that potentially leads protesters to revolt; for each protester *i,* the grievance is assumed to be the product of an index of economic hardship. H is the agent's perceived hardship like physical or economic privation, which is exogenous in the interval (0-1) and a measure of government illegitimacy, defined as $1 - L$, where L is a parameter measuring the legitimacy of the central authority which is exogenous and is equal across agents, and in the runs discussed below, will be varied over its arbitrarily defined range of 0 to 1 (Epstein, 2002). So the grievance will be:

$$G(y_i) = (1 - l)H(y_i) \quad (1)$$

According to Kim and Hanneman (2011), H(yi) as perceived hardship is an ego's wage minus the local average within a certain radius (i.e., 6 patches in our experiment).

$$H(Y)_i = W_i - aveW_j \qquad j = 1, \ldots n \quad (2)$$

Where W_i is the wage of protest i and W_j is the wage of his neighbors in radius. Relative deprivation is required to arrive at its greatest when the populace is similarly isolated into a gathering of rich individuals and a gathering of exceptionally destitute individuals. Notwithstanding, we expect that sentiments of relative hardship come from nearby examinations regarding reference bunch inside which an individual limits her desires. On the other hand, the cost of participating in a riot is defined as the product of the estimated probability of being arrested A_i and the opportunity cost of joining a revolt *J*:

$$N(y_i) = A_i J(y_i) \quad (3)$$

In fact, each protester and mob gauges the likelihood of being captured before effectively joining disobedience. This assessed likelihood is characterized as in Epstein (2002): it is an expanding capacity of the proportion of cops to officially defiant operators inside the hordes and dissenter's vision range (Moro, 2016).

$$arrest\_prob_i = 1 - \exp\left[-k(\frac{C}{A})\right] \quad (4)$$

Where C is the number of cops in radius, A is the number of mobs within the protest's vision, and k would be exogenous. The vision, a circular neighborhood with the center in the protest's position and a radius equal to v, represents the lattice positions probed by the protests.
The main rule for protesters to become active mob is a simple cost-benefit as follow:

If G(yi) - RAi >Tr then be mob. (5)

Where RA_i is the risk aversion of protester i and Tr is a threshold defined by the researcher. the RA_i is formulated as follows:

RA_i=*Nr – arrest-prob* (6)

Where Nr is tolerance specific for each protest and randomly distributed. The one in the past recipe makes unequivocal that, before envisioning in a mob, a challenge will consider himself a functioning specialist; along these lines, the proportion is in every case all around characterized. By and by, the floor administrator is connected to the proportion of police officers to insubordination operators, as in Wilensky's (2003) version of Epstein's model. But the function mentioned above is appropriate for open space. During guardianship of important sites, when the police are 'outnumbered' at a site, the circumstance is viewed as wild, and the police can't make any captures without the expansion of 'reinforcement' (and in this manner, the likelihood is 0). Going to prevention as unpleasant power, we recommend that the essential check by which an individual surveys whether the circumstance at a site is helpful for defiance is the likelihood of capture, dictated by the general quantities of dissenters, crowds, and police: an apparent low shot of catch supports investment.

In Epstein (2002) work, agents move around randomly. But we assume that they wander wisely and under some forces. They wander around and are attracted to get their target (facility agent), evading collision with others and escaping from policemen.

This paper focuses on the microscopic modeling of people's movement on the operational level, where a model generally has to take care of the following two tasks: 1) each pedestrian wants to walk with an individual desired speed to target, while 2) keeps a certain distance from obstacles.

According to Helbing and Molnar (1998) agent wants to reach a certain destination $\vec{r}_1^0$ as comfortable as possible. He normally takes a way without detours, i.e., the shortest possible way.

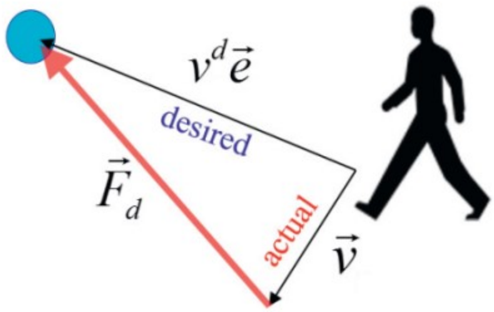

Figure 3. Driving force of an agent

To model moving rebellions, Artificial potential fields are applied. The fundamental building block of potential fields is the action vector, which corresponds roughly to the speed and orientation of a moving robot. Each behavior outputs the desired output vector. For example, consider a *Seek-Goal* behavior assigned the task of making the robot head toward an identified goal. The output of the *Seek-Goal* behavior is a vector that points the robot toward the goal. Let (x_G, y_G) denote the position of the goal. Let r denote the radius of the goal. Let $v = [x, y]^T$ denote the (x, y) position of the agent. So the distance of agent to goal is:

$$d = \sqrt{(x_G - x)^2 + (y - y_g)^2} \tag{7}$$

Also, the angle between the agent and the goal is:

$$\theta = tan^{-1}(\frac{y_g - y}{x_g - x}) \tag{8}$$

If an agent's motion is not disturbed, he will walk in the desired direction $\vec{r}_i^k$ with a certain desired speed v_i^0. On the other hand, It gets interesting when, in addition to the *Seek-Goal* behavior, we have other behaviors such as the *Avoid-Obstacle* behavior.

Let (x_O, y_O) denote the position of the obstacle. Let r denote the radius of the obstacle. Let $v = [x, y]^T$ denote the (x, y) position of the agent. So the distance of the agent to the obstacle is:

$$d = \sqrt{(x_o - x)^2 + (y - y_o)^2} \tag{9}$$

Also, the angle between the agent and the goal is:

$$\theta = tan^{-1}(\frac{y_o - y}{x_o - x}) \tag{10}$$

Within the obstacle, the repulsive potential field is infinite and points out from the center of the obstacle.

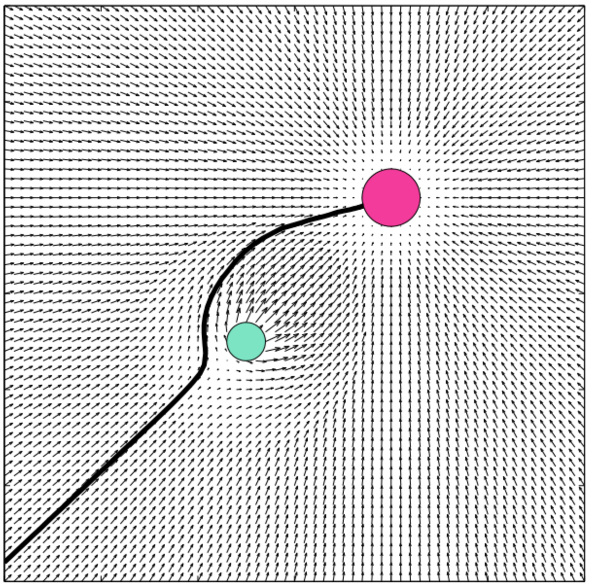

Figure 4. robot behavior when there is a goal (Goodrich, 2000)

4.2. Policemen and facilities

If intelligence indicates the possibility of violence, a Police show of force when the strike begins may prove to be a good psychological deterrent. 1) Only sufficient Troopers should remain on the scene, however, to properly handle the existing problem. Additional personnel should be in a nearby location and held in reserve. We assume that policemen are guardians of buildings to prevent rioters from closing them. Thus, they must not go far from sites and, coincidently, should arrest rioters (protesters and mob) who rich the alert area. The policemen are a lot less complex than imminent rebellions. Their properties are as follows: the cop vision is the number of cross-section positions (north, south, east, and west of the cop's present position) that the cop can examine. It is exogenous and equivalent crosswise over police officers. The police officers' vision need not rise to the specialists; however, it will normally be little with respect to the grid size and police vision is in the neighborhood. Like the other agents, the policemen follow one simple behavior rule: *Inspect around and arrest a protester or mob agent in an alert area*.

As mentioned above, mobs and protesters aim to get facility agents and escape from policemen, while policemen are attracted to arresting agents if they violate the alert area.

As the model focuses on protecting valuable sites, policemen are not allowed to go further. Thus, the movement domain of police agents is in the alert area. Showing off power firstly and arresting closer rioters are the main tactics. The jail terms for arrested agents are exogenous and set by the user. In particular, the client chooses an incentive for the most extreme prison term. At that point, any captured operator is appointed a correctional facility term drawn arbitrarily from $U(0,J^{max})$. J^{max} will affect the dynamics by removing agents from circulation for various durations (Epstein, 2002).

The facility agent is a valuable site that is the target of rebellions to be destroyed. This kind of agent is passive and fixed. The main specification is the degree of importance to be protected (e.g., government site or gasoline station).

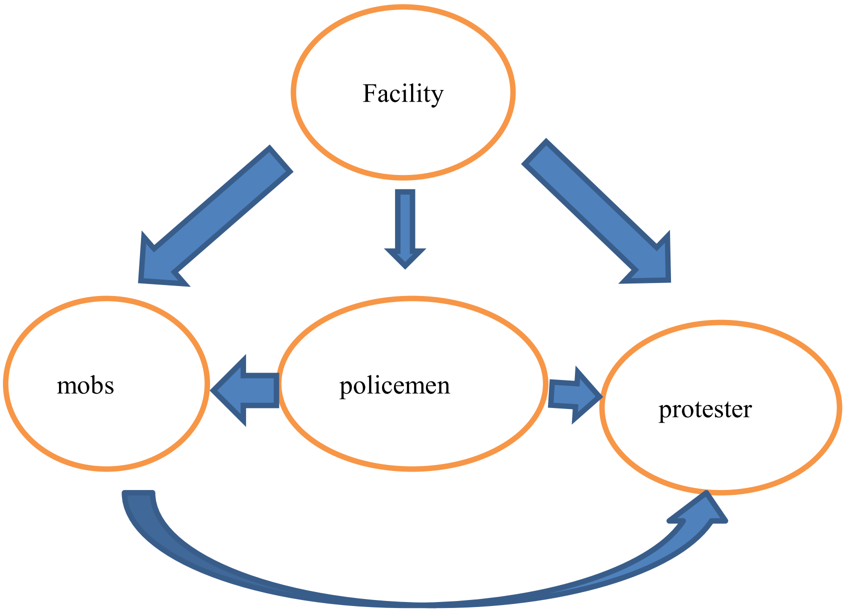

Figure 5. the interaction among agents

5. Results

To implement simulation, we use NetLogo software introduced by Wilensky (2003). Before running, the ODD protocol was provided. Protesters without leaders are located on a 40 x 40. They realize just what is happening in their prompt environment. In our model, an operator watches the conduct of neighboring colleagues whose good ways from her are not exactly or equivalent to 5 (vision). The number of protests differs in 50, 67, and 84. The grid is also occupied by cops agents who arrest active protesters and mobs. As in Epstein (2002), 17 cops are randomly arranged in front of buildings to arrest protesters in the alert area.

We also used the approach mentioned above to localized relative deprivation, which would define it as the difference between each agent's wage and that of the most highly paid agent in the neighborhood. The wage of protesters is distributed in a normal and random way among all of them, $W \sim N(0.5, 0.167^2)$. Figure 6 depicts the wage histogram.

 DOI: 10.22067/JSTINP.2022.76299.1009

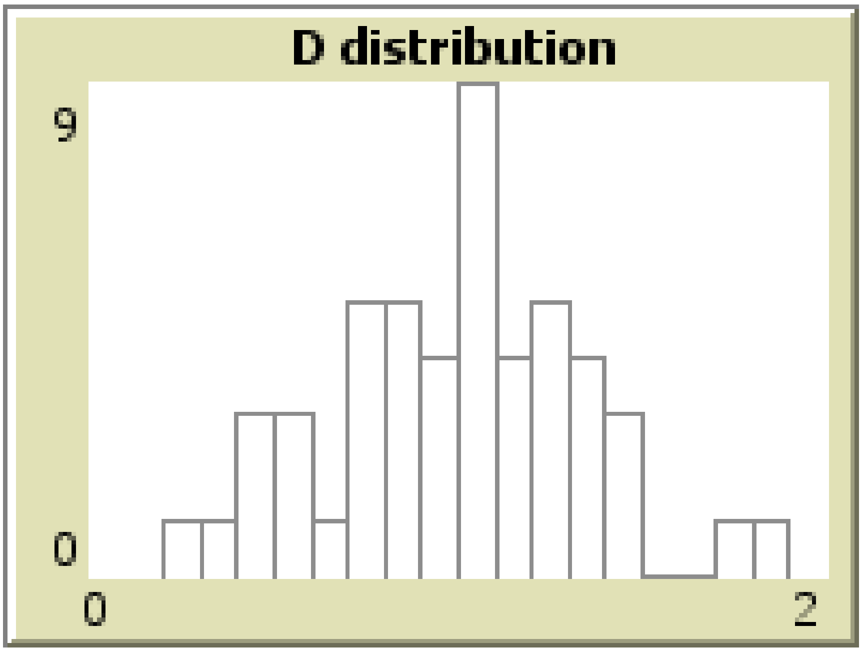

Figure 6 histogram of the initial wage distribution

Agents in our model independently assess the risk. The Nr (tolerance for each protest) as an exogenous variable for calculating deterrence is distributed normally and randomly Nr~ N (0.5, 0.167^2). Following Wilensky (2003), k = 2.3 is a constant set in 'startup' to ensure a reasonable value when there is only one cop and one agent within a certain vision. Also, we run the model in 12 scenarios based on changing legitimacy (0.81 and 0.69) and the number of rebellions (50, 67, and 84) and using obstacles to ban rebellions from closing sites. Table 1 shows the parameters and variables for running the simulation.

Table 1. model parameters for initialization

quantity	Variable or parameter
2.3	K
0.5	lambda
0.4	Alfa

As shown in table 2, The grievance distribution in our model differs somewhat from that of Epstein (2002). In the first scenario (without obstacle), with a moderate number of rebellions (N = 67) and higher legitimacy, the average grievance in our model (0.0254) is a little less than others. Also, at a moderate number of rebellions (N = 67) and lower legitimacy, the average grievance in our model (0.0401) is higher than others. But on the other hand, in the second scenario (without obstacle), grievance, when N = 67 and legitimacy = 0.81, is a little more than others, while when legitimacy = 0.69, the grievance decreases.

Table 2. Averages of Grievance and risk aversion in Epstein (2002) and Our Model (without obstacle)

legitimacy	Number of rebellions	Our work (without obstacle)		Our work (with obstacles)	
		Grievance	Risk aversion	Grievance	Risk aversion
0.81	50	0.0255	0.0409	0.0239	0.0204
0.81	67	0.0254	0.0479	0.0250	0.0300
0.81	84	0.0255	0.0583	0.0249	0.0397
0.69	50	0.0401	0.0535	0.0250	0.0300
0.69	67	0.0416	0.0681	0.0248	0.0397
0.69	84	0.0409	0.0791	0.0395	0.0239

As shown in table 2, the risk aversion increases when the number of rebellions increases. Whether a worker protests or not is contingent on both grievance and a rational calculation of the net risk. The net risk, in turn, is determined by an exogenously fixed individual level of risk-aversion and the estimated probability of being arrested. In our model, risk aversion is equal to deterrence multiplied by Estimated Arrest Probability (P), as is in Epstein's model. But, Nr ~ N (0.5, 0.167^2), instead of Nr ~ U (0,1) in his model. Following Kim and Hanneman (2011), we assume that most rebellions have degrees of deterrence close to the mean in the population, with a small number of outliers above or below the mean.

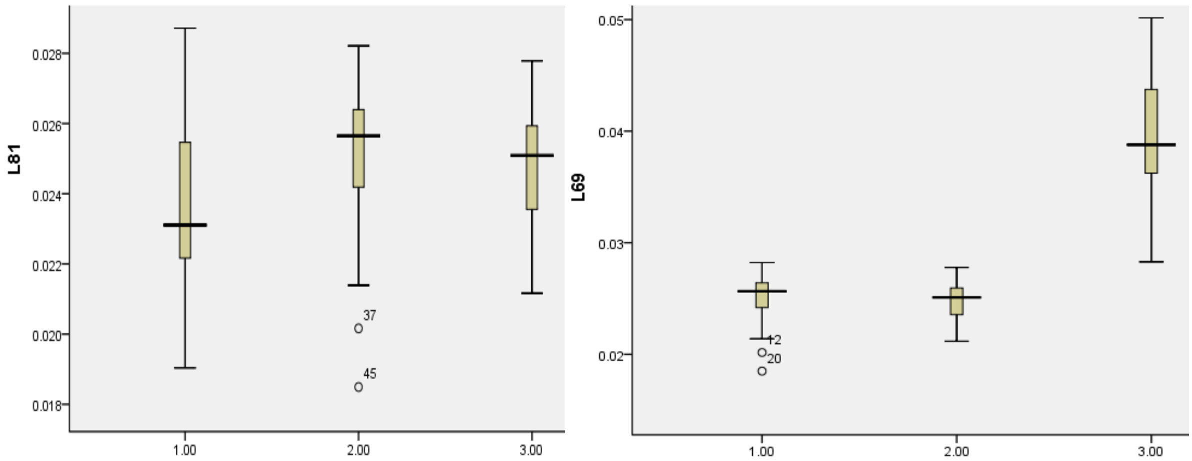

Figure 7. box plots of Grievance with obstacles (L= 0.69 and 0.81)

Box plot summary represents the distributions of grievance in different levels of legitimacy and the number of cops in two main scenarios. The plots depict that the distribution of grievance how varies in scenarios.

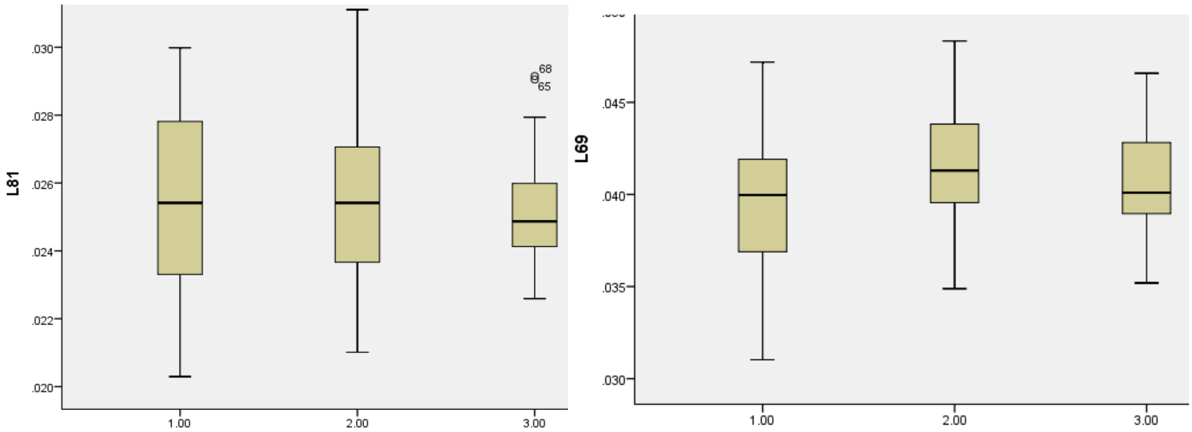

Figure 8. box plots of Grievance without obstacle (L= 0.69 and 0.81)

Comparing these, it is apparent that sensitivity to deprivation is an important factor determining grievance for the conditions analyzed in the experiment.

At the beginning of each round of the simulation, we allow rebellions that are not arrested for moving toward the target considering colliding obstacles. Workers then become active if the difference between their grievance and risk aversion falls above a fixed threshold (0.1, as in Epstein's model). Figure 8 shows the number of protesters and mobs in a repetition of both scenarios.

Table 3 shows the analytical result of simulation when police use obstacles as a tactic for crowd control our let them close to valuable sites without obstacles. As depicted before, the artificial data is not distributed normally, so we employ nonparametric tests. In order to investigate the significant difference between a grievance and risk aversion among groups, we use the Kruskal-Wallis test.

Table 3. The result of the Kruskal-Wallis test for differences in different crowd size

Legitimacy	Test result	without obstacle		with obstacle	
		Grievance	Risk aversion	Grievance	Risk aversion
0.81	chi- square	0.03	5.64	3.90	35.61
	sig	*0.98*	*0.06*	*0.14*	*0.00*
0.69	chi- square	2.22	21.68	49.57	23.25
	sig	*0.32*	*0.00*	*0.00*	*0.00*

Results show that the difference between rebellions' grievances in different amounts is not significant in the first scenario. But in the second scenario, their grievance of them is significantly different only when the legitimacy of the government is low. It means that in the case of protests in a government with a high level of legitimacy, the police are not proposed to use obstacles to reduce their grievance. On the other hand, the topic of risk aversion differs from grievance. The average risk aversion of people in three group sizes is significantly different in both levels of legitimacy when police use obstacles. But when we concentrate on the legitimacy level, the story becomes different from the first scenario. It shows that group size when the degree of legitimacy of government is higher cannot vary significantly.

Table 4 shows the nonparametric correlation test for investigating the correlation between grievance and risk aversion in all scenarios. The results show that when the police do not use obstacles, there is a significant correlation between risk aversion and grievance, when legitimacy is 0.81 and crowd size is moderate and big, while in the case of legitimacy equals 0.69, only in big crowd size we see a significant correlation.

Table 4. Result of correlation test between risk aversion and grievance

Legitimacy	Number of rebellions	without obstacle		with obstacle	
		coefficient	*sig*	coefficient	*sig*
0.81	50	0.033	*0.81*	0.167	*0.024*
0.81	67	0.280	*0.05*	-0.260	*0.06*
0.81	84	0.035	*0.01*	-0.013	*0.926*
0.69	50	0.153	*0.28*	0.140	*0.32*
0.69	67	0.087	*0.54*	-0.20	*0.88*
0.69	84	0.400	*0.00*	-0.260	*0.06*

On the other side, when police use obstacles, there is no statistically significant correlation in the 0.05 significance level. But if we consider the wider level, it is depicted that when legitimacy is 0.81, the correlation for moderate crowd size is significant. Also, the correlation is proved when legitimacy = 0.69 and the number of protesters is 84.

6. Conclusion

Crowd control poses a great challenge for authorities. We usually expect a well-managed crowd; however, it also usually has a surprise factor. If a disruption happens to the crowd, the disorder will appear and hence cause a mess and casualty accordingly. Realistic simulation of a crowd of people and investigating possible decisions are challenging areas of behavioral operation research. So Crowd simulation has been a significant research topic. Several methods have been proposed for modeling and simulating human behavior, but agent-based modeling is increasingly in use. Epstein (2002) presents an agent-based computational model of civil violence. His remarkable work has been developed in several works by researchers. Random movement is one of its limitations, making it inapplicable to reality. This paper aimed to model the civil violence in attacking valuable sites that guardians must protect. As the target is specific, rebellions try to approach them to destroy, and on the other hand, policemen are missioned to protect them by showing off their competencies, putting obstacles, and finally arresting some rebellions in the case of entering the alert area. Following Epstein (2002), our proposed model regards two kinds of rebellions (mobs and protesters). To simulate crowd steering decision-making, we apply an artificial potential field to explain how protesters and mobs wander to reach the target building. The artificial potential field is modified to the case of guardianship and could be modified and calibrated in future works. We conclude that rioters are willing to reach valuable sites while escaping from colliding obstacles and being arrested by policemen. Eventually, they move under the effect of attractive and repulsive forces. Two forces are manually imposed by police (obstacles and the number of officers) that could differ in situations. As an advantage of our work, researchers and police can simulate the effects of decisions on crowd behavior. Results also show that legitimacy can play an important role in crowd control; the higher government legitimacy, the lower grievance.

References

Adang, O.M.J., van der Wal, R. and Quint, H., 2010. *Zijn wij anders?: waarom Nederland geen grootschalige etnische rellen heeft*. Politieacademie.

Auyero, J. and Moran, T.P., 2007. The dynamics of collective violence: Dissecting food riots in contemporary Argentina. *Social Forces*, *85*(3), pp.1341-1367. https://doi.org/10.1353/sof.2007.0030.

Ballinas-Hernández, A.L., Muñoz-Meléndez, A. and Rangel-Huerta, A., 2011. Multiagent system applied to the modeling and simulation of pedestrian traffic in counterflow. *Journal of Artificial Societies and Social Simulation*, *14*(3), pp.1-19. https://doi.org/10.18564/jasss.1789.

Bandini, S., Manzoni, S. and Vizzari, G., 2004. Situated cellular agents: a model to simulate crowding dynamics. *IEICE TRANSACTIONS on Information and Systems*, *87*(3), pp.669-676.

Bandini, S., Manzoni, S. and Vizzari, G., 2009. Agent based modeling and simulation: an informatics perspective. *Journal of Artificial Societies and Social Simulation*, *12*(4), Available at: https://www.jasss.org/12/4/4.html.

Bonabeau, E., 2002. Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the national academy of sciences*, *99*(3), pp.7280-7287. https://doi.org/10.1073/pnas.082080899.

Brondolo, E., Baruch, C., Conway, E. and Marsh, L., 1994. Aggression among inner-city minority youth: A biopsychosocial model for school-based evaluation and treatment. *Journal of Social Distress and the Homeless*, *3*(1), pp.53-80. https://doi.org/10.1007/BF02087359.

Brondolo, E., Eichler, B.F. and Taravella, J., 2003. A tailored anger management program for reducing citizen complaints against traffic agents. *Journal of Police and Criminal Psychology*, *18*(2), pp.1-11. https://doi.org/10.1007/BF02807242.

Davies, T.P., Fry, H.M., Wilson, A.G. and Bishop, S.R., 2013. A mathematical model of the London riots and their policing. *Scientific reports*, *3*(1), pp.1-9. https://doi.org/10.1038/srep01303.

Durupınar, F., 2010. *From audiences to mobs: Crowd simulation with psychological factors* (Doctoral dissertation, Bilkent Universitesi (Turkey)).

Epstein, J.M., 1999. Agent-based computational models and generative social science. *Complexity*, *4*(5), pp.41-60. https://doi.org/10.1002/(SICI)1099-0526(199905/06)4:5<41::AID-CPLX9>3.0.CO;2-F.

Epstein, J.M., 2002. Modeling civil violence: An agent-based computational approach. *Proceedings of the National Academy of Sciences*, *99*(3), pp.7243-7250. https://doi.org/10.1073/pnas.092080199.

Fielding, N.G., 2005. *The police and social conflict*. Routledge-Cavendish.

Fielding, N. and Innes, M., 2006. Reassurance policing, community policing and measuring police performance. *Policing & society*, *16*(2), pp.127-145. https://doi.org/10.1080/10439460600662122.

Fleming, J., 2005, Working Together: Neighbourhood Watch, Reassurance Policing And The Potential Of Partnerships, Trends And Issues In Crime And Criminal Justice, *303*, pp. 1-6. https://www.aic.gov.au/publications/tandi/tandi303.

Friedman, M., Thoresen, C.E., Gill, J.J., Powell, L.H., Ulmer, D., Thompson, L., Price, V.A., Rabin, D.D., Breall, W.S., Dixon, T. and Levy, R., 1984. Alteration of type A behavior and reduction in cardiac recurrences in postmyocardial infarction patients. *American Heart Journal*, *108*(2), pp.237-248. https://doi.org/10.1016/0002-8703(84)90606-9.

Friedmann, R.R., 1992. *Community policing: Comparative perspectives and prospects*. Overview Text United States of America. https://doi.org/10.1007/978-1-137-07200-9_10.

Gerlock, A.A., 1997. New directions in the treatment of men who batter women. *Health Care for Women International*, *18*(5), pp.481-493. https://doi.org/10.1080/07399339709516302.

Goh, C.K., Quek, H.Y., Tan, K.C. and Abbass, H.A., 2006. Modeling civil violence: An evolutionary multi-agent, game theoretic approach. *IEEE international conference on evolutionary computation, 2006,* July. pp. 1624-1631. https://doi.org/10.1109/CEC.2006.1688503.

Goldstein, H., 1979. Improving policing: A problem-oriented approach. *Crime & delinquency*, *25*(2), pp.236-258. https://doi.org/10.1177/001112877902500207.

Goodrich, M.A., 2002. Potential fields tutorial. *Class Notes*, *157*. Available at: http :// borg.cc.gatech.edu/ipr/files/goodrich_potential_fiel ds.pdf.

Helbing, D. And Molnar, P., 1998. Social Force Model For Pedestrian Dynamics. *Physical Review*. E, Statistical Physics, Plasmas, Fluids, And Related Interdisciplinary Topics *51*(5), pp.4282-4286. https://doi.org/10.1103/PhysRevE.51.4282.

Holbrook, M.I., 1997. Anger management training in prison inmates. *Psychological Reports*, *81*(2), pp.623-626. https://doi.org/10.2466/pr0.1997.81.2.623.

Hu, N., Decraene, J. and Cai, W., 2012. Effective crowd control through adaptive evolution of agent-based simulation models. In *Proceedings of the 2012 Winter Simulation Conference (WSC),* December. pp. 1-12. https://doi.org/10.1109/WSC.2012.6465040.

Jackman, M.R., 2002. Violence in social life. *Annual review of sociology*, *28*, pp.387-415. https://doi.org/10.1146/annurev.soc.28.110601.140936.

Kirkland, J.A. and Maciejewski, A.A., 2003. A simulation of attempts to influence crowd dynamics. In *SMC'03 Conference Proceedings. 2003 IEEE International Conference on Systems, Man and Cybernetics. Conference Theme-System Security and Assurance (Cat. No. 03CH37483),* October, 5, pp. 4328-4333.

Kellner, M.H. and Bry, B.H., 1999. The effects of anger management groups in a day school for emotionally disturbed adolescents. *Adolescence*, *34*(136), pp.645-645.

Kim, J.W. and Hanneman, R., 2011. A computational model of worker protest. *Journal of Artificial Societies and Social Simulation*, *14*(3), Available at: https://www.jasss.org/14/3/1.html.

Laclavík, M., Dlugolinský, Š., Šeleng, M., Kvassay, M., Schneider, B., Bracker, H., Wrzeszcz, M., Kitowski, J. and Hluchý, L., 2012. Agent-based simulation platform evaluation in the context of human behavior modeling. *International Conference on Autonomous Agents and Multiagent Systems, 2012,* Springer, Berlin, Heidelberg*, May*. pp. 396-410.

Lemos, C., Coelho, H. and Lopes, R.J., 2013. Agent-based Modeling of Social Conflict, Civil Violence and Revolution: State-of-the-art-review and Further Prospects. *EUMAS*, pp.124-138.

Moro, A., 2016. Understanding the dynamics of violent political revolutions in an agent-based framework. *PLOS one*, *11*(4), pp.1-17. https://doi.org/10.1371/journal.pone.0154175.

Makowsky, M.D. and Rubin, J., 2013. An agent-based model of centralized institutions, social network technology, and revolution. *PloS one*, *8*(11), pp.1-11. https://doi.org/10.1371/journal.pone.0080380.

McKenzie, F.D., Garcia, H., Nguyen, Q.H., Seevinck, J. and Petty, M.D., 2004. Mogadishu terrain generation and correlation for crowd modeling. In *Proceedings of the Spring 2004 Simulation Interoperability Workshop,* pp. 18-23.

McLellan, D., 1995. *The thought of Karl Marx: an introduction*. Pan Books Limited.

Miranda, A. and Jesús Presentación, M., 2000. Efficacy of cognitive-behavioral therapy in the treatment of children with ADHD, with and without aggressiveness. *Psychology in the Schools*, *37*(2), pp.169-182. https://doi.org/10.1002/(SICI)1520-6807(200003)37:2<169::AID-PITS8>3.0.CO;2-8.

Niemann, J.H., Winkelmann, S., Wolf, S. and Schütte, C., 2021. Agent-based modeling: Population limits and large timescales. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, *31*(3), pp.1-17. https://doi.org/10.1063/5.0031373.

National Intelligence Council (Nic) ed., 2012. *Global Trends 2030: Alternative Worlds: a Publication of the National Intelligence Council*. US Government Printing Office.

Park, A.J., Buckley, S., Ramirez, H.C.A., Tsang, H.H. and Spicer, V., 2015. A decision support system for crowd control using agent-based modeling and simulation. In *2015 IEEE International Conference on Data Mining Workshop (ICDMW), 2015,* November. pp. 997-1000.

Pires, B. and Crooks, A.T., 2017. Modeling the emergence of riots: A geosimulation approach. *Computers, Environment and Urban Systems*, *61*, pp.66-80. https://doi.org/10.1016/j.compenvurbsys.2016.09.003.

Pabjan, B. and Pękalski, A., 2007. Model of prison riots. Physica A: Statistical Mechanics and its Applications, 375(1), pp.307-316. https://doi.org/10.1016/j.physa.2006.08.069.

Perez, D.W. and Muir, W.K., 1996. Administrative review of alleged police brutality. *Police violence: Understanding and controlling police abuse of force*, *37*(3), pp.213-233.

Quek, H.Y., Tan, K.C. and Abbass, H.A., 2006, Modeling civil violence: An evolutionary multi-agent, game theoretic approach. *IEEE Trans. Evol. Comput*. https://doi.org/10.1109/CEC.2006.1688503.

Ronald, N., Sterling, L. and Kirley, M., 2007. An agent-based approach to modelling pedestrian behaviour. *International journal of Simulation*, *8*(1), pp.25-38.

Rymill, S. And Dodgson, N., 2005, A Psychologically-Based Simulation Of Human Behaviour. In *Uk Theory And Practice Of Computer Graphics*, pp. 35-42. https://doi.org/10.48456/tr-717.

Reynolds, C.W., 1987. Flocks, herds and schools: A distributed behavioral model. In *Proceedings of the 14th annual conference on Computer graphics and interactive techniques,* August. pp. 25-34. https://doi.org/10.1145/37401.37406.

Stronks, S. and Adang, O.M., 2015. Critical moments in police-citizen reconciliation. *Policing: An International Journal of Police Strategies & Management*, *38*(2), pp.366-380. https://doi.org/10.1108/PIJPSM-12-2014-0136.

Situngkir, H.,2004, On Massive Conflict: Macro-Micro Link, *Journal Of Social Complexity*, *1*(4), pp.1-12. http://dx.doi.org/10.2139/ssrn.601784.

Skogan, W.G., 2005. Citizen satisfaction with police encounters. *Police quarterly*, *8*(3), pp.298-321. https://doi.org/10.1177/1098611104271086.

Stark, R., 1972. *Police riots: Collective violence and law enforcement* (p. 98). Belmont, Cal.: Wadsworth Publishing Company.

Tucker, C.W., Schweingruber, D., & Mcphail, C. , 1999, Simulating Arcs And Rings In Gatherings. *International Journal Of Human-Computer Studies*, 50, pp 581–588. https://doi.org/10.1006/ijhc.1998.0255.

Tyler, T.R. and Huo, Y.J., 2002. *Trust in the law: Encouraging public cooperation with the police and courts*. Russell Sage Foundation, New York.

Weisburd, D. and Braga, A.A., 2006. *Police innovation: Contrasting perspectives*. Cambridge University Press.

Wilensky, U., 2003. Statistical mechanics for secondary school: The GasLab multi-agent modeling toolkit. *International Journal of Computers for Mathematical Learning*, *8*(1), pp.1-41. https://doi.org/10.1023/A:1025651502936.

Wise, S.C. and Cheng, T., 2016. How officers create guardianship: An agent-based model of policing. *Transactions in GIS*, *20*(5), pp.790-806. https://doi.org/10.1111/tgis.12173.

Yiu, S.Y., Gill, A. and Shi, P., 2002, October. Investigating strategies for managing civil violence using the MANA agent based distillation. In *Land Warfare Conference, Brisbane*.

Zhong, J., Luo, L., Cai, W. and Lees, M., 2014. Automatic rule identification for agent-based crowd models through gene expression programming. In *Proceedings of the 2014 international conference on Autonomous agents and multi-agent systems,* May. pp. 1125-1132.