# 3.9 A Model of Rapid Radicalization Behavior Using Agent-Based Modeling and Quorum Sensing

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*Abstract*: Understanding the dynamics of radicalization, especially rapid radicalization, has become increasingly important to US policy in the past several years. Traditionally, radicalization is considered a slow process, but recent social and political events demonstrate that the process can occur quickly. Examining this rapid process, in real time, is impossible. However, recreating an event using modeling and simulation (M&S) allows researchers to study some of the complex dynamics associated with rapid radicalization. We propose to adapt the biological mechanism of quorum sensing as a tool to explore, or possibly explain, rapid radicalization. Due to the complex nature of quorum sensing, M&S allows us to examine events that we could not otherwise examine in real time. For this study, we employ Agent Based Modeling (ABM), an M&S paradigm suited to modeling group behavior. The result of this study was the successful creation of rapid radicalization using quorum sensing. The Battle of Mogadishu was the inspiration for this model and provided the testing conditions used to explore quorum sensing and the ideas behind rapid radicalization. The final product has wider applicability however, using quorum sensing as a possible tool for examining other catalytic rapid radicalization events.

## 1. INTRODUCTION

What is the cause of rapid social and political radicalization? Over the past several years, rapid radicalization has caught the attention of governments because of the potency of radicalized movements and the increased prevalence of radicalized groups. Although studying these types of events after the fact may help shed light on the dynamics of the events, it does not provide much insight into the underlying factors that cause radicalization. Because rapid radicalization events occur so quickly, often with no warning at all, and usually dissipate equally as quickly, within anywhere from a couple of hours to a couple of days, it is very difficult to collect usable data from these events. However, recreating events using modeling and simulation (M&S) allows researchers to study some of the complex dynamics associated with rapid radicalization.

Agent Based Modeling (ABM) is an M&S paradigm well suited for modeling group behavior and for simulating factors that can lead to rapid radicalization. In this paper, we introduce the concept of quorum sensing within an ABM framework as a means of exploring rapid radicalization and as a possible explanation for why and how rapid radicalization can occur.

In biological systems, quorum sensing refers to a decentralized decision making process in which the behavior of a group is correlated with the population density of that group [5]. During a quorum sensing decision, each individual within the group emits and receives a signal from other group members; the behavior of each individual changes when the accumulated signal exceeds a threshold. Due to the reciprocal nature of quorum communication, group behavior often changes rapidly, resembling the rate of change seen in human social and political radicalization.

In the current paper, we will extend a basic quorum sensing model to the domain of human interaction in a volatile social environment. We hypothesize that quorum sensing will result in more instances of rapid radicalization, and the component parts of quorum sensing will help describe dynamic group behavior under stressful conditions.

## 2. BACKGROUND

For the purpose of this paper, we define rapid radicalization as a process in which a small subset of a populace join to perform some radical action; this process spreads quickly until a majority of the population is participating. This term is similar to an event where military personnel will move synchronously to a target or point of contact. Unlike coordinated military movements, however, rapid radicalization occurs despite the presence of a central organizing figure, no defined lines of communication between mobilizing individuals, and no clear process for deciding when individuals should move or take action. Despite these differences, the outcome of organized military movements and rapid radicalization can be very similar.

An example of rapid radicalization can be seen in the Battle of Mogadishu, more famously know as Black Hawk Down. During the battle, US forces were primarily engaged with hostile forces loyal to local warlords. When the battle first began, these factions organized quickly and converged on the location of two downed US Blackhawk helicopters[1]. Over the course of the battle, however, many non-militant forces mobilized in a similarly fast and coordinated manner, taking up arms against the US Soldiers. These non-militant forces included members of small independent groups that were established to protect city blocks from the warlord forces. Within a matter of hours, these independent groups were mounting an apparently unified attack on US Soldiers.

Rapid radicalization events such as this raise questions about the motivation and communication that allow independent groups to operate in a unified, coherent manner. One anecdotal story from the book "Black Hawk Down" by Mark Bowden recounts how a young man was caught in the crossfire between US forces and warlord forces. The young man was a member of the civilian population and was shot and killed by US Soldiers. A friend of the boy witnessed his death and immediately returned home to retrieve his rifle, meant to defend himself from the warlord groups, and returned to engage in the firefight against the US Soldiers. This individual reached a tipping point at which time he felt compelled to act in a radical manner.

Another example of rapid radicalization can be seen in the recent wave of revolutionary uprisings in the Middle East and North Africa, known as the "Arab Spring." Since December 2010, large-scale demonstrations and civil resistance movements have occurred in over 16 countries [2]. Although these demonstrations have been independent, targeting specific issues in each local country, the movement as a whole appeared to share a common momentum and to operate with a unified purpose. Social networking sites are credited with providing a relatively stable and secure communication platform to facilitate the organization of these movements and to broadcast news of the events as they occurred [7]. However, access to these sites alone does not explain the speed and magnitude of self-organization within each individually motivated population acting against similarly independent governments.

We propose that in rapid radicalization situations, there are underlying factors that affect each individual; communication media such as social networking sites simply provide a tool each individual can use to observe the state of others in a similar situation. When a person is motivated to act against a larger force to change their situation, taking action may expose that person to an unacceptable level of risk; when a quorum arises, the person no longer faces this risk individually and enjoys “safety in numbers.” We believe that this type of decision process characterizes rapid radicalization. The goal of this paper is to explore the factors that contribute to this decision process and to understand what compels an individual to commit to a radical course of action that, when taken as an individual, is prohibitively dangerous.

## 2.1. Quorum Sensing

In biological systems, quorum sensing refers to a decentralized decision making process in which the behavior of a group is correlated with the population density of that group [5]. Quorum sensing operates through a reciprocal communication process in which each individual in the population signals its presence to its neighbors, and each individual detects the presence of its own neighbors. The detected signal is therefore directly proportional to the population density. When the quorum population density exceeds a threshold, behavior of each individual in the population changes very rapidly. For this reason, we have chosen to use a mathematical model of quorum sensing as the basis for the current model of rapid radicalization.

When examining human behavior as a quorum-sensing decision within a population, one must make several assumptions about each individual in the population. First, in order for quorum sensing decisions to occur, each individual in a population must have some capacity for signaling their presence and for detecting the presence of other elements. Second, quorum sensing assumes that each individual in a population is motivated to perform some action, but taking action under the current conditions is not advantageous for the individual due to a high cost of action and perhaps a high likelihood of failure or economic loss.

The current paper evaluates a quorum-sensing model that is based on passive, spatial and temporal diffusion of information. While the focus of the current paper is rapid radicalization, results will focus on the time of first radicalization, the duration of radicalization from first attack, and the total time for full population radicalization to occur from the initial state of the model.

## 2.2. Line-of-Sight

This paper also includes a default radicalization model based on line-of-sight contact with radicalization events such as death or loss of/damage to valued assets. The motivation behind this model was the radicalization of neutral civilian forces observed in the Battle of Mogadishu, described earlier. In this model, individuals in the population decide to attack in response to a death event occurring within an individual’s line of sight. Following initial mobilization, the individual will influence other neighbors to join the attack.

This model differs from the quorum-sensing model in several respects, specifically, the style and speed of communication between individuals, the motivation of individuals in the simulation, and the catalyzing events that lead to radicalization. Unlike the quorum-sensing model, the line-of-sight model assumes that, by default, individuals are not motivated to attack. Individuals will only take action and join the attack after witnessing a catalyzing event such as a death or by coming into close contact with a neighbor who is fighting. This assumption is made deliberately so that the model will be devoid of past influences, i.e. the majority of the population is politically neutral and has no preexisting bias toward action or inaction without the target posing a real threat. The quorum-sensing model, on the other hand, assumes that individuals are motivated to attack, but choose to remain passive because of the prohibitively high personal risk that is inherent in attack.

# 3. METHODS

All models were created using an ABM framework with the NetLogo platform [6], an ABM environment developed in the Java language. In ABM, each individual is represented as an agent, operating independently and in parallel with other agents in the model. The framework can also include real world constraints and life events [3]. Agents in these models behave according to a set of rules specified by the programmer and then interact with one another according to this rule set, recreating complex human interactions [4]. Researchers often employ ABM because it allows them to control precise individual behaviors and to monitor the aggregate behavior of a group for the purpose of experimentation and study. We chose to use this framework because we are interested in the activity of multiple individuals within a group. ABM allows us to create this group and to provide discrete rule sets describing quorum sensing and line-of-sight behavior.

We selected an M&S approach because it is not feasible to examine rapid radicalization as it unfolds, interviewing individuals and collecting data. M&S provides a means to simulate these events in a highly controlled and replicable fashion, repeating simulations and modifying details of the simulations on subsequent runs.

### 3.1. Model Construction and Behavior Specification

Both models consisted of 300 agents distributed randomly across a 33x33 grid of "patches." During each simulation, agents interacted on this grid over up to 24 time steps, with each time step arbitrarily defined as equivalent to 1 hour. During each time step, agents cycled through four behaviors: broadcast status, sense status, fight, and move.

Each agent is described by several variables: *attack status*, *agitation level*, *attack threshold*, and *spatial position*. By default, all agents begin in a non-attack status and with agitation level equal to zero. Agitation level ranges from 0 to 1, and attack threshold also ranges from 0 to 1. By default, the attack threshold is equal to 0.9 +/- 0.1. Agents in the quorum-sensing model contained an additional *risk* parameter defining the percent-level risk associated with attack (0% = no risk, 100% = maximum risk).

At the beginning of each time step, agents broadcast their agitation level to other agents; the broadcast method varies between quorum-sensing and line-of-sight models and is described in more detail below. During the sense stage, agents detect environmental events including death events as well as the agitation level of neighboring agents. These inputs increase or decrease the agents agitation level during the fight stage; if the agitation level exceeds the attack threshold, the agent goes into an attack status. At the end of each behavior loop, agents move one patch in a random direction.

Specific operations carried out during the broadcasting, sensing, and fighting stages differed between quorum-sensing and line-of-sight models. Behaviors and associated equations are described below for each model.

*Quorum-sensing*

broadcast: each agent emits a persistent agitation signal defined as *emission strength*, ranging from 0-1 that decays exponentially with distance and time

sense: incoming agitation signals are added; total incoming agitation is subtracted from risk and transformed into a local agitation level according to the sigmoidal decision function shown below in eq. (1) and Fig. 1.

**Eq. (1)**

$$local\ agitation = \frac{1}{1 + \mathrm{e}^{(\mathrm{risk} - \mathrm{incoming\ agitation})}}$$

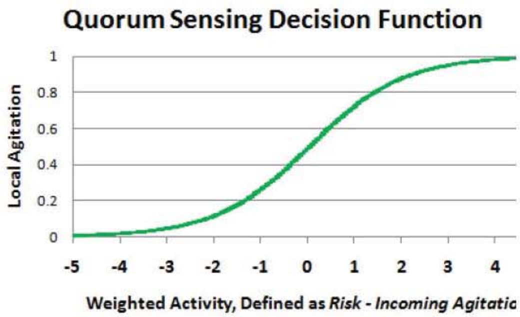


**Figure 1: Sigmoidal Sensing Function Graph**

fight: if local agitation exceeds threshold, switch to attack mode

*Line-of-sight*

broadcast: if attacking, agents communicate their attacking status to other agents within a 6-patch radius; signal is weighted according to a *social influence* parameter that ranges from 0-1 (i.e. recruiting neighbors to attack); signal decays linearly with distance

sense: incoming agitation signals are added to calculate a local agitation level

fight: if local agitation exceeds threshold, switch to attack mode; if agent is located within 8 patches of the center of the simulation and a death has occurred, set movement to false; with 20% probability, increase agitation level of link neighbors by a parameter that ranges from 0-1 (i.e. death of a family member or friend); remove the dead agent from the simulation

### 3.2. Experimental Protocol

For each model, we are concerned primarily with the time of first radicalization, the duration of the radicalization process, and the total time for full radicalization to occur from the initial state. These variables were measured at the conclusion of the 24 time steps, or when percentage of radicalized agents reached 100%. Parameters of each model were varied systematically in an effort to understand the role of each factor in the radicalization process. The specific manipulations that were made were determined through a piloting process intended to discover values of each variable that would produce a complete range of the outcome variables.

In the quorum-sensing model, level of risk and emission strength were varied independently. Level of risk was set to 26.7%, 30.0%, and 33.3%; emission strength was set to 0.5 – 0.7 in steps of 0.05. These manipulations represent a change in the risk associated with action, and a change in the level of agitation that each agent expresses.

In the line-of-sight model, social influence and death influence were varied independently. Social influence was set to 0.3, 0.4, 0.5, and 0.6; death influence was set to 0.5, 0.6, 0.7, and 0.8. These manipulations represent a change in the affect an attacking agent has on neighboring agents, and the affect a death event has on nearby agents.

To account for random outliers in simulation results, each simulation was run 10 times for each manipulation and the results below consist of the average outcome across all 10 iterations.

## 4. RESULTS

The quorum-sensing and line-of-sight models were explored parametrically in order to evaluate the radicalization effects produced by each. Rapid radicalization is defined as a process in which a small subset of a populace join to perform some radical action; this process spreads quickly until a majority of the population is participating. Based on this definition, the model behaviors of interest to the current paper are the time of first radicalization or attack, the net duration of radicalization process, and the total time for full population radicalization to occur from the initial state. These data are shown graphically in figs. 2-7 below.

### 4.1. Quorum-Sensing

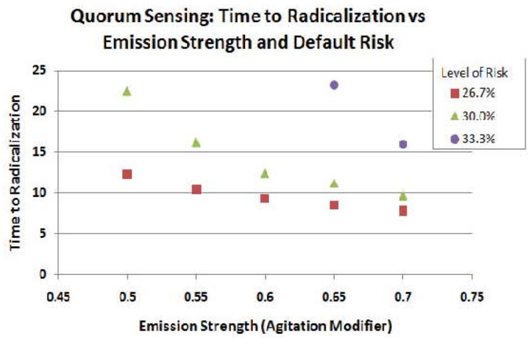


**Figure 2: Total time to radicalization in the quorum-sensing model, from the initial state of the model for varying levels of risk and emission strength (magnitude of agitation expressed).**

Figure 2 shows that at 33.3% risk, emission strength below 0.65 did not result in rapid radicalization suggesting that the desire to express feelings of agitation was outweighed by the risk associated with taking action.

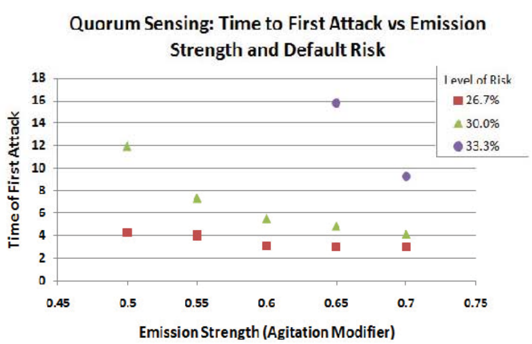


**Figure 3: Time to first attack in the quorum-sensing model.**

The numbers in Fig. 3 reflect the speed with which the population begins to become radicalized. For example, during the Battle of Mogadishu, the population became radicalized within 4-6 hours after the battle began suggesting that individuals had little to lose by joining the battle.

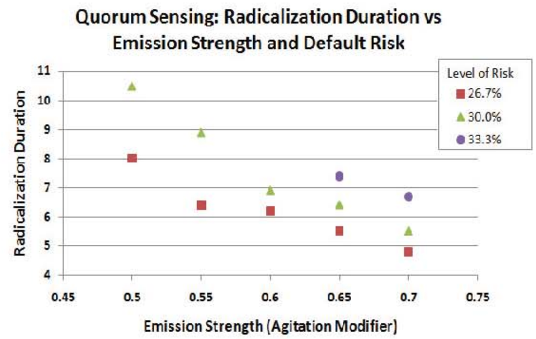


**Figure 4: Radicalization duration from the time of first attack in the quorum-sensing model.**

Figure 4 reflects the rate of radicalization in the population: the lower the number, the faster the population (N = 300) became fully radicalized. These results suggest that the population in the Battle of Mogadishu was highly expressive in their agitation.

## 4.2. Line-of-Sight

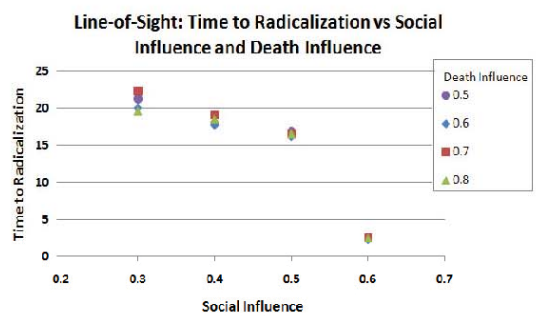


**Figure 5: Total time to radicalization in the line-of-sight model, from the initial state of the model for varying levels of social influence and death influence.**

Figure 5 demonstrates time to radicalization varies as a function of social influence, but is unaffected by changes in death influence.

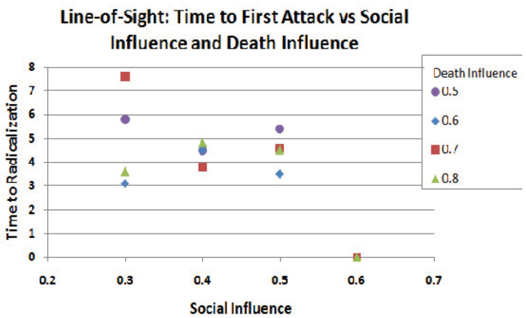


**Figure 6: Time to first attack in the line-of-sight model.**

Figure 6 demonstrates that similar to the total radicalization time, high social influence seems to lead to rapid radicalization whereas there is little affect of death influence. In the data shown above, the effects of death influence are unstable when social influence drops below 0.6

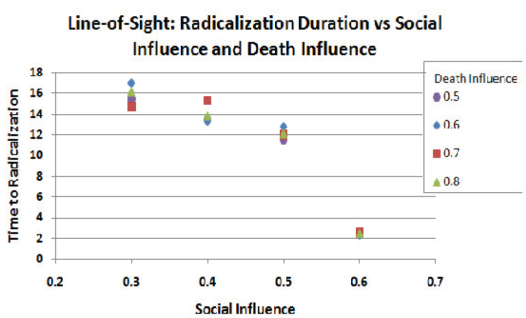


**Figure 7: Radicalization duration from the time of first attack in the line-of-sight model.**

The rate of radicalization in Fig. 7 appears to depend primarily on social influence, not on death influence. This is not surprising given that, in the current simulation, death was the catalyzing event and only affected those agents nearby, whereas social influence played a continuous role in the radicalization of other members of the populace.

## 5. CONCLUSION

The goal of the current paper was to explore the radicalization of a population as modeled using quorum sensing and line-of-sight influence. As shown in the figures 1-3 above, changes in both risk and expressed agitation yielded visible changes in the onset and speed of rapid radicalization. These changes decrease monotonically with both increasing risk and increasing agitation. As shown in figures 4-6 above, line-of-sight influence varied significantly with changes in social influence, but there were no visible changes apparent with change in death influence. The only exception to this is instability in time to first attack during situations where social influence is weak (fig. 5). It is possible that this instability occurred because line-of-sight influence is highly sensitive to the spatial distribution of agents; if a death occurred in a relatively sparse area, the time to first attack would be substantially increased.

Given the dynamics demonstrated in the current model, quorum sensing or line-of-sight (or some combination of the two) may be used as a basis for modeling other rapid radicalization events such as violent insurgency, political uprising, and other forms of radical action. Such movements have occurred numerous times, both recently and in more distant past. Recent insurgency may provide a model for understanding radicalization as it occurs in spatially-diffuse networks with unreliable communication. Similarly, older examples such as the revolutions of 1989 in Poland and Eastern Europe and even the revolutions of the 18th and 19th centuries (notably, the US and France) may provide examples of slow radicalization occurring over extended distances and timescales.

Using a common modeling framework for each of these older cases would allow one to draw interesting comparisons between older revolutionary periods and the current Arab Spring, especially in examining the role that modern social networking sites have played in facilitating communication between individuals. The results of the experiment further confirm this as the line-of-sight model demonstrated high sensitivity most likely owing to the distance between agents. The socially connected nature of many members of the Arab states experiencing uprisings would remove the limitations imposed on agents in the line-of-sight model.

These models may also be augmented to include networks of unique networks such as independent countries seeming to act in parallel, or with competing populations who vary in terms of their decision priorities (for example, honor-based versus reputation-based societies). Finally, it may also be possible to adapt the models to situations involving fewer agents in a spatially enclosed area, such as a prison riot.

While the performance of these models suggests the promise of explanatory power, these models can also be used to understand how one may disrupt and/or facilitate the radicalization of the population through methods such as communication disruption, quorum quenching, or systematic agitation; manipulations that are possible to explore within an ABM/M&S framework.

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