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Comparing Discrete Simulation and System Dynamics: Modeling an Anti-insurgency Influence Operation

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Abstract

This paper contrasts the tradeoffs of modeling the same dynamic problem at a micro scale and at a macro scale of analysis: discrete system simulation (DS) versus continuous system simulation or system dynamics (SD). Both are employed to model the influence of entertainment education on terrorist system decay, with implications for field application. Each method optimizes different design, scope/scale, data availability/accuracy, parameter settings, and system sensitivities. Whether the research served by the computer model is applied or theoretical, DS tends to be useful for understand low-level individual unit/step influences on system change over time, whereas SD tends to shine when a wide-angle focus upon sociological/aggregate change is required.

Keywords: terrorism, terrorist cell, social science simulation

1. Introduction

This paper responds to the call by Casdagli (1991), read before the Royal Statistical Society at a meeting on Chaos, to explore the relative accuracy of deterministic versus stochastic approaches to prediction. We contrast stochastic,

discrete time/entity-based simulation (discrete system or DS, c.f., Law & Kelton 2000) and deterministic differential equation-based system dynamics modeling (SD, c.f., Sterman, 2000) in the context of modeling a counter-insurgency influence operation.

A comparison of modeling paradigms may clarify a researcher's array of choices for modeling a particular situation. This paper considers each method on eight dimensions: 1) overall design, 2) scope and scale of the model, 3) methods for gaining and testing knowledge, 4) availability, quantity, accuracy of system data, 5) underlying mathematics and analysis, 6) ease of communicating behavior and results, 7) sociological research relevance, and 8) educational potential.

The challenge was to build two models of the same terrorist system, using DS and SD, with the goal being to determine whether one modeling approach or the other makes a stronger argument in favor or against of the use of Entertainment Education (EE) soap operas (Singhal & Rogers, 1999) to support anti-terrorist influence operations. Terrorist system and EE background data is provided next, followed by a detailed description of the application of DS to terrorist cell dissolution. The application of SD to the same problem context is then described, followed by a summary comparison and concluding remarks.

2. Background

System Strength

Traditional military strength lies in an army's ability to lay siege to a physical system, attacking physical resources from the outside. However, terrorists shift the battlefield from large-scale and simple, where they are weak (conventional capital-intensive warfare), to a small-scale complex battlefield, where terrorists possess the greater strength, the field of beliefs. Beliefs are hidden and difficult to locate; a warfare of beliefs is complex. In complex warfare, the battlefield is shifted from simple to complex systems where it is difficult to distinguish between friend, enemy, and bystander (Bar-Yam, 2004; Kress & Szechtman, 2009).

Conventional wars are won by destroying physical people, places, and cutting off resources. However, applying conventional warfare to fight terrorism has the effect of dousing a fire with gasoline. Terrorist *martyr cards* are passed from friend to friend to strengthen ideology and recruit new terrorists (Oliver & Steinberg, 2005). Killing one terrorist generates multiple new ones, revealing a hydra-headed monster. Terrorist systems redouble and get stronger after physical attacks (Kress & Szechtman, 2009), pumping up ideological and social support (Fraser & Fulton, 1984; Stern, quoted in Greenberg, 2005) to maintain system equilibrium.

Communication channels become ideological supply lines. Terrorist groups employ media to feed passive fringe supporters, keeping them pumped up and mobilized, to demoralize the enemy (Burns & Slovic, 2007), and to glorify themselves (Borowitz, 2005; Fraser & Fulton, 1984; Harmon, 2000; Wright, 1985). Execution videos are popular (Schuster, quoted in Greenberg), as are websites, TV productions, and news coverage of their destructive heroism. Media events serve as a kind of tree shaking that showers recruits with intelligence, promises of spiritual

rewards, emotional support, hero worship, cash, medical supplies, safe houses, forged documents, travel papers, and transport (Stern, quoted in Greenberg, 2005).

Physical supply lines (Harmon, 2000) are guarded by a trinity of impoverished desperation, family ties, and ideology. Ideological anti-globalization support is reinforced by 1 billion Muslims. However, only 6 out of 100,000 Muslims are active supporters who generate recruits for terrorist training (Fraser & Fulton, 1984). Training camps swell with cliques of family and friends, whose ties of childhood loyalty are strengthened by recruiters' propaganda (Harmon, 2000). Shrewd professional recruiters (Burke, 2003; Harmon, 2000), some are angry students denied US visas (Wright, 1985), preach a "doctrine of necessity" (Harmon, 2000; Wright, 1985). Driven to desperate measures for a desperate cause (Burke, 2003; Cooper, 1977; Rubenstein, 1987; Wright, 1985), parents pay recruiters in children, as a tax to fight devil globalization (Stern, quoted in Greenberg, 2005).

System Destabilization on the Macro Scale

The supply line is both the strength and the Achilles heel in the insurgent network. Field reports estimate that an insurgent system requires approximately 250 supporters to maintain a healthy lifeline to the average 5-7 member terrorist cell. When the community falls below 150 supporters, terrorist cell viability wanes. Within days to weeks the cell dissolves (Adams, 1986; Financial Action Task Force, 2001; Fraser & Fulton, 1984; Wright, 1988). Below 150, cells receive insufficient food and cash, tension mounts, misunderstandings and ever-present discipline problems worsen, and suspicions rise. Leaders are known to make an example of contentious members by ordering harsh punishments and executions (Bodansky; 1986; Burton, 1976; Harmon, 2000). The Achilles heel of the macro system is internal fomentation.

An internal-fomenting influence operation is offered in the form of the empirically supported EE soap opera. EE provides a smart-target vehicle to seed internal questioning. Community-wide questioning foments changes in deeply held beliefs and behaviors.

Deployed by radio, EE is documented as changing ideologies and behaviors in 60-90% of listeners (Bandura, 1986; Bandura, 2004; Singhal & Rogers, 1999; Singhal & Rogers, 2002). For example, the EE soap opera *Hum Log* influenced strong reversal in traditional beliefs and behaviors among 92% of listeners in India. In Mexico, *Ven Conmigo* increased enrollment in literacy classes by nine times over the previous year. After one night's episode, "250,000 newly enrolled literacy students converged on a warehouse to obtain their literacy booklets...an unprecedented traffic gridlock was created in downtown Mexico City, lasting until after midnight" (Singhal & Rogers, 1999, p. 55).

System Destabilization at the Micro Scale

The most effective EE influence operation is comprised of soap operas written by community natives, in this case defectors. Writers reproduce community life, dramatizing typical choices with high stakes. Viewers identify with characters like themselves via parasocial interaction (Horton & Wohl, 1956). Episodes purposefully end as cliffhangers, without resolution. They end instead with a favored character

asking the audience how a character should choose, between personal ethics versus upholding an outmoded ideology targeted for destabilization. Individuals view in clubs to excitedly question each other's beliefs, advising, and becoming change agents (Rogers, 2003). In India, 63% of men and 37% of women listened to *Tinka Tinka Sukh*; 50% made changes in their personal daily schedules to listen to episodes, and 43% offered advice to influence some character's decision (Singhal & Rogers, 1999).

An Achilles heel in the psychology of active insurgents is the individuals' abhorrence of violence. Defection from terrorist groups is most likely when the individual's underlying revulsion for the group doctrine of violence is brought into question. At first, the individual is attracted by the heroic glory and adventurous lifestyle. Driven by hatred toward globalization and the impoverished status quo, the individual justifies violence as necessary to transform an unjust world (Cooper, 1977; Post, 1987).

Destructive heroism is known as the Herostratos syndrome after a Greek youth who sought immortality via destruction (Borowitz, 2005; Burke, 2003; Cooper, 1977; Harmon, 2000; Hoffman cited in Greenberg, 2005; Stern, quoted in Greenberg, 2005; Stohl, 1988; Wright, 1985; Wright, 1985). Usually recruited in groups of friends, members socially reinforce each other's Herostratos syndrome, justifying destructive crimes within new group norms (Bandura, 1986; Bandura, 2004; Burke, 2003; Nechaev, 1869; Post, 1987; Wilkinson, 1974).

However, there is a constant tension between thinking global and acting local. Infighting, competitions with other members over resources (Burke, 2003), and assassinations of contentious members backfire. Disgruntled friends leave in twos and threes (Bodansky, 1986; Wright, 1985). Older terrorists stay for the excitement, but most individuals outgrow it and revert to nonviolent convictions (Harmon, 2000, Wright, 1985). Individual conviction is a reactant in the change process, lowering the threshold for behavior change by increasing variance or error that departs from the group mean.

Micro/macro Destabilization Model Comparison

A DS (micro) model can focus on how individual random decisions compound group variance and emerge as system behavior breakdown. On the other hand, an SD (macro) approach can model the aggregate decision change process, using aggregate stocks to represent group thoughts, ideas, and behaviors. Although DS and SD tend to emphasize different levels of scale and different units of analysis, it may be argued that each method can be adapted to represent both macro and micro behaviors to some extent. The present research explores the limits of DS and SD models to do exactly this.

Previous Terrorism Systems Research

To provide a specific context for comparing DS and SD, we reviewed several papers that presented relevant data and/or models, (including *number of terrorist supporters, number of terrorist acts, TV coverage as ideological reinforcement, concerned talking, message decay rate, and ideological perception changes*). After exploring different modeling approaches, we selected two SD papers as the basis for

comparison. The primary advantages of these two papers were that the authors provided estimated parameter values and differential equations. Although much of their data were “notional assumptions” (Weaver, 2008), their models were well developed in a progressive fashion. Weaver suggested that accuracy of future models would “depend heavily upon model parameterization and the formulation of effect functions” (p. 19). The present study employs intelligence from field operations to answer Weaver’s call.

Kress and Szechtman’s (2009) model considered collateral damage that occurs when large-scale U.S. operations take a high-force buck-shot approach to eradication, killing civilians, which serves to increase the number of new insurgents. They hypothesized that an influence campaign could reverse this reinforcing loop. Without specifying the type or details of the influence operation, they expected that numbers of defectors would increase. Increased numbers of defectors would provide more accurate intelligence for smart-targeting insurgent locations. Civilian deaths could be reduced if the killing were more selective. They recognized that killing caused the problem, but maintained that increasing killing accuracy was the best-case scenario. They assumed that “the government cannot totally eradicate the insurgency by force. The best it can do is *contain* it at a certain fixed level” (p. 1).

Kress and Szechtman (2009) recognized that ideology might play a role in waging an anti-insurgent “war of attrition,” but excluded ideology from the model, claiming it was too difficult to measure. However, given the high correlation between ideological strength and insurgent community size, and given insurgents’ employment of ideology as a currency to recruit supporters, the size of the insurgent community may serve as a proximal metric of its ideological strength. The present research demonstrates how communication treatments can optimize the self-destruct mechanism inherent in extremist groups. A model is proposed that offers a means to undermine ideology and the insurgency it feeds, without the killing that increases insurgent activity. This smart-target eradication of ideology extends a comparative SD model presented by Weaver (2008).

Weaver (2008) extended the Kress and Szechtman (2009) model by adding the concept that insurgent ideologies could be targeted. She moved the discussion beyond Kress and Szechtman’s *reduction of killing* approach. While she was transparent about her notional assumptions of system parameters and functions, yet she foresaw that a model could test alternative influence campaigns. She extended the war of attrition model proposed by Kress & Szechtman to include impact of the influence operations. Weaver defined *defection messaging* as an anti-insurgent influence campaign that could target ideology, but was not aware of an empirically supported model. The EE treatment model in the current study articulates and provides an in-depth example of a defection messaging influence operation, its component parts and their relationships.

The present research reports insurgent system parameters and functions based on intelligence provided by career field agents. Data on terrorist individuals, their recruiters, and community dynamics have been employed as a verification check on steady state model outcomes. Data on individual and community responses to EE soap opera treatments have been employed to set parameters that would replicate an EE effect (Singhal & Rogers, 1999) in the treatment model.

First, we model the terrorist system in a steady state. Parameter values are tied to historical data regarding the dynamics between a terrorist support community and the terrorist cell. Second, we consider the same system after a change in social values, which increases defection from insurgent communities by 60%. This percent is a change ratio on the low end of the range typically invoked by an EE soap opera influence campaign (Singhal & Rogers, 1999).

3. Application of DS to Anti-terrorist influence operations

In discrete simulation models, the properties of the system are described with a flowchart and probability density functions that govern the movement of individual entities (units) through complex transformation processes (Extend Manual). This type of modeling paradigm originated in the field of industrial engineering, where research into risk reduction and production optimization is employed.

Scope and scale of the DS model

There are three levels of scope in this DS process-oriented model. The first level of scope is a *community* word-of-mouth system (see Figure 1). The model assumes an average of 175 to 250 supporters for six active field agents with a standard deviation of two as the average size of the active portion of a terrorist cell (Bodansky; 1986; Burton, 1976; Harmon, 2000). The model begins with initial conditions set at 250 insurgent supporters who maintain a 5-terrorist cell and varies thereafter depending on probability conditions of other sections of the model.

A *random generator process block* models increases and decreases to the community stock. New community members enter at the average rate of five per month in a normal distribution with a standard deviation of two. The *inflow into the community* random generator is pictured at the bottom left of figure 1. The generator influx is augmented by an influx from the terrorist camp dropouts and tired, disillusioned, terrorists who have returned to the support community from the field. Inflow from all sources is labeled *inflow into community*. In another location in the model, given circumstances and decisions that weaken their ideology, members may leave the community.

Community ideology and membership is strengthened by pro-terrorist news. In figure 1, news may be seen as entering into a *priority queue* where the news with highest priority exits first. This structure represents normative gossip, where the biggest news concerning terrorist heroism (local boy becomes hero) is talked about first and has most impact. The *how bad attribute* is a measure of import assigned to media news about hometown-boys' insurgent activity. This media news merges with the oral news generated by individuals in the community. All types of news flow into a holding tank that represents the stock of *community talk*. Terrorist news stays alive for five days (Poisson distribution, $M = 5$, $SD = 2$) before decaying. Non-terrorist news is assigned a less important value distribution with a decay rate of two days (Poisson distribution, $M = 2$).

FIGURE KEY:

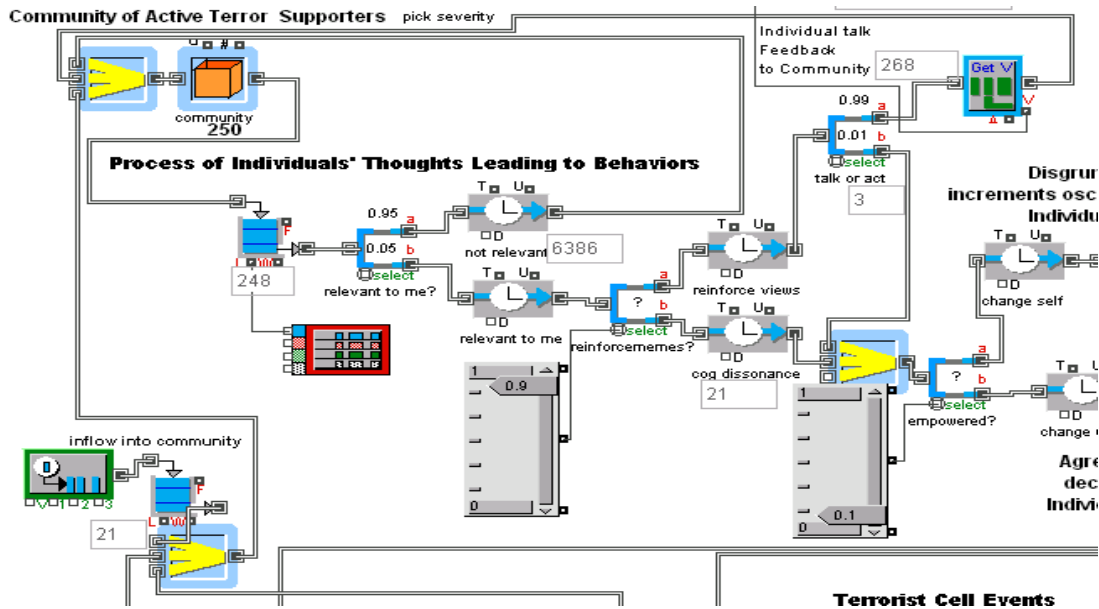
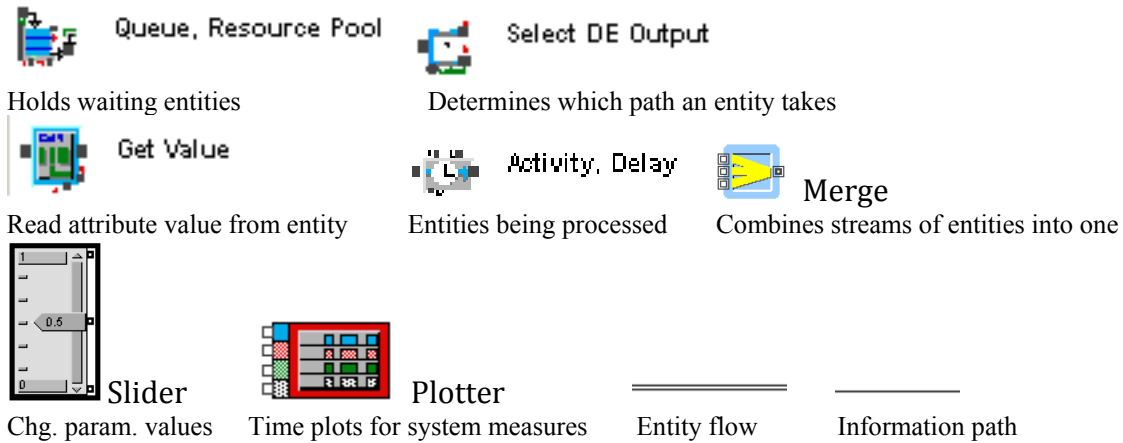


Figure 1: Community and Individual Interactions, Thoughts, and Behaviors. Each block in the model receives individual entity (unit) input flow, transforms them in some process, and outputs individual entities to the next process step. Viewer *windows* in the model animate the number of entities currently being processed in a block. For example, in the model screen capture for figure 1, there are 248 *community members* considering if the news is *relevant*, and most news (6,386 pieces of information, 95% of news processed) is just daily chatter, not relevant to ideology. However, 5% is relevant to ideology. When ideology reinforcement is set at 90%, for the steady state initial condition. At this ratio, only 21 pieces of information cause dissonance from terrorist ideologies. Odds are such that 10% or 2.1 of these sound bytes will potentially transform an individual into action. Transformative news sound bytes are tagged as such and sent into an empowerment transformer where dissonant thoughts are segregated into *change myself*, (where the individual decides to respond to cognitive dissonance such as “my community is oppressed” by changing his own belief system to defect to a non-insurgent belief system), or *change the world* (where the individual decides to respond to cognitive dissonance by acting to change an unjust external world by joining angry insurgent system views, and gets recruited to terrorist camp).

The second level of scope is the level at which the *individual*, prospective terrorist, finds his worldviews reinforced. At this level, he also reinforces the worldviews of others in his terrorist support system. The community at this level is proto-alternative because it both exists in the legal and legitimate world society and also at the same time is a breeding ground for entrance into the terrorist group. In the upper left corner, the community supporters flow into the individual thought-to-action process of the model, with probabilities in a range supported empirically from the widely researched theory of reasoned action (Fishbein & Ajzen, 1975; Fishbein & Ajzen, 1980; Fishbein, & Yzer, 2003).

The third level of the model is the *terrorist cell level*. Reinforcement from ideological community gossip and the probability of 0.0045 out of six to seven thousand thought-to-action processes lead to joining a terrorist training camp. Training camp data indicate that of those, 20% of camp recruits return to their support community without ever joining an active terrorist cell. Of those who are remaining, 80% of the camp graduates apply to an active terrorist cell where most of their time is consumed with making rough plans, talking, and taking care of daily needs. Preoccupation with daily routines leaves less time for terrorist acts (Wright, 1985). Once a member joins a cell there is a 60% chance they will split off to another cell or to leave the community. Cells are highly factious and competitive. They are plagued with a high turnover rate (Oliver & Steinberg, 2005).

The *terrorist cell* level outputs an average 2 to 3 terrorist acts per year, as reported by anti-insurgent intelligence. As per intelligence, the cell produces propaganda. Insurgent propaganda influence is modeled as news at the *community* level of scale. News also influences supporters at the community (second) level of scale. Dynamics are modeled such that, the *terrorist cell*, *community*, and *individual* scales influence each other.

Every member in the community possesses equal likelihood of taking any thought process path, which replicates *in vivo* data. This model feature replicates real data. For example, Stern (quoted in Greenberg, 2005) says one young man that he interviewed was training to be a chef. The young man unexpectedly dropped out to travel to a terrorist training camp because news convinced him it was a more adventurous life. However, the majority of community members maintain their civilian lives. The norm behavior is modeled at a 0.95 probability of no behavioral reaction to news, a 0.045 probability the thought will lead to contributing to the community gossip mill, a 0.0005 probability any particular thought will lead to leaving the community, and a 0.0045 probability a thought will affect an action of joining a terrorist training camp. The recruitment ratio is small. Out of millions of angry young Moslem men only a 6-12 per million choose to join terrorist cells (Fraser & Fulton, 1984; Hoffman, cited in Greenberg, 2005).

A sensitivity analysis was conducted to match the model output with reference behavior data. Model output was matched with reference data. Given the data, there is reasonable evidence to believe that the process represented in the model is accurately portrayed.

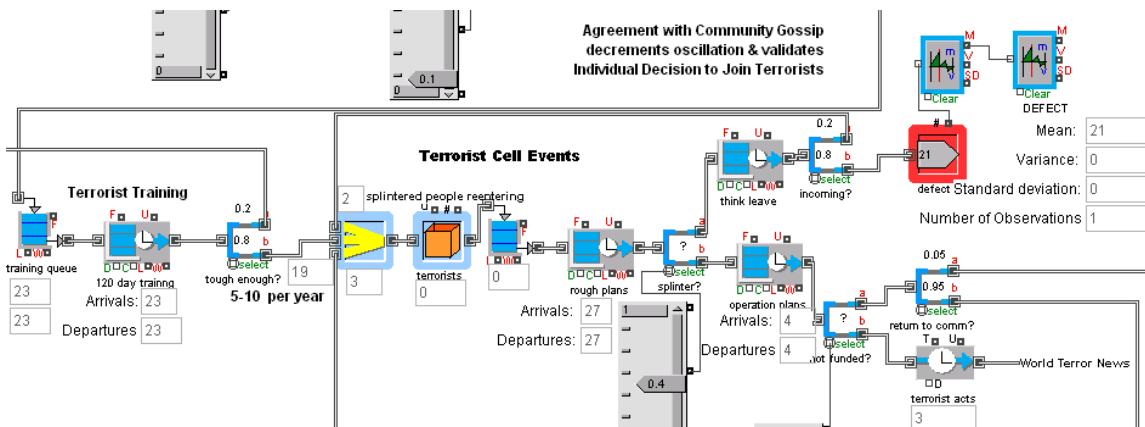


Figure 2: Terrorist Cell Group and Individual Interactions, Thoughts, and Behaviors.

The screen capture for figure 2 illustrates the following. There are 23 *community* members that have been transformed into the terrorist camp training queue. Of the 23 that entered camp, matching field data, 19 have left camp and of those, matching field data, 5-10 per year enter the cell. The remainder has decided to return home. These entities flow upwards, back into the top of the model, into the *community* stock. Of those individuals who enter the *cell*, the window (above the yellow 3-to-1 funnel) shows that 2 individuals splintered out of the group right away, probably due to arguments, and they too return to *community*. Three stay in the cell where plans are being contrasted and argued. Each cell member advances his own ideas, forming coalitions with similar others within the cell. As per field data, quite a few rough plans are discussed on a daily basis, causing turmoil within the cell. In the current screen capture, 27 plans are heatedly discussed. Of those, 40% are promoted to operation plans but only 4 receive funding support and three major acts are enacted as terrorist acts per year. This is the average number of major terrorist acts per cell, given observations reported by intelligence field agents, publications cited in the text. Destructive heroic acts are videotaped by the cell members and delivered to local and international news stations. Upon international distribution, the ideological influence demoralizes the enemy system (the effect upon the enemy is exogenous to the model) and ideologically galvanizes the home community (see how news enters the community gossip cycle, shown in figure1). In all this turmoil, only one person was observed to leave the entire insurgent system. He could have defected or have been murdered as a disciplinary example to the others. Murder is more likely, given the data. In any event, he exited the cell and the community, whether dead or alive.

The DS model is a non-terminating model. The baseline model was run in a steady state (on the average) for ten years. The length of the runs swamped any bias or warm up in the initial state of the model (Extend Manual). During the model verification, sensitivity analysis was performed where model output was validated and balanced with key assumptions derived from actual field data. The simulation was run at first for one year, then five year and then ten year runs to "swamp" the biasing effect of the initial conditions (Extend manual). Since the model was a nonterminating model it was thus run for long enough periods of time such that we are confident that every type of event happened at least several times. We matched reference behaviors, and matched expert review expectations as detailed in the next section on verification.

Key Assumptions and Baseline Model Verification with Field Data

Probability levels were determined via sensitivity analysis during which model output was matched with constraints of real life data. In 2003 there were 175 terrorist events world wide. In 2004 there were 651 significant terrorist events (Bloomberg, 2005). Assuming an average terrorist cell size of five highly active field agents (Burton 1976; Harmon, 2000) there were approximately three agents involved in each of the incidents. That makes approximately three hundred significant terrorist cells in 2004.

To estimate the number of new terrorists per year the following assumptions were made. 651 significant terrorist events in 2004 less 175 significant terrorist events in 2003 (Bloomberg, 2005) leaves 476 new events between 2003 and 2004. Multiply 476 new events multiplied times 3 active field agents behind each event equals 1,428 new terrorists per year. Round to a more conservative 1200 per year. It may be argued that 100 new terrorists per month graduated from terrorist training camps worldwide. Of these 1200 per year, 80% are accepted into the 300 estimated active cells. At this rate, there would be an average of 3 new terrorists per year entering from training camp into each active cell. Model behavior tie-in to the publically available agent field reports.

Probability levels were reverse engineered from available data about how many were likely active cell members (5-10), how many were new per year (3), and how many were support community (35-50 active support community per active cell member = 175-250 in the active support community for each active cell) (Bodansky, 1986). Dynamics of thought-to-action were assumed to follow functions that were arrived at empirically via communication and social psychology theory. The structure of these theories led to quantification of assumptions regarding cognitive dissonance and cognitive elaboration (Festinger, 1957, Petty & Cacioppo, 1986). The transformation from individual thought processes to action is based on empirical tests of the theory of reasoned action (Fishbein & Ajzen, 1975; Fishbein & Ajzen, 1980; Fishbein, & Yzer, 2003).

The model's systemic network of probabilities, empirically based thought-to-action functions, and data, were analyzed in iterative processes. Ratios were adjusted until they produced a process flow that matched key assumptions. Process flows were balanced so that the model output a key number of active community members in the community queue (175-250), a key number of new terrorists per year per cell (5-10) and a key number of terrorist acts per year per cell (2-3), matching *in vivo* system behaviors. A 1-10% probability of action or deep thought versus peripheral processing was estimated based on communication literature (Petty & Cacioppo, 1986). The probability outputs and data outputs were adjusted until they matched expected outputs in the baseline model (see Figure 3).

Results of DS Model after EE Soap Opera Treatment

After iterative balancing of the model to match field data, the probability of a terrorist cell splitting was changed from the baseline setting of 0.40 to 0.75 to match the treatment effect obtained in the support community. The funding ratio for terrorist acts is changed from 0.60 to 0.25. Only 1-2 new terrorists came in per ten years and only 3 terrorist acts occurred in ten years. At this negligible level of

activity, the terrorist cell was considered to be eradicated. Ideological influence operations had weakened and dissipated the entire insurgent system.

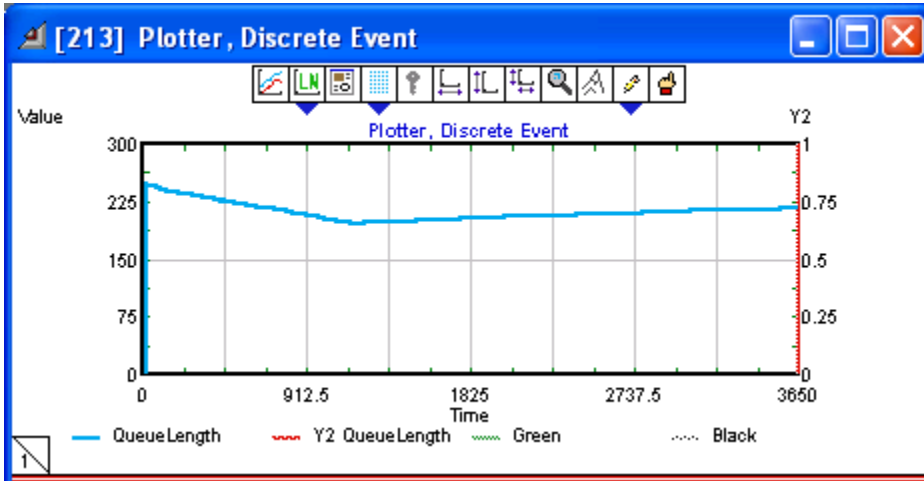


Figure 3: Steady State Terrorist Support Community Pre-treatment.

In the initial equilibrium state, strong ideological support continued for ten years for a terrorist group. Figure 3 is typical of 76% of the sample 100 runs. For 25% of the runs, there was a natural decline in the support community below the level necessary to sustain a terrorist cell. In the sample runs for the steady state model, average outputs tied to field data on terrorist cells and their support communities.

Assuming a low-end treatment effect of 60%, which is a modest effect for an internally-seeded EE soap opera influence campaign, there was a 73% probability that a terrorist support community would fall below the 150-person sustainability level over ten years and a 54% probability that the support community would completely dissolve within three and a half years (Figure 4).

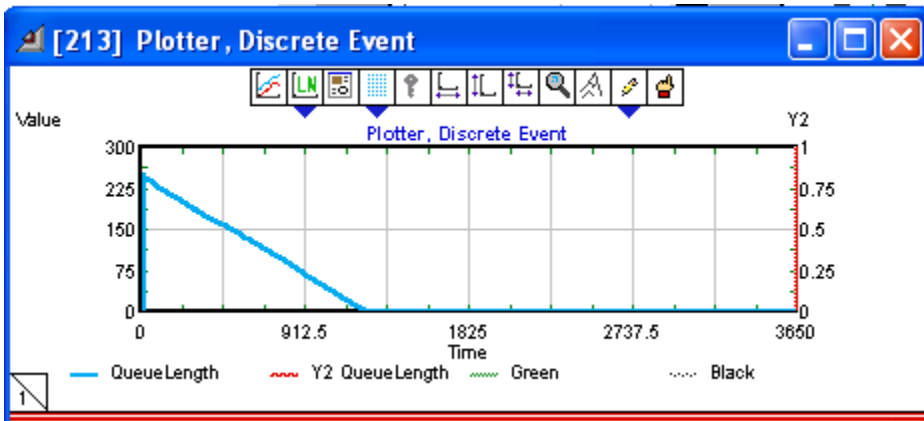


Figure 4: Dissolution of Terrorist Support Community.

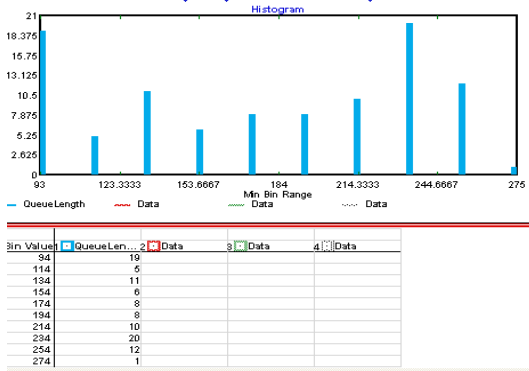
As the terrorist support community declines in size, it approaches an asymptote as the pro and con debate over ideology equalizes the rates of change in a balancing loop. The approach to an asymptote of zero terrorist support occurs typically after 3.5 years of EE treatment.

The model indicates that based on a low-end historical effect size, an EE soap opera might empower insurgent communities to seek happiness via methods other

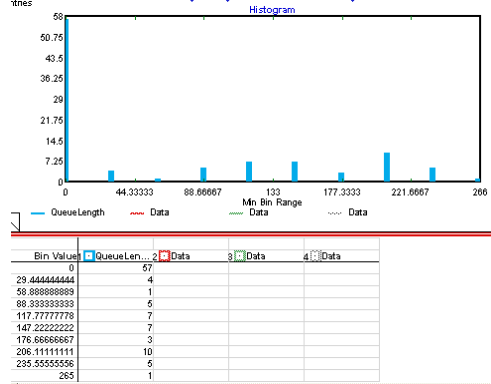
than terrorism. Community buzz could be redirected from insurgent grumbling to interest in education and development that would grow the community economy and improve living conditions.

Figure 5 shows histograms for pre and post treatment conditions for 100 experimental runs. The terrorist support community, requiring a minimum of 150 members, typically persisted in steady state over ten years ($M = 188, CI = 177-200$). However, after applying a low-end EE treatment effect, the support community typically declined and dissolved ($M = 73, CI = 54-91$). The treatment model was associated with a significantly decayed support community to the point of dissolution ($p < .001$).

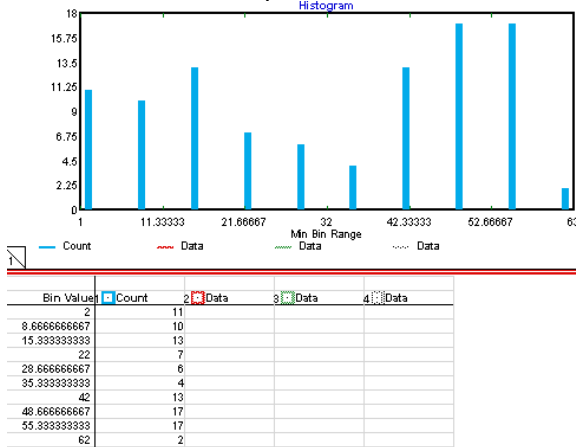
Baseline Pre EE: Support Community



Post EE Treatment: Support Community



Baseline Pre EE: Freq. Terror Acts



Post EE Treatment: Freq. Terror Acts

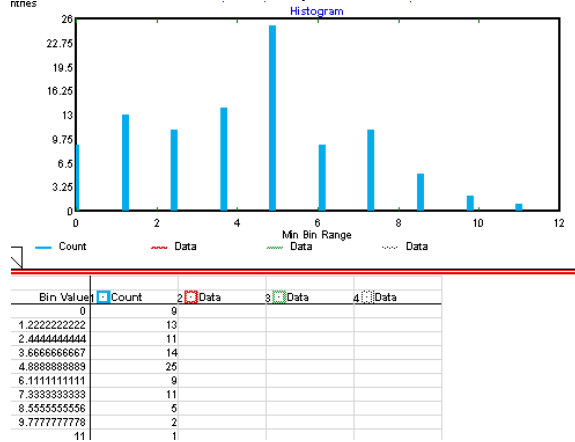


Figure 5: Histograms comparing Pre/post EE Soap Opera Treatment DS Results for 100 Replications. The number of community supporters declined between pre and post EE treatment models. As the number of members in the terrorist support community declined, the terrorist activity measured in number of terrorist acts also declined.

4. Application of SD to Terrorist Cell Dissolution

SD is based on ordinary differential equations and their numerical solution over time. The governing rate equations for the system are developed, parameters are estimated, and the time trajectories of the variables of interest are computed and displayed. Differential equations have been applied in the social sciences to model the control or decay of insurgent systems (c.f., Kress & Szechtman, 2009; Weaver, 2008). The top-down SD perspective smoothes out individual unit and step irregularities into aggregated components. When tested, aggregate model can be easily benchmarked against known system behaviors. Our background includes the application of DS, SD, and agent base simulation to a variety of problems. In some cases, we have compared different methods on the same problem, such as non-equilibrium receptor binding with SD and with agent based simulation (Wakeland, Gallaher, Macovsky & Aktipis, 2004), and acute inflammatory response with a hybrid SD and agent based simulation model (Wakeland, Macovsky & An, 2007). We have modeled diffusion of new ideas through a complex social system, employing power law analysis (Rogers, Medina, Rivera & Wiley, 2005).

The SD Model

The SD terrorist dissolution model was created, to reflect to the degree possible, the same parameters as used in the DS model. The SD model focuses on three of the DS (*community*, *terrorists-in-training*, and the *terrorist cell*). Instead of focusing on message generation, due to SD's higher level unit of analysis, auxiliary variables were used to reflect the *rate* at which terrorist acts were being committed, and how those acts impacted community opinion. Community opinion was also impacted by a factor representing exogenous environmental events and news.

Figure 6 depicts the flow diagram for the SD model. Parameters are shown in very light grey so that the primary flow and feedback structure will be more apparent. Table 1 displays the baseline parameter values that were taken from the literature when possible, or estimated, for a baseline model that would maintain an approximate steady state. Due to space limitations, we will not detail the model logic. However, a sense of the logic is apparent from a visual inspection of the flow diagram and parameter values.

Calibrating the SD model for long-term steady state was not difficult. Figure 7 shows the model maintaining steady state for ten years at. However, the model is sensitive to slight variations in inputs, which necessitated model parameters to be finely tuned to avoid a growth or decline. This is because the model does not contain any powerful balancing feedback loops or non-linearities that would tend to drive population levels [back] towards steady state. If this mirrors reality, one would expect terrorist cells and their associated support communities to be relatively fragile. In fact, *in vivo* data supports this observation of system fragility (Fraser & Fulton, 1984; Wright, 1985).

Figure 8 depicts the impact of an EE operation, simulated by reducing the rate of relevant *insurgent news* by 25% partway through the run (a low-effect EE intervention.) The insurgent system behavior rapidly declined. This decline cannot be taken too seriously. The SD model has not yet been thoroughly tested. Testing is

further discussed in the limitations and future research sections at the end of the discussion.

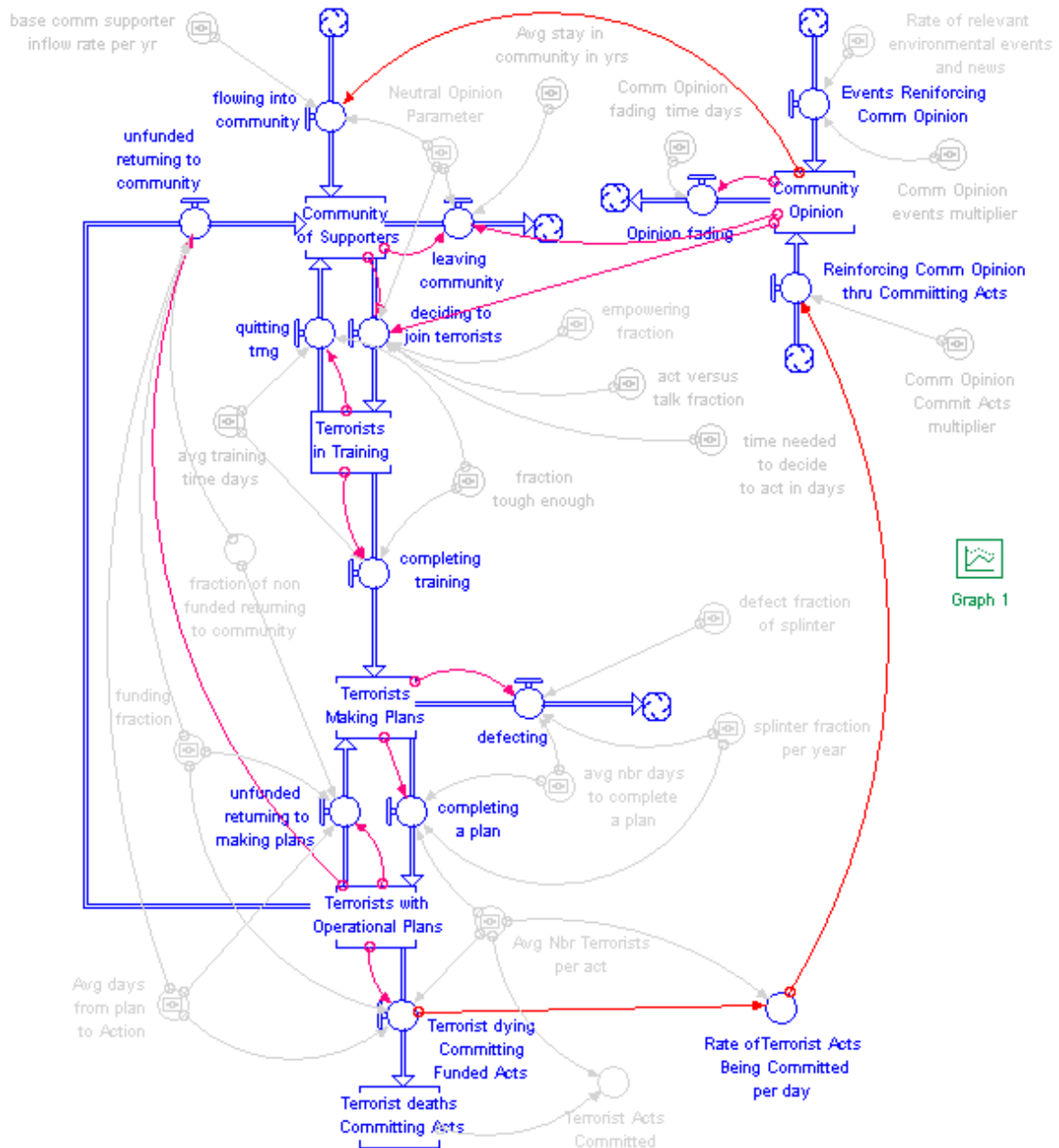


Figure 6: System dynamics flow diagram for terrorist dissolution model. The model contains several feedback loops, most of which are short balancing loops in which the value of a stock impacts its outflows rates. The most important positive loop involves terrorists acts influencing community opinion, which in term impacts the rate at which people join the community, leave the community, and decide to go to a training camp. While this loop is powerful, it operates over a long time period. Fundamentally though, it is this loop that tends to make the system equilibrium unstable because it amplifies deviations. If community opinion is shifted, the shift is exaggerated by the positive feedback loop.

Table 1: Initial Baseline SD Parameter Values

Act_versus_talk_fraction = .05
 Avg_days_from_plan_to_Action = 200
 Avg_nbr_days_to_complete_a_plan = 250
 Avg_Nbr_Terrorists_per_act = 2
 Avg_stay_in_community_in_yrs = 2
 Avg_training_time_days = 120
 Base_comm_supporter_inflow_rate_per_yr = 100
 Comm_Opinion_Commit_Acts_multiplier = 2.5
 Comm_Opinion_events_multiplier = .05
 Comm_Opinion_fading_time_days = 100
 Defect_fraction_of_splinter = .7
 Empowering_fraction = .1
 Fraction_of_non_funded_returning_to_community = .2
 Fraction_tough_enough = .2
 Funding_fraction = .3
 Neutral_Opinion_Parameter = 6
 Rate_of_relevant_environmental_events_and_news = 1
 Splinter_fraction_per_year = .6
 Time_needed_to_decide_to_act_in_days = 14

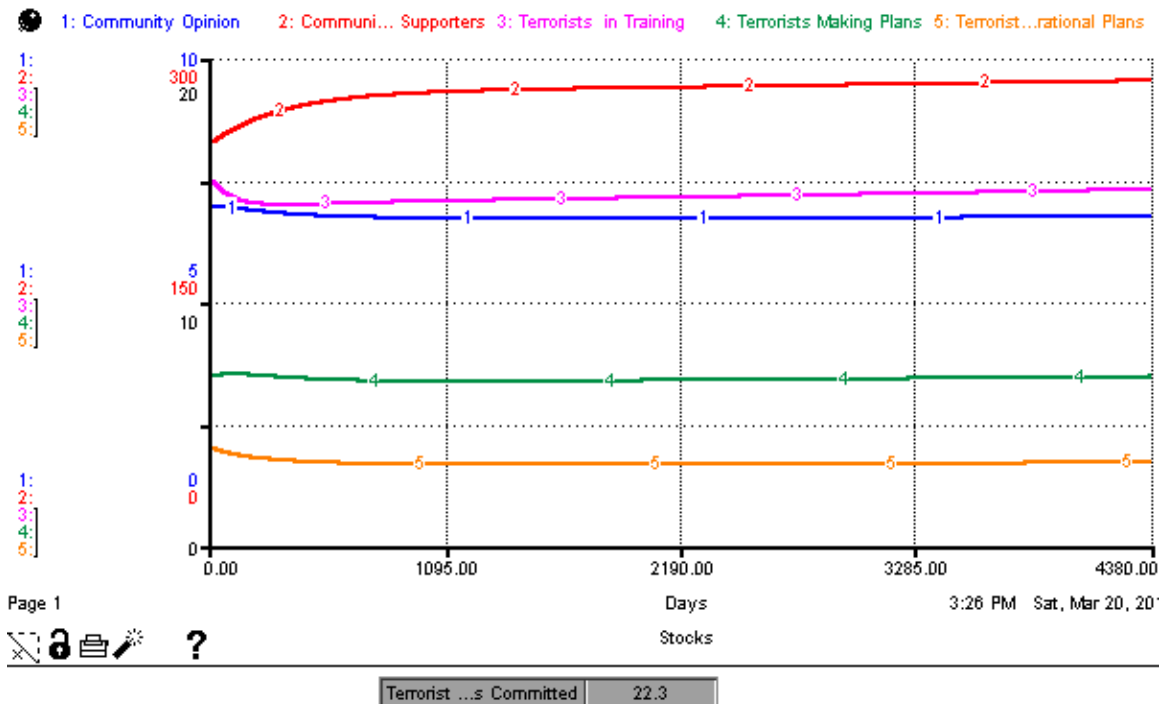


Figure 7: Population levels and community opinion when model is calibrated to maintain steady state. At steady state, three terrorists have funded plans, seven more are formulating plans, about fifteen are in training, and the support community includes just under 300 people. Community opinion is stable at seven, slightly above the neutral value of six. The cell commits a terrorist act every five or six months over the simulated ten-year period.

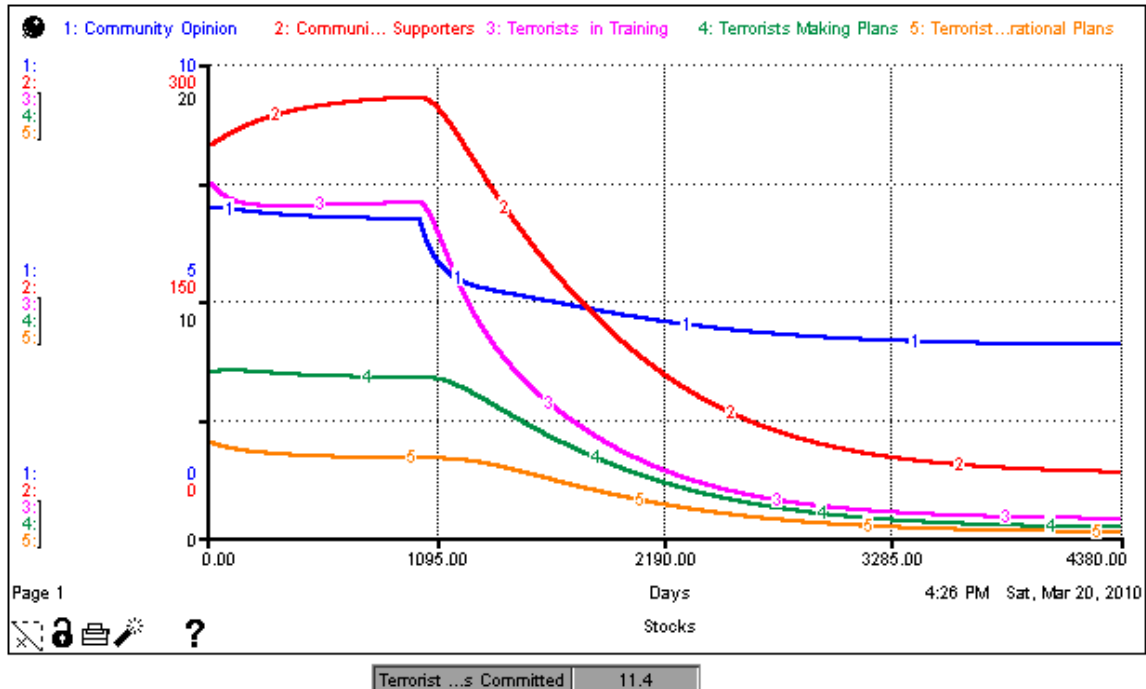


Figure 8: Impact of an intervention that reduces the rate of environmental news that is favorable to the terrorist cause. The nascent SD model indicates rapid shift in community opinion and the size of the terrorist cell drops between years 3-6. As a result, the number of terrorist acts is reduced dramatically by year 3.5. This behavior in the SD model is qualitatively similar to the DS model behavior.

5. Overall Comparison of DS and SD for Studying Terrorist Cell Dissolution

We found the process of developing and testing models using two very different paradigms to be incredibly useful. For example, an individual's variance from the group mean influenced system decay in the DS model. In the SD model, the same dynamic was modeled using a balancing loop for the group. Comparing similar modeling tasks in two methods yielded comparative insights about how systems work.

We believe that both paradigms could be productively used to help educate researchers and assist with laboratory research. Conducting dynamic experiments on the computer, and observing simulations unfolding on the screen, greatly enhances awareness of the interesting underlying dynamics. We believe that this enhanced awareness could lead to the design of better influence campaigns, and problem solving for model builders interested in exploring multiple paradigms. SD may be more appropriate for modeling social systems at a highly aggregated level, whereas DS seems better suited for studying how interventions directed at the individuals and their relationships to each other could change communities.

The DS simulation paradigm requires the modeler to determine probability functions to describe individual motivations and changing behaviors. DS models are able to reflect interactions at the level of the individual, which allows the models to mimic the probabilistic chain of events in which individuals are ideologically

politicized and de-radicalized. Thus, DS is ideally suited for studying problems when the aggregate view from a sociological level is less informative than a microanalysis of how changes in individual beliefs might affect community behavior.

SD models portray the *structure* of the interrelationships between variables very effectively and allow the user to easily experiment with different parameter values and compare the resulting graphs of behavior over time. SD models may be considered more conceptually descriptive than DS models, and they force the modeler to consider carefully the appropriate level of aggregation. The mathematical foundation of SD is solid, general, and powerful. The SD method relies mostly on the enumeration of feedback loops and calculating time behavior; there tends to be only limited analysis of system properties. Because SD diagrams can be made reasonably intuitive, they can be used to communicate model behavior and results to non-technical people. However, because of its generally high level of analysis, SD may be only moderately relevant for sociological research in general. SD is easily employed for educational purposes, due to the visual accessibility of diagrams, and intuitive transfer of concepts via visual time and behavior plots.

Table 2 compares DS and SD with respect to the criteria outlined in Section 1. Both methods have clear strengths and are complementary in an overall sense. We recommend that modelers consider the application of multiple modeling paradigms to the same problem to improve understanding of complex systems.

6. Discussion

Weaver (2008) foreshadowed one of our conclusions by stating that the accuracy of future models would “depend heavily upon model parameterization and the formulation of effect functions” (p. 19). We responded to Weaver’s call, and have reported our insurgent system parameters and functions, which were based on intelligence provided by career field agents regarding terrorist individuals, their recruiters, and their community dynamics. We obtained and interpreted these data to create our simulation models. Weaver (2008) obtained generalized information from Internet sources, and Kress and Szechtman (2009) suggested that data on ideological change was simply not available.

We collected, applied, and explored numerical and operation details for the *defection messaging* treatment we applied to our model of the *war of attrition*. We documented and substituted EE soap opera media, for insurgent-produced propaganda. A 60% reduction in pro-terrorist media was highly effective in the DS model, whereas the response in the SD model was significantly sensitive at a 25% reduction in insurgent media. A 60% impact is on the low end of the range typically invoked by an EE soap opera influence campaign (Singhal & Rogers, 1999).

Even if the equations and parameters of Weaver’s model had been provided, they could not have been directly compared with our model due to our differences in model components. Weaver’s (2008) SD model was designed to study the counter insurgency operations in a country, and is therefore broader in scope than the present study. In addition to the level of popular support, Weaver also modeled the role of collateral damage, the quality of intelligence, and their effect upon influence

Table 2. Comparison of DS and SD on high level criteria

		Discrete Simulation (Extend)	System Dynamics (STELLA)
1	Overall approach	Physical emulation of entities as they move through processes	Abstract, via state variables and equations that are solved to simulate behavior over time
2	Scope and scale of the model	Narrow and low level	Broad and high level
3	Methods for gaining and testing knowledge	Empirical: Can create simulated samples, compute confidence intervals, t-tests, etc.	Deductive: knowledge is interpreted from behavior over time; can be qualitative or quantitative
4	Availability, quantity, accuracy of system data	Relatively time-consuming to obtain quantities of narrow, low-level, probabilistic data for each entity and transformation process. Compensation for data inaccuracy via probabilistic analogs to a deterministic approach.	Relatively easily available, small quantities of generalized central tendency data. Sensitive to data accuracy: small errors in data of initial conditions can result in large deviations from predicted behavior.
5	Underlying mathematics and analysis	Logic, algorithms, probability distributions	Calculus; numerical integration of differential/difference equations
6	Ease of communicating behavior and results	Excellent for showing the behavior of individual entities	Very good for showing model structure and numerical results
7	Sociological research relevance	To model the movement and state changes of individual entities, and interactions between entities	To model aggregate behavior resulting from dynamic interactions.
8	Educational potential	Very useful due to the way it mimics the actual psychological and social processes	Particularly useful for increasing conceptual understanding

campaigns. Nevertheless, our analysis agreed with Weaver's conclusion that an influence operation directed at defection bears further study.

Similar to our study, Kress and Szechtman (2009) hypothesized that an influence campaign could reverse the strongly reinforced loop between passive (civilian) and active (terrorist) insurgents. They modeled at the level of a nation,

the shifts in support for the insurgents and counter insurgency forces model, based in part on collateral casualties. By considering the fixed point attractors of the system, they concluded that containment is a best case scenario and that eradication is not likely. Their equations are not comparable to ours, nor are their parameters, which are abstract and not based on empirical data.

Given the fact that insurgents employ ideology as a currency to recruit supporters, the present study operationalized ideological strength as the size of the insurgent support community, such that as ideology and the support numbers weakened, terrorist acts dwindled. This demonstrates how social science may contribute details on communication treatments. Communication scholars may offer means for smart-target eradication of insurgent ideology. The EE treatment, as modeled in the current study, articulates and provides an example of a defection messaging influence operation, including what its component parts and interrelationships might look like.

Weakening subscriptions to manic *doctrines of necessity* serves to weaken the need to pour resources into insurgent supply lines. Expertly crafted influence operations can starve an insurgency without killing the adherents. Deployment of *defection messaging* as smart-missiles that kill ideas rather than people was foreshadowed by Weaver (2008), who foresaw that a model could be used test development of influence campaign policy.

The present study offers specific details about a how type of empirically supported communication treatments may be employed. A message can be an ideological weapon. Warfare of the mind is fought on the battlefield of thought. Word weapons can activate self-destruct mechanisms inherent in extremist groups while starving its supply lines.

Reflections on Scant Time Duration Data

Although initial SD models can be built quickly, highly credible SD models require much time and effort, due in part to data limitation, especially regarding how quickly systems respond to changes. Other modelers of insurgent communities coincide with our comments that in order for results to be considered informative for important policy decisions, they must be tied to well-validated models with solid empirical support.

Empirical researchers could make model construction easier by reporting intermediate results. Unfortunately, social scientists are less likely to conduct time series analysis and more likely to conduct pre/post studies with just two time-points.

Reflections on EE Soap Operas Applicability

E. M. Rogers remarked in a personal communication (February 10, 2003), that EE soap opera treatments work best in communities where people share strong normative ties. These communities are generally low-literacy oral communities where there is a strong pressure to conform, such as are found in developing or undeveloped countries. He said that nobody knew with certainty why EE soap operas are more effective in low-literacy low-income countries. Certainly media affects viewers and listeners in all countries, but the EE venue asks people to stop

and think, question values, reform group norms. It requires group participation in listening clubs.

Rogers strongest hunch was a hypothesis that wealthier countries are not as sensitive to the EE format because individuals are saturated with entertainment. Or perhaps, since in wealthier countries each person has their own television or radio, the hot debates that occur in third world listening clubs, crucial to EE social change, are less likely to form. Rogers considered whether difficulty in accessing entertainment media caused it to be shared and more prized. He considered whether the social buzz factor of novel media played a role in the EE success among low-income groups. In 2004, at the end of his career, Rogers was in the process of conducting an Internet-based EE campaign at community center computer labs. The soap opera featured a young Spanish woman doctor in a story that promoted early detection of breast cancer. The treatment groups were highly normative friendship groups of low-income Spanish-speaking women, in a southwestern U.S. city.

Foreign governments generally fund EE treatments to tackle pernicious social problems among illiterate or semi-literate populations. EE soap operas have successfully reversed rates of AIDS infection in Africa, and eradicated anti-social practices such as bride burning in India. They have improved practices of hygiene, birth control, and increased literacy enrollments, all economically beneficial to the sponsoring governments. These foreign governments have found EE soap operas to be good investments, based on their returns. Some have run as long as 20 years.

Limitations of the Current Iteration of the SD Model

The overall SD approach focused attention on the flows and the feedback loops and identified a strong dependence on the accuracy of the parameter values. Model scope was limited to key population numbers and associated flow rates, which nevertheless permitted useful conclusions to be drawn, mostly via appreciation of the feedback structure.

In the SD model, the flow of people into and out of the support community is larger than was represented in the DS model, and this change represents a potential change in our understanding of system. However, since both DS and SD steady state models were balanced to output similar behaviors, we retained the original model parameterization in order to maintain its internal consistency.

Preliminary SD model testing shows a high degree of sensitivity to initial values and also to many of the parameter values. A full battery of model tests has not been completed. Furthermore, the model represents a vast oversimplification of the real world where many other complex processes are continually playing out, and these processes could kick in to moderate a downward trend or could further reinforce downward or upward trends as they develop.

Future Research

Before any of the model results could be taken seriously, the testing must be completed, additional empirical support must be found for several of the parameters, especially for those to which the model behavior is highly sensitive, and logic added to reflect the most important feedback processes that help to stabilize terrorist cells and their support communities.

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