# Agent-Based Simulations as a Modeling Solution for Understanding Use of Improvised Explosive Devices in Insurgencies and Rebellions[1]

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**Introduction:**

During military operations in Iraq and Afghanistan, Improvised Explosive Devices (IEDs) became the single most deadly weapon used by insurgents against the U.S. military and allies. IEDS have accounted for at least half the American casualties in the conflicts (Krepinevich & Wood, 2007) – roughly 3,800 dead and 33,000 wounded between 2003 and the end of 2013 (Zoroya, 2013). In response, the U.S. Department of Defense has poured billions of dollars into countering the threat. According to one estimate, the Pentagon has spent roughly $75 billion on vehicles and equipment designed to counter IEDs during the length of the Iraq and Afghanistan conflicts (Zoroya, 2013). The focus of the vast majority of this spending to counter IEDs has been on narrow technical approaches to counter the problem. For example, new armored vehicles to protect soldiers from blasts or high-tech devices to hunt IEDs made up the lion's share of funding – 22,000 Mine-Resistant Ambush-Protected vehicles (MRAPs) alone cost $36 billion (Carey & Yossef, 2011).

This emphasis on detecting IEDs in place or directly protecting soldiers, while understandable, ignores broader questions about the use of IEDs in insurgencies that are useful to both policymakers and field commanders. We use this paper to theorize about and develop methods to answer the question of under what circumstances would an insurgent group deploy IEDs instead of other available weapons. Unfortunately, specific scholarly work on IEDS is technical and too narrow to be of much use to develop a theory of insurgency. Additionally, existing political science theories on violence are too broad to be of much use in modeling adoption of specific weapon types. To bridge this gap, we build on Wood's concept of the "repertoire of violence" (2006) as a foundation for constructing a theoretical model of the changing patterns in the use by insurgents of different weapon types. Next, we mine both scholarly and journalistic descriptions of IED use in numerous insurgencies to outline distinctive features of IED use in conflicts. We then develop a country-level Agent-Based Model (ABM) for studying the interactive and evolutionary dynamics produced by competition within an insurgency among different tactics available to insurgents.

Building an ABM entails endowing a mix of computerized "agents" with a lifelike mix of attributes and decision-rules that mimic the power structure of a real country. Complexity and dynamism can then render visible the emergent properties of IED threats and can help identify the types of networks that encourage and sustain IED use. Because we can trace the distinctive influences that actors have on other actors across each time step, an ABM can investigate causal mechanisms in ways that traditional statistical modelling or historical analysis cannot. Finally, producing large batches of model trajectories under carefully controlled comparative conditions allows for systematic experimentation to help us understand the likelihood and patterns of IED use, given a set of particular initial conditions.

**Political Science, Insurgencies and Weapons types**

An important trend in political science research has been to model insurgent organizations as firms operating in an environment of uncertainty and beset by the standard array of principal-agent problems. From this perspective, differential strategies of violence adopted by these groups evolve in response to circumstances of the conflict. These include competition for recruits with other rebel groups, tradeoffs between control over subordinates and vulnerability to regime countermeasures, challenges to maintain internal coherence and willingness to impose long-term damage on civilian populations to achieve short-term objectives. These circumstances and selection processes often produce increasingly ruthless organizations inclined to use violence, both selectively and indiscriminately. (Shapiro, 2013) (Berman, 2009) (Weinstein, 2007).

Wood (2009) (2006) noted that insurgents and state forces possess a wide range of violence types that they can choose to employ against opponents or noncombatants, conditional on goals. Some forms of the repertoire of violence are more suited to precise targeting, while others, such as artillery strikes or area bombing, are indiscriminate. Closely related is the dimension of target discrimination, the ability to deliver an attack accurately against a target of choice. This ability is partially conditioned on the method of violence employed. However, it is also dependent on the skill and training of the individual combatant, as the discipline and command and control features of the forces employing the tactic (Weinstein, 2007) (Kocher, et al., 2011).

Yet political science research remains extremely thin to the point of non-existence on the choice or use of particular weapon types within an insurgency or counterinsurgency groups. To develop, analyze and deploy the actual component of the repertoire of violence that interests us, namely IEDs, we exploit a wealth of material on IEDs provided in reports of government and non-profit agencies, as well as in journalistic sources. It is to this task we turn below, after developing a definition of an IED.

**IED Definition**

In this work, we use Gill, Horgan and Lovelace's definition of an IED to anchor our own:

> An explosive device is considered an IED when any or all of the following—explosive ingredient, initiation, triggering or detonation mechanism, delivery system—is modified in any respect from its original expressed or intended function. An IED's components may incorporate any or all of military grade munitions, commercial explosives or homemade explosives. The components and device design may vary in sophistication from simple to complex and IEDs can be used by a variety of both state and non-state actors. Non-state actors can include (but not be limited to) terrorists, insurgents, drug traffickers, criminals and nuisance pranksters. (Gill, et al., 2011, p. 742)

A critical aspect of this definition is the requirement that some part of an IED is "modified" from its intended purpose. So a buried artillery shell rewired to explode with jury-rigged tripping device, or a bomb made with explosives fashioned from fertilizer and emplaced on a road would be an IED. A traditional land mine would not. If the key aspect of an IED is not its lethality, destructiveness, or accuracy, but the relative ease and diffused capability among potential insurgents for deploying and adapting it, this must be reflected in its operationalization within a modeling context that distinguishes IEDs from other types of weapons. The platform must also enable insurgents to change their tactical commitments in response to changing circumstances, including countermeasures, while taking into account the resources required for the deployment of different types of weapons. By incorporating these elements into the modeling platform, patterns of competitive adaptation among insurgents and coevolution between insurgents and state actors can be studied, creating opportunities to systematically study the direct and indirect effects of countermeasures on insurgent use of IEDs.

**Variables Governing the Potential for Effective IED Attacks:**

We operationalize these principles by including five factors that influence the availability of IEDs in the violence repertoire of insurgents and their decisions to deploy are cost, range, risk, expertise, and flexibility.

*Cost:* The problem for most revolutionary or insurgent organizations is their weakness relative to the state power arrayed against them; in which weakness is measured politically, financially and militarily.

Accordingly, insurgents often cannot directly fight the state with conventional weapons in a conventional battle and hope to survive, let alone win. In most cases rebels do not have access to advanced armored vehicles and weapons, especially in the early stages of an insurgency. Most IEDs can be fashioned from components available in everyday items. Moulton (2009) points out that consumer demands for lighter, smaller, and more reliable electronic devices make elements convenient for use as power sources and triggers widely and cheaply available. As easily available and increasingly sophisticated technology spreads, insurgents find different ways of using their components, thereby multiplying variation in IED operation and potency. Accordingly, IEDs provide considerable "bang for the buck" – they can kill soldiers or destroy armored vehicles for relatively little cost and risk for insurgents, who are removed from the immediate scene.

The number of low-cost and ubiquitous options available to IED manufacturers is illustrated by the wide variety of high explosives and triggers used. In Iraq, early IEDs often incorporated rewired artillery shells from unsecured munitions depots (Zorprette, 2008) (Naval Research Lab Washinginton DC, Materials Science and Technology Division, 2006) (Barry, 2006) (Eisler, 2007) (Wilkinson, et al., 2008) (McFate, 2005). During later stages of the conflicts in Iraq and Afghanistan, widely available fertilizer became a major component for explosives (Zorprette, 2008) (Webb, 2012) (Faroq, 2013) (Haber, 2014). After the Afghan government banned sales of ammonium nitrate-based fertilizer, Taliban insurgents switched to potassium chlorate, a cheap and common industrial chemical (Vanden Brook, 2013) (Haber, 2014). Afghani IEDs often use simple pressure plates triggered by a vehicle or soldier (Castner, 2012) (Webb, 2012) In Iraq, in contrast, triggering devices moved from simple short-ranged remote-control devices like doorbell devices and garage-door openers, to cell phones that could trigger a device from miles away, to advanced military-grade infrared triggers that resist jamming (Wilson, 2007).

IED use can thus help establish the bona fides of an insurgent group by giving them initial successes that can then establish themselves as serious and worthy of support of potential sympathizers (Martin, 2009). IEDs are thus one particular cheap technique used in asymmetric warfare to minimize the stronger side's advantage in conventional forces (Mack, 1975).

*Range:* The range of a weapon time is how far from the attacker's base an operation can be mounted. Planes have a much greater range than tanks, which in turn have more range than infantry. Although in themselves they are static weapons, IEDs functionally have considerable range – they can be quickly (and inconspicuously) transported by vehicles to sites far from their assembly points in ways that conventional infantry or armored forces cannot.

*Risk*: Risk recognizes that failed tactics entail costs to the attacker. For example, the defeat of a conventional infantry unit leads to heavy casualties, and possibly many prisoners and abandoned equipment. In turn, these may in turn lead to intelligence windfalls for an opponent and possible dangers to both attackers and their network of contacts. A failed missile strike or rocket attack on the other hand, simply means the waste of ordnance. One major aspect of risk, then, is the proximity of the individual combatants to the combat. Infantry are quite close and exposed to the action, while aircraft tend to be farther away. IEDs provide considerable tactical depth to their operators on a number of levels. Many IEDs are automatically triggered, by a component as simple as a pressure plate or as sophisticated as a laser beam, which ensures that the person who planted it and any observers can be far away from the site of the attack. (Vanden Brook, 2013) (Webb, 2012) (Zorprette, 2008). Other IEDs are remotely triggered by control devices (such as cell phones) that enable operators to be fairly far away from the attack. (Moulton, 2009) (Zorprette, 2008). For a low cost then, IEDs provide considerable range and relatively low risk.

Note that independent of considerations of standoff, even successful attacks retain an element of risk. Casualties occur, equipment gets destroyed, left behind or captured, and tactics and techniques are exposed to enemy inspection and analysis. Successful IED attacks are no different – exploded bombs leave valuable intelligence clues about their construction and possible DNA evidence of their handlers. Sophisticated forensics investigators work to turn these clues into operational intelligence that can facilitate undermining IED users and networks (Castner, 2012) (Webb, 2012) (Moulton, 2009).

*Expertise:* Much of the knowledge relevant to building and deploying IEDs is quite simple and can be acquired through trial and error. As insurgents observe the results of their handiwork, they tweak explosives and devices to control yield, increase the lethality and reliability of their devices, and evade tactical countermeasures. However, there is also considerable evidence of professional expertise supporting insurgents to varying degrees across conflicts. In the case of Iraq, skilled operatives from the Iraqi intelligence agencies went underground after the 2003 U.S. invasion and anchored numerous bomb-making networks (McFate, 2005). Networking across terrorist groups also spreads expertise. For example, Osama Bin-Laden sent Al Qaeda members to Hezbollah to learn about suicide bombs, a particularly lethal form of IED (Horowitz, 2010). The United States has accused Iran of providing both supplies and techniques that allowed insurgents to more effectively target vehicles (Zorprette, 2008). In Afghanistan, bombs tended not to be as sophisticated,[3] but still evolved to effectively target allied forces.

*Resources*: *Flexibility:* Because many components of an IED come from off-the-shelf repurposed parts, it is relatively easy for insurgents to quickly adapt to defeat the very expensive and slower high-tech countermeasures employed by occupiers and state forces. For example, American forces in Iraq spent $57 million deploying thermal probes in front of thousands of vehicles to prematurely trigger IEDs set to go off when they detected the heat source of a vehicle. Insurgents quickly negated the program by adjusting the shape of the charge to shower fragments on the vehicle when set off by the probe (Carey & Yossef, 2011).[4] In another case, an expensive pre-detonation device deployed by coalition forces was nullified by "10-cent" change in the triggering mechanism (Zorprette, 2008).

**Results of IED attacks:** Inherent in IED attacks, as we have defined the term, is a dynamic relationship between the environment, the attackers, and the attacks. Therefore, modeling IEDs in a way capable of identifying the implications of alternative countermeasures requires an ability to register and monitor not only first order, but also second, and perhaps third order consequences of attacks. For IEDs trigger reactions from both the forces of the state and the local population. These reactions in turn affect calculations by attackers about how to deploy and use IEDs. Therefore, we need to discuss the damage IED use can inflict on the "forces of order" that confront insurgents and consider how those impacts feed back into tactical propensities.

IEDs deployed against government forces result in three distinct types of damage.

1. *Direct Material Damage:* They impose material costs on occupying forces, hindering freedom of maneuver, killing soldiers and damaging or destroying billions of dollars in equipment. (Vanden Brook, 2013) (Zorprette, 2008).

[3] A badly-made bomb is often more dangerous than a well-made one, for both the maker and for the bomb disposal teams (Webb, 2012).
[4] Ironically, the $57 million program itself was inspired by the quick and cheap informal adaptation by an American soldier serving in Iraq who purchased a toaster at the local bazaar, then jury-rigged a contraption to hang its heating element in front of his vehicle.

2. *Political Damage:* IED explosions are spectacular and show insurgent forces can successfully attack state forces. The attacks appear on international news media, which may sap morale of foreign occupiers while perhaps obscuring less sensational successes in other areas of the counterinsurgency effort (Moulton, 2009) (Zorprette, 2008). Publicity may help recruitment – insurgents often record successful attacks to use in propaganda videos (Wilson, 2006)
3. *Psychological Damage:* To reduce anxiety and stress on state forces associated with prolonged exposure to invisible and possibly catastrophic threats, state forces seek to isolate themselves from citizens, seen as potential attackers or spotters. Increased body armor (Cox & Van Winkle, 2006)), larger vehicles with greater armor like MRAPs (Krepinevich & Wood, 2007), training weapons on civilian vehicles as a precaution and placing large signs on military vehicles demanding that traffic keep back 20 meters (Moulton, 2009) all dehumanize soldiers to civilians and make the forces of the state seem more like alien occupiers and less like fellow citizens.[5]

**The Right Tool for the Job: Agent-Based Modeling and the IED Problem**

In order to predict the circumstances under which adversaries will act in particular ways, we have to move beyond the two prominent approaches to the problem--game theoretic and aggregate data (statistical) models. While each can provide insight into the IED challenge to counterinsurgency, neither captures the threat as an element of a complex and adaptive process.

Standard game-theoretic models give valuable insight into abstract situations (e.g. the prisoner's dilemma), but only by strictly confining those situations with unrealistic, simplified, and static assumptions. For example, games can only have two real players[6]; the utility functions of the players are fixed a priori and cannot change; player choice is not only be limited, but completely known by each player; and the payoff schedule must be established a-priori and must also be completely known by each player. While evolutionary game theory adds a promising level of dynamism through iteration in a game with players following sequential strategies, the payoff structure and available strategies remain static.

Game theoretic models are deductive; statistical models are inductive. Game theoretic models start with theoretical hunches and then use assumptions about rationality to forecast strategic choices (e.g. regarding IED attacks) under different conditions of choice. Statistical models start with large data sets containing information on many dimensions about the phenomenon of interest, in this case IED attacks. These data sets then serve as test-beds for different algorithms that might elements of interest, such as the number, intensity, effectiveness, and collateral damage of IEDs. Essentially, statistical models are based on snapshots of proxies for variables we expect to be relevant. The correlations that may be established between a particular set of variables and the outcome of interest are representations of a static set of relationships.[7] Typically, the variables are state or structural variables describing "global" attributes of a situation or setting. This wide focus and the model's inability to capture the local interactions behind outcomes such as IED attacks severely limit the statistical approach's potential for discovering signatures for the likely appearance or prevalence of IED's in complex and dynamic settings.

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[6] So-called N-player games simply extend these assumptions.
[7] Note that this is true even if those relationships incorporate lagged variables or other methods of time-series analysis.

Indeed, our research into the chameleon-like threat of IEDs shows them to be the result of interactions so complex, so long-linked, so thickly-interdependent that neither the imaginative thought experiments of game theory nor the elaborate mathematics of statistical models are capable of capturing the interesting elements.

Agent Based Modeling (ABM) is a methodological approach designed to handle complex systems with dynamic, evolutionary natures. It naturally suggests itself as useful for addressing this problem. These features of ABM are crucial both with respect the development of an insurgency to the a point where IED use becomes a possibly attractive option; and in terms of patterns of adaptation in IED usage as insurgent forces come up against the "selection rule" of effective countermeasures. ABM models can offer unique opportunities for examining both expected and unexpected interactions among actors and circumstances that lead to successful or unsuccessful attacks. Second, ABM allows for many runs of the same scenario, subject to stochastic shocks, to give an idea of how often identical initial conditions veer into different results. Finally, the method allows for experimentation to simulate the likely impacts of different kinds of countermeasures targeted at either the bomb or the bomb-maker.

ABM computer simulations are able to cope with this complexity by building representations of complex realities from large numbers of simple, rule-governed but theoretically realistic agents and implemental circumstances. Each run of an agent-based modeling program produces one "history" of that model's virtual world. Multiple runs produce multiple histories, each one of which has features consistent with the laws governing the model (the virtual world) and with the specific initial conditions (which can be produced randomly). If the virtual world is constructed to mimic key elements of the real world, and if the theories used to do so are good, then patterns discoverable in multiple histories of this virtual world are the basis for testing hypotheses about relationships and phenomena that exist, and will exist, in the real world.

While ABMs rely on processes of emergence to illuminate the nth order effects of the interactive implications of simple things we do know, they are limited by the quality of available theory, data and modeling techniques. Agent based models can only produce useful results to the extent that their construction operationalizes well-grounded social science theory.  Using them for forecasting purposes requires, in addition, that the models are initialized with accurate real-world data. As with any research procedure, avoiding bias is crucial. That means, inter alia, that algorithms  animating agent behavior must be devised to honor the assumptions and theoretical commitments *prior* to formulation of the questions to be asked about the phenomenon and without introducing rigidities liable to confine results to a range that guarantee either the confirmation or disconfirmation of interesting hypotheses (Dekker, 2010).

**Previous Use of ABMs for Studying IEDs**

Attempts to model IED use and placement using ABM have been limited by two issues.  The fundamental problem is the overly abstract nature of these models.  Closely associated with a level of abstraction too high to permit focus on problems of real policy interest is an inability to integrate or leverage available theories that can help capture the complex and dynamic aspects that make IEDs so adaptive and distinctive a threat. By carefully increasing the complex of our ABMs we aim to go beyond capturing the tactical interplay among insurgents, state forces and a one-dimensional civilian population.  Our objective has been to make progress toward incorporating a detailed multidimensional representation of the civilian population and its interactions with the combatants. In this section, we review both objections we take with current ABM research and broadly discuss the concepts we will incorporate in our current model to transcend them.

Early ABMs exploring insurgencies e.g. (Bennett, 2008) (Epstein, 2002) offer some useful insights into conflict dynamics. For example, Bennett's counterinsurgency simulation suggests it is more important for state forces to accurately target insurgents (and limit collateral damage to civilians) than effectively target them (ensure insurgents are killed) in order to prevent an insurgency from spreading (Bennett, 2008). However, the only choice that potential insurgents make is whether or not to assault a nearby soldier. They have no choice from a menu of possible tactics. They make no decision regarding the risk or rewards of attacking in various ways and each as the same choice to make at every attack opportunity.

More recent attempts make some improvements to these basic models by explicitly incorporating IEDs and other tactics into the model. In Martinez and Fitzpatrick's conception (2009), IEDs are one of a menu of strategies that insurgents can use. However, those strategies are a parameter of the simulation; the operator selects the insurgent tactics beforehand and is limited to choosing a single tactic, which merely reproduces a limitation of game theoretic approaches.[8] Kase and Ritter include IEDs as a random parameter designed to model collateral damage in their insurgency work (Kase & Ritter, 2012). During every insurgent attack, an IED has the potential to go off, hurting nearby civilians. Again, however, this eliminates the crucial element of agency that real-world insurgents have: the choice to use an IED.

While these models do begin to capture the *effects* of IEDs in combat, the insights gained are limited by IEDs being treated as an exogenous and fixed parameter, which Dekker (2010) warns will artificially bias agents and create unrealistic results. Since IED use is a fixed parameter of both models, the models squander the biggest potential advantage of an ABM with regard to IEDs: the ability to capture emergent behavior. By liberating IED use from a preset and making it part of the dynamic menu choices of an insurgent, we can discover the conditions that lead to IED use, most notably the conflict dynamics between the state and insurgent groups, and the organization of the insurgent groups themselves. In sum, these papers implement an incomplete concept of IED that deprives modelers of opportunities to investigate the implications of IEDs as an element in a multifaceted strategy evolving to exploit state weaknesses or counter state initiatives.

Here we seek to move considerably beyond on the insights and arguments advanced by Bennett and others to provide a realistic model that provides insight into the chains of events that produce and guide patterns of IED development and deployment. This will begin with the five factors discussed above: materials, information, motivation, targets and discrimination. Combined with the effects of IED use on the state and the resulting feedback loops, these factors provide a useful framework to think systemically about building an ABM to study IED use in an insurgency.

Lustick and Miodownik (2009) distinguish three broad classes of ABMs deployed in the social sciences. *Abstraction* ABMs, such as the examples discussed above, use a few stylized variables to make general predictions about insurgencies. At this point we do not possess the knowledge or experience to be confident that a *virtualization* model, of particular IED attacks in particular settings, at particular points in time, can be built and deployed to good effect. But we can assess prospects for that task by building an *ensemble* type IED attack model—one featuring substantially more complex algorithms than the

[8] These tactics include guerilla hit-and-run tactics, a suicide bomb strategy, implanting IEDs, surrounding themselves with civilians and goading security forces into committing collateral damage, and conventional warfare.

relatively abstract models we have reviewed, algorithms capturing much more of what we do know about the distinctive characteristics of IEDs and the networks and individuals who deploy them. Ultimately, our goal is to develop a *virtualization* model capable of representing and analyzing the range of variation and expected probabilities regarding IED attacks in particular, real-life regions of interest.

**Building a Tactical Counterinsurgency Model**

The model we have built to study IED use in a counterinsurgency context is based on Lustick Consulting's well-established PS-I agent-based modeling framework. Over the past six years, we have used PS-I successfully to model conditions in several countries of interest. Here, we offer a brief summary of the model's mechanisms. For detailed descriptions of the framework and examples of countries we have modeled, see Reichert et al. (2014, pp. 18-20), Alcorn and Garces (2012), Lustick et al. (2012), Lustick, 2014. For the original description of this model (updated here) see (Lustick, et al., 2015)

PS-I country models are country-specific virtualizations that feature key generic modules applied to every country. The most important of these modules is the Dynamic Political Hierarchy (DPH). The operation of this module is governed by the activated and subscribed identities of agents, the changing relationship of each identity –which is measured by patterns of overlap in the identity subscriptions of agents, to the most influential and prevalent identity in the array – and the actions that any agent can take based on its position in the hierarchy formed and tracked by this module's operation. Below, we explain the operation of this module in detail.

**Identities:** Based on theories of constructivism (Lustick, 2012), an agent in our models can have (be *subscribed* to) several different identities, though it will only emphasize or advertise one of those at a given time. For example, an agent can be an Arab, a Shia Muslim, a member of a particular tribe, and an army officer. We call the collection of identities to which the agent is subscribed its *repertoire*. The identity shown publicly to other agents and drawn from the agent's repertoire is that agent's *activated* identity. An agent chooses which identity to activate based on what it has done in the past, conformity to what other agents it observes are doing, and other signals exogenous to agent behavior indicating the relative attractiveness of different identities. We adjust neighborhood sight range, elite networks, listening rules, and range and volatility of exogenous perturbations, known as *biases*, based on relevant data on the country being modeled.

We then aggregate the mix of identities into a power structure called the Dominant Political Hierarchy (DPH). When a country is divided into zones of political contestation where the dominant political constellations are radically different across regions – like in a well-developed insurgency—we build the model with multiple DPH. Within each DPH zone, the number of agents activated on and subscribed to each identity is used to identify the *dominant* identity in that zone. This identity is then in turn used to determine the pecking order of the various other identities. Identities whose subscriptions significantly overlap with the dominant identity make up the *incumbent* elements of the ruling coalition. Activated identities with less overlap to either dominant or incumbent are classified as further from the center of power and the loyalties proximity to the ruling group produces. These categories of identities are the *regime, system,* and *non-system* levels. As shorthand, think of agents with activated identities in the dominant or incumbent positions (which are the top tiers of the regime level) as members of a governing coalition, those at the broad regime level as the loyal opposition, and those below the regime level as potential insurgents.

To build a realistic looking insurgency, we can use the DPH concept to produce a "state zone" and a separate "insurgent zone," though their boundaries can change in response to agent behavior and patterns of affiliation among agents. In general, insurgents will be on the margins in state-dominant zone, and agents with state-associated activated identities will be on the margins in insurgent-dominant areas.

When an agent is activated on an identity that according to exogenous signals is substantially less attractive than another identity in its repertoire, it is dissatisfied with the behavior it has been constrained to adopt. These "angry" agents may mobilize, and how disruptive this mobilization is for other agents depends on the agent's position in the DPH. Agents closely tied to the current government in the dominant and incumbent zones lobby, while regime-level agents will protest. Outright violence can come from two groups: the dominant identity can strike out at marginal minorities at the system level, while outcasts at the system level can symmetrically attack the dominant identity.

**Tactics**

To study the specific phenomenon of counterinsurgencies and IEDs, we take our generic country-level ABM and graft onto it a module that incorporates the basic give-and-take of an insurgency's tactical environment. Using Wood's idea of methods of violence; the five features of cost, range, risk, expertise, and flexibility; and the types s of material and political damage we outlined above, we can incorporate IEDs into a tactical module.  This module is incorporated within the country model so that repertoires of tactics are available, to different kinds of agents, in different circumstances. Here we discuss the tactics implemented in the model. Next, we outline the features that operationalize real-world distinctions between them. Finally, we describe how tactics are integrated into the ABM.

We model four distinct categories of violence, or attack vectors, or "tactics," as typical of insurgencies. Note that not all tactics are available to all agents, and that the state and insurgent variations of the same tactic have differing levels of effectiveness, reflecting the higher levels of training and equipment usually available to state forces with respect to conventional tactics. Brief verbal descriptions of each tactic are presented below. Table 1 provides a simple matrix showing the base levels of effectiveness of each tactic vis-a-vis all the others. The asymmetric nature of the graph shows the different effectiveness that the same tactic may have when used by state or insurgent forces. Table 2 shows the basic costs and range characteristics of each tactic for participants.[9]

> **Engagement:** A high risk, low range tactic that has the benefit of being the cheapest available. Even the most cash-strapped organization can field a squad of men with AK-47s, capable of inflicting newsworthy harm upon the enemy. State infantry, while a step up in training and equipment, are fielded for comparable objectives.
>
> **IED:** A cheap (being built from whatever is readily available), low-risk (as the expert builders are nowhere near the battlefield), and reasonably effective tactic, particularly against vehicles. IEDs are only available to insurgents. (In accordance with our definition, mines that may be used by

[9] We recognize formal sensitivity tests will be likely required in follow-up research to justify our use of these specific values regarding tactics. However, based on our extensive research of IEDs and other insurgent tactics, we believe these are reasonable settings relative to one another and adequate to establish the plausibility of this approach for studying insurgent and counterinsurgent tactics.

state forces are standardized, mass-produced, and deployed as per their originally intended purpose.)

**Mechanized:** This tactic has higher costs than engagement, though with greater range, the mechanized tactic covers armored vehicles, tanks, and artillery. This tactic is generally effective against infantry, but is vulnerable to air power. For insurgents, this is the most expensive tactic available.

**Air:** In return for a very high cost, air power provides state forces with unparalleled range at minimal risk.

**Table 1: Tactic Effectiveness Matrix Showing the Probability of a Tactic Succeeding in an Attack**

| Attacker Tactic | Defender Tactic | | | | | |
|---|---|---|---|---|---|---|
| | I.ENG | I.MCH | I.IED | S.ENG | S.MCH | S.AIR |
| I.ENG | 0.5 | 0.4 | 0.7 | 0.4 | 0.3 | 0.1 |
| I.MCH | 0.7 | 0.5 | 0.3 | 0.6 | 0.3 | 0.0 |
| I.IED | 0.4 | 0.6 | 0.1 | 0.5 | 0.6 | 0.1 |
| S.ENG | 0.6 | 0.4 | 0.7 | 0.5 | 0.3 | 0.2 |
| S.MCH | 0.7 | 0.6 | 0.3 | 0.6 | 0.5 | 0.3 |
| S.AIR | 0.6 | 0.8 | 0.2 | 0.6 | 0.8 | 0.6 |

Key:
I= Insurgent Forces
S= State Forces
ENG= Engagement/Infantry
IED= Improvised Explosive Device
MCH=Mechanized/Armored forces
AIR= Air power

*Note that insurgents and state forces can theoretically attack within their own zones (gray values). Multiple insurgent groups might attack each other, or insurgents or state forces could discipline rogue units. We do not allow intra-DPH zone attacks in this model, however.

**Tactic Attributes**

Besides effectiveness, we note three salient features of tactics at our model's level of analysis: Cost, Range, and Backfire Risk. "Cost," refers to the relative amount of resources required to attack using a particular tactic. "Range" is a measure of the radius from the location of the attackers within which potential targets can be identified. "Backfire risk" refers to the degree to which attacks may provide valuable intelligence information to the adversary permitting it to take or improve countermeasures. "Risk" represents the probability that a defeated agent suffers a loss of influence. Because backfire exposes communication links to network members as well as information on methods, it can penalize agents linked to the attacking agent, though less severely than the damage to which the actual attacker is exposed as a result of backfire.

**Module Integration**

In addition to their chosen tactic, our agents have three other attributes that further condition the use of tactics: expertise, resources, and flexibility. Expertise measures an agent's technical ability to use a given tactic effectively through attacking or defending. An agent with high expertise can make even a weak tactic effective, and will be less likely to experiment with new tactics. Agents also have a measure of resources, which is compared against a tactic's cost to determine what methods of warfare an agent can afford to use and maintain. We use the size of a group as a good proxy for the support base that funds mobilization. Finally, agents also have a tactic flexibility variable that describes how willing an agent is to discard old tactics and try something new.

The results of combat within the tactics module graft onto the ideas of elite networks built into the generic ABM. Successful attacks result not only in a gain of expertise to the attacker, but also a possibility of sharing expertise in that tactic with other agents in the attacking agent's network who share that agent's identity or allowing those agents to switch onto the more effective tactic. This process represents the diffusion of successful tactics across different units. Unsuccessful attacks result in a decrease in influence for the attacking agent. This training/learning process also occurs for defenders. Additionally, the tactics module's distinction between state and insurgent tactics pairs very well with the DPH Zone module's two political regions.

Note these processes of victory and defeat also essentially incorporate the ideas of material damage and political damage. Defeated agents lose influence, which can represent both losses in material capacity as well as reductions in political credibility with potential allies.  In contrast, victorious agents gain expertise and disseminate their ideas to like-minded agents, which represent an increase in their prominence of their preferred tactic among potential insurgents, as well as a relative increase influence over the state.

**Table 2: Base Attributes for Each Tactic**

| | Tactic | Cost | Range | Backfire Risk |
|---|---|---|---|---|
| Insurgent | Infantry | 0 | 1 | 100% |
| | Mechanized | 2.4 | 2 | 100 |
| | IED (Insurgent only) | 1.1 | 2 | 5 |
| State | Infantry | 0.5 | 1 | 100 |
| | Mechanized | 3.2 | 2 | 70 |
| | Air (State Only) | 5 | 4 | 5 |

In studying tactics, we are less interested in a particular country than the phenomenon of IEDs in general. As a result, we develop a generic model representing features of a number of countries in which a long-running insurgency battles an established counterinsurgency. Therefore, the default landscape we use to model an insurgency has two separate hierarchies, reflecting a strong insurgency that has managed to create and/or dominate the political system of a region within the country. An agent sees the whole map through the lens of the hierarchy it belongs to, so different agents may have very different ideas about which identity is dominant.

In order to initialize our model with real-world characteristics, we have selected a number of countries that are both in the World Values Survey dataset and have experienced a long-running insurgency to use as a foundation for identities model.[10] For each randomized model run, two of these countries are selected. Three quadrants of the map are seeded according to three districts from the first country, while the insurgent zone is seeded according to a random district from the second. The three-quarters model the larger state DPH zone, with the final quadrant set as the separate insurgent zone. Certain generic identities (state and military) are artificially weakened in the insurgent zone, but still guarantee some overlap of identities between the two zones, along with international identities such as religions, languages, and political parties.

Our case selection includes countries with a well-established insurgency that is the country's largest source of violence, so we only model violence for which the attacker and victim are in different DPH zones and ignore other violence not associated with the state-insurgent clash.

**A Hypothetical Example of the Model in Action**

To illustrate how all of these concepts work together, consider the following account of a representative hypothetical process of a single agent attacking. Our hypothetical attacking insurgent has some experience with the IED tactic and is activated on the dominant identity of the insurgent zone. Its actual range is calculated from the size of the agent's group, and the IED tactic's base range.

Any agents that our attacker perceives as being low in its political hierarchy are valid targets. In our example, an insurgent agent using the IED tactic targets an agent with a state-friendly identity who uses the engagement tactic. The probabilities of success of each agent given the chosen tactics are shown in Table 1.

Let us stipulate that both agents have equal expertise, so there is no net effect on the effectiveness of IEDs against engagement and it remains at around 50%. In this case the attack succeeds, which means the target agent loses all of its expertise, as well as significantly reducing the victim's influence with respect to identities. The victim's identity then becomes temporarily toxic and nearby agents may shift off of it.

Because the attack was successful, the attacker gains some expertise. Other nearby agents may gain benefits as well, if they share the attacker's network and subscribe to the attacking identity. Of those agents in the attacker's network, some share the attacker's tactic and gain some expertise from the event, learning from the attacker any new discoveries of what worked and what did not. Instead of gaining expertise, agents in the network using a different tactic have the opportunity to change tactics, learning from the recently successful attack. They are more likely to learn the new tactic if they have high tactic flexibility and low expertise with a different tactic (a sign their current tactic has not been successful). If the attack had failed (i.e. the defender succeeded), then the defender would be the one advertising its tactic, as well as gaining and sharing expertise with its local network in the manner described.

In our hypothetical example, even though the attack succeeded, it revealed key information about the

[10] For validation, we use *Janes' Terrorism and Insurgency* state and insurgent attack data for Colombia, Egypt, India, Nigeria, Pakistan, the Philippines, and Thailand. Since the most recent World Values Survey was not available for all seven countries, we expanded the list for identity initialization to similar countries including Colombia, Iraq, Mexico, Nigeria, Pakistan, Peru, the Philippines, Tunisia and Turkey.

experts, techniques, and network behind the attack. Therefore, due to the backfire effect, the attacker and agents in its network lose a set percentage of their expertise. Such backfires can occur after either successful or failed attacks, but a failed attack has a bigger backfire effect, i.e. a higher likelihood that levying a small and temporary influence penalty will be levied on the failed attacker. This represents the social and political weakness of a cell that is both exposed and unsuccessful.

This model both extends existing political science and improves past insurgent models in several important ways. Theoretically, it increases the granularity of models of insurgencies and violence down to individual tactics, thereby expanding opportunities to apply political science theories to a level that may be useful to analysts and field commanders dealing with real conflicts. Next, it dramatically increases realism. Compared to previous insurgency models, it allows combatants to choose from several different tactics, develop those tactics over time, and share what they learn with other forces on their side. In this way, conflicts develop organically. Resulting patterns are and emergent; protected from conscious or unconscious pre-selection by model operators. The IED tactic itself is modeled in a very specific way to reflect peculiarities of that attack vector and is operationalized with data from reports on real insurgencies.[11] Finally, the model is couched in a realistic insurgency setting. Instead of having undifferentiated civilians that can be influence by the state or insurgents, model agents represent the complicated realities and mixed loyalties of a multicultural society.

**Applying the model to evaluate different styles of fighting insurgency**

The primary purpose of this paper is to explain the analytic strategy behind our use of ABM to study IED's and to give an account of our model design. As a conclusion, however, we report on a face validity test we conducted. If the model can be as useful as we suggest in can be, it should be able to interact effectively with high quality research that has been done on the kind of counterinsurgency situation imagined as the context for our investigation of IEDs.

Accordingly, we applied our model to evaluate the effect of each of the four counterinsurgency strategies identified by Lalwani's (2014) typology of counterinsurgency strategies, work that seeks to classify and historical responses to insurgencies that colonial overlords and other state forces approached insurgencies with. The typology is a useful attempt to bring clear theorizing to an often ad-hoc descriptions and definitions of counterinsurgency strategy in political science.

Lalwani's four strategies differ on levels of effect and violence that state forces use. Briefly, the four strategies are as follows: Attrition is a high-effect, high –violence strategy that involves state military forces imposing maximum military effort. Population control is a high-effort, low violence strategy that involves state forces keeping military action to a minimum, while attempting to maximize investment in civilians. Enfeeblement is a high-violence, low-effort strategy that surgically targets key nodes in an insurgent network, while co-optation is a low-effort, low-violence strategy in which the state outsources fighting the insurgency to local elites in return for benefits. By coding our tactics in terms of the two variables that cross to produce these four counterinsurgency strategy types, we were able to replicate effects implied by the different strategy types. This was accomplished by running each strategy 500 times with 251 time steps in each strategy. Additionally, we also let each model run "naturally" without

[11] Though most of the sources cited in this paper deal directly with Afghanistan and Iraq, we have reviewed government reports, presentations and news articles that suggest that IED use in other insurgencies, notably the Philippines, Thailand, India, Sri Lanka, Colombia and Nepal share similar characteristics, if not the same volume of attacks as the former two countries.

applying any strategy to provide a baseline.

Results showed that the success of counter insurgent strategies varied in effectiveness. Perhaps unsurprisingly, the high-effort, high-violence attrition strategy on average was the most adept at decreasing insurgent attacks of all types – including improvised explosive devices, while the more targeted strategies were ineffective. Of special interest was the mechanism through which this result was achieved, however. As we note elsewhere, in a fuller report of this research:

> Overall, we found that fewer agents tend to have access to the IED tactic, but those that do generally accumulate much higher levels of expertise. The greater cost of implementing the tactic explains the low rate of access, but the tactic pays off in the long run if agents can manage to use it early and build up enough expertise to fend off attacks from the state.[12] This is perhaps one of the key reasons that our counterinsurgency strategies perform so poorly in our experiment. The cooptation, enfeeblement, and population control strategies all target engagement agents most heavily, which in turn reduces their overall expertise and effectiveness. However, this destruction of the engagement tactic drives those agents to try other tactics like IEDs that are more costly, but also ultimately more effective. In contrast, the attrition strategy actually tends to encourage engagement tactics, therefore increasing the average expertise of insurgent engagement agents and causing them to lock themselves into a local maximum, which conventional forces of the state can easily contain. (Lustick, et al., 2015)

Though these results may be an artifact of our model, the potential of an ABM for identifying opportunities to counter IED attacks comes through in three ways. First, the ABM allows us to run multiple trajectories to generate estimates of counterinsurgency tactic efficacy without relying on field work or experiments that could endanger troops or civilians in the field. Second, unlike traditional methods, the ABM allows us to look under the hood and examine the sequences of events that built up to each result –helping us understand a counterintuitive and surprising mechanism through which the attrition method can control IED use. Finally, these results give us some interesting new hypotheses to test more directly in future iterations of our model.

**Conclusion**

For a short paper, this study has taken the reader down a long and winding road. This has perhaps been inevitable given the objective and the strategy for achieving it. The objective was to contribute meaningfully to addressing a specific policy problem that tens of billions of dollars of research have failed to solve. The strategy was to mobilize strong but fairly abstract social science theory, operationalized with advanced, but historically underdeveloped computer simulation techniques. It is therefore worthwhile recapping what we have attempted and putting into more familiar language, perhaps, why we believe our first attempt at testing the model's face validity has been successful.

A substantial school of thought has arisen in the wake of the failure of expensive, engineering-

[12] This is exactly what happened in Iraq, where bomb making abilities were already well-honed in Saddam Hussein's intelligence services, which seeded the proto-insurgency with high levels of expertise in IEDs (McFate, 2005). The IEDs in Iraq were also much more technically advanced and effective in a wider variety of contexts than ones used in Afghanistan (which, of course, are still a large problem) (Castner, 2012).

type solutions to solve the IED problem by focusing on protecting soldiers or neutralizing IEDs. We concur with the critique introduced by McFate and others that more attention needs to be directed to the “bomber” not “the bomb” and to the left of “boom,” rather than to its right. Indeed our focus became, not the bomber, per se, but the character of the network of people, resources, and expertise that produced both bombers and bombs. For it is ultimately the evolutionary imagination this network naturally displays in the face of serial countermeasures that results in the particular difficulty posed by IEDs as an insurgent tactic.

But if the problem is not merely a technical one, solved by supplying troops in armored personnel vehicles with devices to automatically find and neutralize deployed IEDs, then combating the threat requires synthesizing and integrating knowledge about people, groups, mobilization frameworks, and emergent processes characteristic of insurgencies. This necessity led to our adoption of a definition of IED precise enough for it to be distinguished from other tactics –both in the world, and in a modeling environment. An added constraint on the process was that theories and conceptual approaches used to represent the problem could not require more information than could be acquired or that could be fitted within the categories of available theoretical knowledge. We proceeded to identify how theory –of-the-firm and organization-based approaches to armed rebellion, along with general theories of repertoires of violence, and understandings of the limitations of the most popular forms of modeling, justified investing in the relatively undeveloped technique of computer assisted agent-based modeling. Examination of efforts that had been made to apply ABM methods to problems related to IED use showed that only an ambitious attempt to reduce the level of abstraction of these simulations could advance knowledge in a way that would be useful for addressing IED’s as a policy problem.

To even hope that the resulting model would have face validity in relation to current findings and thinking about counterinsurgency meant that the categories of the model would have to be able to absorb data from the real world. That in turn would not have been possible without the prior existence of validated modeling platforms at the country-level scale required to study the evolution of different kinds of insurgent tactics in relation to endogenously produced violent conflicts. We achieved these tasks were achieved by adapting published Lustick Consulting models and supporting infrastructure, developed for DOD and intelligence community use over the last fifteen years, and by exploiting new data sources from ongoing insurgencies and counter-insurgency campaigns in a variety of different countries.

All of this, and more, constituted the conceptual, theoretical, and technical basis for this paper. Its explication was, by necessity, abbreviated and dense, but the results of initial experiments have been illuminating. By replicating the categories of counterinsurgency tactics published by Lawlani[13], we were able to establish the face validity of the model. When we investigated further, probing our experimental results for the mechanisms that produced them, we discovered a previously undiscussed and potentially extremely important dynamic relationship. Our findings suggest that the potency of an IED threat depends first and foremost on how long

[13] Note that we were unaware of Lalwani’s research when we developed the model.

that threat is allowed to sustain itself and therefore adapt to countermeasures. That, of course, is not a wholly original finding. The adaptiveness of IEDs is well known. What was not appreciated, but what has been documented in our small study, is that a potentially important way to prevent the IED evolutionary mechanism from operating may be to initially use apparently suboptimal tactics which prevent expertise from accumulating in ways that lead to the emergence of truly dangerous IED networks.

By seeking direct engagement with the adversary rather than pursuing, for example, "clear and hold" policies, or policies aimed directly at IED networks, insurgents are drawn to encounters that offer opportunities to significantly reduce their ranks while not providing them with the incentives to develop the kind of expertise effective IED networks require. By drawing the adversary into overcommitting to the engagement tactic, opportunities are naturally created to inflict heavy and perhaps decisive defeats. This sequence of measures is thus suggested as a technique for inhibiting or preventing development of entrenched IED networks whose extraordinary resilience has been repeatedly and bloodily proven.

Of course, our theoretical process began with the insight that IEDs are only one aspect of an insurgency, and the reduction in IEDs is not the end of the analysis. The suboptimal strategies that deny insurgents the incentive to build IED networks are suboptimal for a reason, resulting in far greater risks and casualties for state forces. Furthermore, the attrition strategy causes a significantly greater amount of total violence, which will produce more opportunities for collateral damage that assists in insurgent recruitment or in other serious pathologies that are currently outside of our model's parameters. Finally, our model itself presupposes an already highly-violent insurgency, meaning tactics may have different results under lower-level or simmering insurgencies.

Our results require far more scrutiny, and tests under experimental conditions simulating a variety of types of insurgencies if this suggestive finding is to be the basis for application in planning or in actual operations. Nevertheless the demonstration model represents tremendous advances in realism for modeling strategic conditions surrounding insurgency tactics and demonstrates the potential to vastly improve the ability of field commanders to understand the dynamics of an insurgency and to find and implement effective counterinsurgency strategies.

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