Improvised Explosive Devices: Assessing the Global Risk For Use In Terrorism

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ABSTRACT

Improvised Explosive Devices: Assessing the Global Risk For Use in Terrorism

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Purpose: The purpose of this study is to investigate the risk of Improvised Explosive Device (IED) employment at the national level, the subnational level, and the street level, and to investigate innovative applications of Risk Terrain Modeling for IED risk analyses across these different levels of study.

Methods: This study utilizes three separate applications of the Risk Terrain Modeling technique to determine the risk of IED emplacement at three separate analysis extents. Each level of analysis utilizes Geographic Information Systems to build composite risk maps from different types of risk factors that are associated with IED emplacement. Multivariate regression analysis is used to determine the association and significance of the risk factors as they relate to the outcome events.

Results: Composited global level risk factors associated with permissive environments are positively associated with increased IED emplacements. Countries at highest risk of IED emplacements, as determined by the global level model, can be composited with areas of operation for terrorist groups and densely populated areas to identify microplaces for further study. Those microplaces can be assessed for risk using RTMDx.

Conclusions: The present study established a link between country level risk factors related to permissive environments enabled by state fragility and IED emplacements at the street level. As such, there are policy implications for strategic action to reduce state fragility and the establishment of permissive environments to curtail explosive violence. Furthermore, the identification of risky areas for IED emplacement can drive risk reduction techniques at all three levels of analysis.

Keywords: Improvised Explosive Devices, Crime, Terrorism, Risk, Risk Terrain Modeling

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

At some point during the 9th century, Chinese alchemists searching for the secret ingredient for an immortality elixir happened upon a volatile mixture of saltpeter – a form of the oxidizer ammonium nitrate – and charcoal laced with sulfur. After working through at least thirty-five different previous mixtures with no results, they were surprised to see that this latest iteration burned their hands and faces and reduced the house in which they were working to cinders (Kelly, 2004). While this mixture did not grant immortality, it did make for some fantastic fireworks displays. It was soon after the invention of this mixture that it was weaponized with fuzing and basic ballistic applications (Gray, et al, 1982). Flamethrowers and anti-personnel mines followed, initiating an unceasing development cycle of explosive weaponry, and with it explosive violence.

This was the origin of gunpowder, the first chemical energy explosive. It was a watershed moment in the history of mankind that changed warfare forever and led directly to the reorganizing of social structures throughout the world, including the decline of feudalism in Europe and the rise of the centralized nation-state (Yates, 2000). The world as it exists today, including the millions of lives lost in the wars that were characterized by gunpowder's rampant proliferation, was shaped by the accidental mixing of common ingredients by men searching for eternal life.

As long as there have been explosives, there have been Improvised Explosive Devices (IEDs). Since the invention of gunpowder in the 9th century enterprising individuals have been repurposing explosive materials for their own ends, and it should not be shocking that more than 1100 years after ammonium nitrate was used to make the first gunpowder, the very same basic chemistry availed itself to Timothy McVeigh, who used it to bomb the Murrah Federal Building in Oklahoma City in 1995 (Oxley, et al, 2002).

Though they have gone by many names, IEDs have existed in innumerable configurations from the mines described by Yates (2000) during the Song Dynasty to the 14th century Chinese "Ground Thunder Explosive", a primitive form of victim-operated landmine (Needham, 1986). So-called "Land Torpedoes" emerged in the American Civil War and railway bombs were employed to deny fording sites by the British in World War I (Schneck, 1998) and the Belarusians in World War II (Stockfish, et al, 1970).

Simplistic but deadly booby-trapped mines made from scavenged materials like ration cans surfaced in Vietnam during the conflict there (Magner, 1968), the improvised nature of which echoed the French experience confronting the insurgency in Algeria in the 1950s and 1960s (Ouellet, 2008). In Northern Ireland, car bombs continue to be used as weapons for assassination and disruption of order (Horgan, 2012), and though their historical use and success there likely influenced the current IED employments in Iraq and Afghanistan, the tactics, techniques, and procedures (TTPs) used in those conflicts have migrated back to Ireland[1], bringing the development cycle full circle.

In Iraq and Afghanistan, the IED has been the marquee weapon for the insurgencies and violent extremist organizations operating in those areas. Of the 4890 deaths documented by the website iCasualties.org[2] for the totality of Operation Iraqi Freedom up to this point, nearly 1900 were attributed to IEDs. This accounts for more

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[1] http://www.guardian.co.uk/uk/2012/feb/13/northern-ireland-man-accused-ied
[2] http://icasualties.org/Iraq/Fatalities.aspx

than two thirds of hostile deaths among Coalition Forces during the campaign. In Afghanistan, where there were nearly 14,500 IED events in 2012, IEDs have accounted for more than 60% of United States combat casualties (Barbero, 2012).

In addition to casualties of war, IEDs continue to negatively impact the health and safety of civilians, making the issue of IED violence particularly prescient for practitioners of human security. In a report from the United Nations Secretary-General's Office before the Sixty-seventh session of the General Assembly and Security Council on December 6th, 2012, Secretary-General Ban Ki-moon explained that IEDs were the leading cause of civilian casualties in Afghanistan, accounting for 967 deaths and 1,590 wounded in just the three month period from the 1st of August to the 31st of October in 2012 (Ki-moon, 2012). The website iraqbodycount.org[3], which hails itself as the world's largest public database of violent civilian deaths since the beginning of Operation Iraqi Freedom in 2003 accounts for anywhere between 182,078 and 204,334 documented violent civilian deaths as of September 11th, 2018, many of which can be attributed to IEDs. On February 26th, 2013, the White House issued a policy statement for countering improvised explosive devices citing the responsibility to provide for the safety and security of American citizens[4].

IED use and its consequences are not limited to active theaters of war, either. As violent groups dedicated to crime, terror, and violence converge – especially in Africa and the Middle East – their propensity to use IEDs increases, as do the avenues for sharing knowledge about the devices and how to acquire, build, and operate them. These

[3] http://www.iraqbodycount.org/
[4] http://www.dtic.mil/dtic/tr/fulltext/u2/a574504.pdf

flows of precursor materials and technological know-how are enabled by the processes of globalization making the threat of IED use a truly global conundrum.

Statement of the Problem

IEDs are ubiquitous across time and space. They have existed since the discovery of explosive chemistry and have likely surfaced in some form and under some name in every recorded violent conflict. They are currently at use in most countries around the world.

IEDs exist at all points across the spectrum of conflict from pipe bombs used for pranks and disruptive purposes in the otherwise domestically tranquil United States to improvised "toe-popper" mines in the criminally contentious drug turf of Columbia, to the failing and failed states of the African continent and the all-out warzone of Afghanistan.

They are cheap, costing at most a few hundred dollars to manufacture[5] and are easy to make, consisting of local or household items, discarded and salvaged refuse, and often simple fertilizers common to the most rural and agrarian societies or leftover munitions from fallen regimes and wars long since passed.

They are massively deadly, killing scores indiscriminately, but can be as precise as a well-placed bullet when designed for assassinations. They are dangerous to military and civilian populations alike whether inside or outside of active combat zones. To date, despite billions of dollars and decades of organized effort spent on technologies to defeat

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[5] See, for example http://www.npr.org/2011/12/18/143902421/in-iraq-fighting-an-improvised-war and http://www.wired.com/dangerroom/2011/09/ied-cost/

them, they have resisted any attempt to render them ineffective. They are enabled by globalization such that wherever the internet can reach, so, too, can information on their design and emplacement.

IEDs disrupt order at the local level and influence policy and governance at the global level. Every country in the world experiences at least some risk of IED employment, but that risk has not yet been quantified outside of micro-level analyses.

Purpose of the Study

The purpose of this dissertation is to use the technique of Global Risk Terrain Modeling (GRTM) pioneered by Kennedy and Caplan (2012) to determine the risk of IED employment at the national level, the sub-national level, and the micro-level, and to investigate the application of GRTM for IED risk analyses across these different levels of study.

GRTM is a sub-discipline of Risk Terrain Modeling (RTM), a criminological technique where crime risk factors are overlaid to create composite risk scores suitable for display on risk maps showing places where crime is likely to occur (Caplan, et al 2011). Areas of interest are divided into raster grids composed of small cells with risk scores based on the presence or absence, proximity, or density of known spatial risk factors. These scores can be then be weighted or adjusted to help determine the relative risk that one area poses versus another. The basic tenets of RTM will provide the technical basis for this study.

Every country in the world experiences some risk of IED employment; determining where that risk is highest would be useful to policy makers, law enforcement, and first responders in both civilian and military realms. Explosive Ordnance Disposal (EOD) teams and other organizations tasked with the "reduction[6]" of IEDs could benefit from more optimal resource allocation to areas of greater risk, as risk must be continually balanced against resources. For example, V-shaped hull Mine Resistant Ambush Protected (MRAP) vehicles developed after the South African involvement in the Rhodesian conflict (Russel, 2009) were not acquired prior to the engagements in Iraq and Afghanistan partially because they were costly, but also because the risk of IEDs was not properly accounted for in those countries. Because of their propensity to save lives over other available vehicles, the MRAP acquisition has since been called the single most important military acquisition program in recent time, even at a cost of tens of billions of dollars (GAO, 2008).

This study used the GRTM process to answer some critical questions about the risk posed by IEDs at the national level, the sub-national level, and the micro-level, and to investigate the applicability of GRTM across these levels of study. It determined what the risk factors for IED emplacement are and how they can be operationalized. It built a GRTM model based on those risk factors to determine which countries are at the highest risk of IED emplacement, where that risk manifests, and how it changes across space and time. Based on that model, it determined what correlation exists between historical patterns of IED use in those countries assigned risk scores by the model and finally determined whether or not the model is predictive and at what level of confidence.

Significance of the Study

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[6] A term used in the EOD community to mean safe removal of an emplaced device, or failing that option, a controlled detonation.

This study determined which places are most at risk of IED emplacement. While IEDs have been the main casualty producers in the conflicts in Iraq and Afghanistan, their minimal cost and low barriers to entry (contrasted with, say, nuclear weapons which receive more attention in the literature) make them dangerous in other areas without the benefit of the attention of deep pocketed defense departments as well. If the risk of IEDs can be more accurately accounted for and if risk factors can be identified, national governments, non-governmental organizations, local police forces, and others responsible for counter-IED work can more effectively dedicate resources to their local IED issues and set about attending to those risk factors so that future IED risk might be mitigated. Any successful attempt in part or in whole to defeat the threat of IEDs can save military and civilian lives and avoid costly property damage, both of which can contribute to national and global security.

Furthermore, GRTM is a relatively new and exciting methodology that provides value to the agencies tasked with IED defeat programs, especially the United States Department of Defense Joint Improvised-Threat Defeat Organization (JIDO), above their current predictive models that rely primarily on “hotspot” mapping. GRTM is rigorous, proven, and cost-effective. If the GRTM process and product are found to be satisfactory at the national level, the process can be scaled to sub-national and micro-level applications for counter-IED work, having already been established in use for other criminological applications.

CHAPTER 2: LITERATURE REVIEW

This section discusses relevant published literature and data related to RTM and IEDs. The pertinent discourse around RTM and IEDs begins with a discussion of the general tenets of terrorist activity, how it relates to insurgencies and other environments in which IEDs may be used, how crime and terrorism intersect, and finally how IEDs – as criminal events with associated risk – are defined, used, and modeled.

Terrorism

There is no universally agreed upon definition of terrorism, and the closest idea to consensus is describing terrorism as the reliance on violence to further political goals (Crenshaw, 1992), but the lack of definitional clarity does not preclude it as a topic of serious study (Laqueur, 1977). There have been many, many studies of terrorism in general both before and after the watershed events on September 11th, 2001 when terrorists caused thousands of casualties in New York, Pennsylvania, and Washington, D.C., and while public acknowledgment of the scourge of politically motivated violent terrorism may have increased in the wake of that day, the amount of global terrorist activity – as measured in time series analyses – stayed mostly consistent (Enders & Sandler, 2004). There was, however, a structural shift in the way that terrorists chose to attack their targets. They moved away from kidnappings and hostage crises and towards explosive devices.

Since the initial studies in the aftermath of September 11th, empirical and analytical study of terrorism has grown dramatically, but with the caveat that good data on terrorist activity are hard to come by (Safer-Lichtenstein, et al 2017). Likewise, causal relationships for terrorism can be difficult to establish. One useful framework found that preconditions, if not direct precipitants, could be established that could set the stage for terrorism over the long run, with the most useful factor being a permissive environment where bodies of governance were unwilling or unable to prevent acts of terrorism (Crenshaw, 1981). Permissive environments leading to terrorist activity were most commonly associated with failed or failing states experiencing some type of war or other political turmoil (Coggins, 2014).

These permissive environments manifest as social disorganization or political instability typified by rapid social change and divergence from social norms and laws (Fahey & LaFree, 2015) creating “terrorist black holes” of ungoverned territory (Korteweg, 2008). This makes it easier to commit acts of violence, particularly terrorist acts, which require planning, manpower assignment, resourcing, and other activities that could potentially be discovered and interdicted in well governed environments.

Terrorism, Insurgency, and Counterinsurgency

As long as people live under the rule of sovereign governments, rebellion and insurgency will be employed as a strategy of resistance (Weinstein, 2006). This has been happening for some time and has not been exclusively the result of any conception of a new international system, but rather a symptom of a series of protracted conflicts (Fearon & Laitin, 2003). Insurgency may be a force for ostensible good, producing positive gain for organized society, or it may be avaricious and opportunistic, as in the case of the subversion of the Malian rebellion by both the state-run military and the Islamist and terrorist groups in the north. Most wars of the kind typified by insurgencies are fought by irregular rather than conventional means (Kalyvas, 2006). Increasingly, this type of irregular warfare has been characterized by IEDs.

O'Neill's definition of insurgency is one of the most commonly cited:

> "A struggle between a nonruling group and the ruling authorities in which the nonruling group consciously uses political resources (e.g., organizational expertise, propaganda, and demonstrations) and violence to destroy, reformulate, or sustain the basis of legitimacy of one or more aspects of politics (1990).

The distinctions that Hoffman (2006) makes between insurgencies and terrorism are instructive as well. Whereas insurgencies and terrorism can both be categorized as forms of political violence and are commonly equated with one another due to increasingly similar tactics and methods, they are not synonymous. Insurgencies are mostly concerned with taking and holding both territory and popular opinion, and attempt to do so in the open with armed units. Terrorist groups do not function the same way, as they are generally uninterested in seizing territory and usually avoid direct, protracted engagement with legitimate military forces.

The insurgencies in Iraq and Afghanistan saw a continual blurring of the line between insurgent and terrorist operations. The movements in both countries resorted more and more to clandestine guerrilla tactics more typically associated with terrorist groups while still maintaining their political aspirations. In addition, the willingness to target civilians was more commonplace, and Taliban campaigns like the writing of "night letters[7]" induced fear in the way that terrorist operations are meant to (Johnson, 2007).

One of the most important features of insurgency is its focus on taking and holding territory. Insurgencies by nature seek to establish themselves (Lofland, 1996). For national revolutions, taking territory is an imperative. Mobile warfare is difficult and leads to capture and defeat. Only those movements that are able to take and hold land can effectively fight for their grievances (McColl, 1968). In Afghanistan, the ability of the Taliban insurgency to take and hold land has manifested itself in a complete "shadow government" where each district with Taliban influence houses not only a district governor recognized by the central government, but also a Taliban-assigned shadow governor to maintain influence[8].

Aside from furthering the cause of undermining the ruling group by reducing its area of influence, taking territory – especially populated, urban and suburban areas – has the effect of prolonging insurgencies by offering cover and deterring traditional military forces (O'Sullivan, 1983).

The disparity between insurgent forces and the traditional military forces that oppose them is one of the defining characteristics of asymmetric warfare, irregular warfare, and the general catch-all terminology of counterinsurgency operations (referred to colloquially as COIN). Generations of practitioners have struggled with the proper application of force in quelling insurgencies, and for hundreds of years the accepted

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[7] Night letters are intimidating Taliban propaganda letters delivered under the cover of darkness to individuals or organizations suspected of assisting Coalition Forces in Afghanistan. They often threaten death.

[8] http://articles.washingtonpost.com/2009-12-08/world/36804633_1_kandahar-islamic-emirate-khalid-pashtoon

method was war by attrition (Findley and Young, 2007). Attrition seems to favor the ruling military force at first. It is usually larger, well equipped, and able to mobilize freely. However, the nature of counterinsurgency is reactive. It cannot exist without insurgency. The insurgents maintain the strategic advantage and dictate the pace and location of the conflict (Galula, 1967).

This idea of attrition has only recently been supplanted in theory by a gentler, "hearts and minds" approach that accounts for the welfare of the population caught between the government and the insurgents. Winning hearts and minds has become the de facto motto of late period counterinsurgency, buoyed by the popular rise (precipitous fall notwithstanding) of retired General David Petraeus, co-author of the joint US Army and US Marine Corps Field Manual 3-24, Counterinsurgency (2006). The manual, which attempts to establish doctrine for military operations in a counterinsurgency environment, states that the trend in counterinsurgency has indeed been attrition for far too long, and that the trend should be reversed. It accepts that attrition was based on a paradox, that the more force a ruling party used, the less secure it often turned out to be, and that the best weapons for counterinsurgency often did not harm, but rather established and maintained relationships. In fact, the force structures of modern militaries could be seen as fueling, rather than deterring insurgencies based on their inability to collect information at the local level and apply rewards and punishment accordingly (Lyall and Wilson, 2008).

Indeed, "A successful counterinsurgency construct requires an extremely capable intelligence infrastructure endowed with human sources and deep cultural knowledge (Cassidy, 2006)." These are the relationships that capture hearts and minds – the relationships between those seeking to hold land and those with intimate knowledge of the land itself. Petraeus's doctrine has come under scrutiny since his retirement from the Army and resignation from public service, but it lent credence to a popularly accepted belief that traditional forces were at a loss against the guerrilla tactics practiced by insurgencies, including the rampant use of IEDs[9]. That more was written about counterinsurgency in four years during the conflict in Iraq than during the previous forty years attests to that (Kilcullen, 2006).

The future of insurgency almost certainly holds the increased use of IEDs (Jones and Johnston, 2013). Since insurgencies end either by government loss, government victory, stalemate or negotiated settlement, or inconclusively if at all (Connable and Libicki, 2010), those attempting to defeat IEDs should choose tactics that force their desired endgame. In most cases this will be governments working towards their own victory, and since that outcome is likely to be enabled by a counterinsurgency model, having knowledge of areas at risk of IEDs would fill the requirement for intimate knowledge of the contested terrain that so characterizes successful counterinsurgency operations.

Crime, Terrorism, and Insurgency

The study of crime compares favorably to the study of terrorism because terrorism is inherently criminal in nature (LaFree & Dugan, 2004). Crime and terrorism enjoy a particular nexus despite their differing aims of illegitimate economic enterprise and violent political aspiration respectively (Shelley & Picarelli, 2002; Picarelli, 2012), and a study of Mexican drug cartels and Middle Eastern terrorist groups confirmed that, aside

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[9] See Schneller (2010) and Kaplan (2013) for example.

from political motivation, the two groups shared many commonalities in their operations (Flanigan, 2012). Many more similarities between crime and terrorism make the topic of their intersection rife for study (Mullins, 2009). Volumes have been written on the intersection of crime and terrorism focusing on all manner of topics from funding (Hardouin and Weichhardt, 2006) to tactic sharing (Oehme III, 2008) to weapons proliferation (Curtis and Karacan, 2002), with the concession that crime is often financially motivated while terrorism is generally driven by ideology (Griffiths, et al 2017).

At some level, terrorism may be seen as an extension of trans-national criminal enterprise (Makarenko, 2004). As tools of both criminal organizations and terrorists, IEDs sit right on top of this nexus. In Afghanistan, for example, funding from illicit opium farming is used to recruit fighters, acquire weapons and components, and pay bribes (Piazza, 2012). The gains afforded by the drug funds are then protected with IED emplacements near drug production locations and the cycle continues.

Insurgencies and criminal gangs have been compared, as well, as both contribute to systemic instability and challenge the authority of governments (Manwaring, 2005). In Medellin, Colombia, for example, the weakened state infrastructure has created conditions where the criminal groups, insurgents, and counterinsurgents have all made arrangements to provide security for themselves in the absence of a legitimate police force, just as criminal gangs in under-resourced urban areas have done (Sanín & Jaramillo, 2004).

Improvised Explosive Devices

The North Atlantic Treaty Organization (NATO), in its glossary of terms and definitions, defines an IED as:

> "[a] device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals and designed to destroy, incapacitate, harass or distract. It may incorporate military stores, but is normally devised from non-military components (NATO, 2010).

This is the definition commonly used by NATO members and the military and law enforcement communities that they interact with, and it includes language on the capabilities of the devices as well as their intent. This is likely intentional, as traditional measures of threat are commonly conceptualized as some combination of capability plus intent (Little and Rogova, 2006).

Figure 1: IEDs made from military grade munitions (source: Wikipedia)

Despite this seemingly parsimonious definition, there is some disparity among descriptions of IEDs in the literature. Gill, Horgan, and Lovelace (2011) attempt to provide a content analysis of the many different definitions of IEDs encountered in contemporary writings and include a brief history of the term itself, citing the first recorded instances of the descriptor “Improvised Explosive Device” by the British Army in the 1970s following the conflicts, or “troubles”, in Northern Ireland. Despite the long history of improvisation in destructive explosives, this seems to be the genesis of the current nomenclature. The authors, citing a lack of coherence in the popular definitions, propose their 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).

This definition is more thorough and includes descriptions of the critical components of an IED. However, it disregards an important component – the power supply. This component is accounted for in the jointly produced Weapons Technical Intelligence (WTI) IED Lexicon authored by JIDO (then the Joint Improvised Explosive Device Defeat Organization, or JIEDDO) and the United States Defense Intelligence Agency (DIA). This document, the result of government-industry collaboration, is intended to provide a conceptual framework and operational vocabulary to address the worldwide

IED threat (JIEDDO, 2012). Though the document is exempt from the Freedom of Information Act (FOIA) and marked “For Official Use Only”, it does contain many references to items that appear in publicly releasable documents including a definition of improvised weapons derived from the NATO IED definition and a discussion of the five critical components common to most modern IEDs.

Figure 2: IEDs utilizing homemade explosives in plastic containers (source: SPC Ian Schell, US Army)

A listing of the components also appears in the publicly available United States Department of Homeland Security (DHS) IED fact sheet[10]. These are the container, which holds the explosives and often the other components, the main charge which provides the explosive impulse, the switch which supplies connection (usually electrical),

[10] http://www.dhs.gov/xlibrary/assets/prep_ied_fact_sheet.pdf

the initiator, which begins the explosive chain, and the power supply, often a battery, which stores or releases energy to the complete device. According to a model developed by Liu and Pond (2016), IEDs exist in one of four states: construction, emplacement, detonation, and found devices. This study is concerned with IEDs that are in the emplacement state.

IEDs and Terrorism

IEDs are the preferred weapons of terrorists and generally follow trends in terrorist activity, but not every IED event is a case of terrorism and not every case of terrorism involves an IED. IED events and terrorist events do share many similarities, however. Terrorist events are the result of planning and execution by individuals (Kennedy, et al 2011), as are IED events; they do not simply happen spontaneously or by pure opportunity. Terrorism is likewise a local event, with most terrorists living no more than 30 miles from the site of their intended event and conducting their planning activities within the same space constraint (McGarrell, et al 2007).

Because an IED must be emplaced at the site it intends to target, it, too, is likely to be prepared nearby to minimize the risk of discovery and interdiction. In the case of larger IEDs, it may be too physically taxing to transport them far. IED emplacements are by their very nature local events. The device and the target must physically occupy the same space at the same time for the event to be successful. Just as with terrorism in general, the lack of a definitive definition for IEDs does not preclude determining how IEDs and terrorism are related.

IEDs and Crime

IED attacks conceptualized as the outcomes of the utilization of explosive weapons are inherently criminal events (Brehm, 2012). In fact, when Weapons Technical Intelligence (WTI) teams investigate IED blast sites, they treat them like forensic investigations of crime scenes[11]. Like crimes they are not random (Siebeneck, et al 2009), but rather are the product of structured interactions between individuals and systems that cluster in space and time (Kennedy and Van Brunschot, 2001).

Certain crimes exhibit seasonal trends. Property crimes, for example, are driven by pleasant weather (Hipp, et al 2004), and weather patterns can affect violent crime as well (Sorg & Taylor, 2011). They are the result of an interaction between a criminal and a weather system. Likewise, there is a seasonal component to IED violence, especially in Afghanistan. The so-called "Fighting Season[12]" follows the spring thaw and lasts until the first snow when outdoor movement becomes difficult and the ground is frozen solid enough to preclude IED burial.

In addition to seasonality, there are other temporal characteristics to IED attacks that exhibit themselves at different levels of analysis. The distribution of IED attacks in a given area varies not only over space, but also over time (Townsley, et al 2008). These temporal trends will decay over time similar to the spread of disease or crime (Braithwaite & Johnson, 2012). This means that risky places for IED attacks will vary over time. For a Risk Terrain Model this is important because the relative transitiveness of terrain features will influence the fit of the model. While certain terrain features may be more likely than others to move or decline in influence in the short term, others may

[11] https://www.jieddo.mil/article.aspx?ID=803
[12] http://www.npr.org/2011/03/18/134652285/with-spring-comes-fighting-season-in-afghanistan

not be. One of the strengths of RTM is the ability to respond to these changes and adjust risk accordingly based on the geospatial information available.

IEDs used by criminals do not necessarily have to be part of a larger group or cause. They may be the work of individuals with vendettas[13] or petty actors playing pranks[14]. Often IEDs will be hidden inside valuable items and left in the open for victims to find[15] where they will function, playing on the greed or curiosity of the victim[16]. These types of attacks are generally decentralized outliers and not part of a larger pattern of attacks by a dedicated group.

IED Operation and Activation

Explosive devices like IEDs cause damage via blast pressure or fragmentation, the former occurring when large amounts of air are moved at great speeds by way of explosive forces and the latter occurring when fragments either packed in with the explosive or created by the destruction of the container are expelled during the explosion (McGrath, 2000).

IEDs are activated by switches that are usually simple in nature but can be configured with escalating levels of complexity depending on the intended emplacement and the materials available to the bomb maker. They can be operated on command by an individual rubbing two wires together, pushing a button wirelessly linked to an initiator, or with specially configured tonal relay devices. IEDs can also be operated by the victims

[13] http://www.telegraphindia.com/1121005/jsp/calcutta/story_16054408.jsp#.UQlDNqt9Ps0
[14] http://www.tillamookheadlightherald.com/news/article_713054d2-4676-11e2-9aa3-001a4bcf887a.html
[15] http://www.nytimes.com/2012/06/29/us/phoenix-area-rattled-by-booby-trapped-flashlights.html?ref=improvisedexplosivedevices&_r=0
[16] http://publicintelligence.net/atf-criminal-bombers/

of the IEDs themselves, whether by old fashioned tripwires, pressure plates, or even photocells. IED activation systems are limited only to the physical constraints of the explosive train (Mostak & Stancl, 2006).

How IEDs are built and used is a function of the materials available to the bomb maker and the strategic, operational, and tactical goals of the groups using them. In countries like Iraq where military grade munitions were readily available following the collapse of the government and dismantling of the military, mortar bombs and artillery shells were repurposed as IED cases and the explosive fills were used as main charges. In Pakistan and Afghanistan where fertilizer is manufactured and abundant, homemade explosives from nitrate-rich materials are prevalent. In countries with active mining or construction industries, IEDs may be made out of pilfered commercial explosives like TNT and detonating cord. Likewise, Radio Controlled Improvised Explosive Devices (RCIEDs) may be prevalent in countries with robust cellular phone networks and an absence of jammers. In rough or undeveloped terrain IEDs may be buried more effectively, but in cities or other areas where digging would be obvious they may be surface-laid and camouflaged by rubble or detritus.

IED Data

There is a lack of available, high-quality data on IED events worldwide (LaFree & Legault, 2009), and many countries lack the ability to properly track official statistics on terrorist and IED events (Ackerman & Pinson, 2016). What data sets do exist are segregated into multiple databases with different methodologies for collecting and sorting, and with various levels of accessibility to the general public. With the emphasis on IED defeat by the Department of Defense (DoD) and the funding available as a result, many private contractor organizations have begun to collect and analyze their own data for profit. This adds levels of complexity to an already messy data picture. Even the data that United States military organizations collect are massive, diverse, incomplete, and noisy (NRC, 2007). This makes it very difficult to accurately analyze IED threats and trends with any level of confidence, although some previous efforts have been made (Buchalter and Curtis, 2003).

Primary event data sources are diverse, and each source has attributes that make it attractive for its intended audiences even if the data are messy, duplicitous, or otherwise less than perfect. In addition, most available data sets that include IED information are terrorism data sets. IED violence is not always analogous to terrorism even though IEDs have become the preferred weapon of international terrorists and follow many of the general trends of terrorist activity (LaFree & Legault, 2009). Determining which IED events may have been excluded from terrorism data sets, and why, becomes an important, time consuming task.

The Global Terrorism Database[17] sponsored by the University of Maryland is an open-source collection of terrorist events including information on explosive device violence at the global level from 1970 through 2016 (and whether or not the event in question was definitely or only maybe caused by an IED). Data are coded, and annual updates to the data are planned. The database contains more than 100,000 events, many of which are domestic cases. These data are be used to provide the statistical annex to the

[17] http://www.start.umd.edu/gtd/

United States Department of State's congressionally mandated annual reports on global terrorism[18].

It is possible, however, that domestic events may be overrepresented as a percentage of the global total due to the more readily available nature of domestic reporting and the propensity for local law enforcement to document every potential explosive device as an IED event due to stringent terrorism laws. For example, two teenaged Virginia college football players were suspended when a soda-bottle prank in which no injuries were incurred was categorized as an IED event[19]. This tendency to over report domestic IED events is likely to be shared by any database using open source reporting.

The Institute for Defense Analyses (IDA), a Defense contractor, also maintains a global IED event database[20]. This database contains classified military information and is the primary data source of choice for JIDO. It can commonly be seen in reference lists on JIDO briefings and its aggregate data occasionally occurs in other analyses of the IED issue. IDA commonly sends its personnel to active combat zones to help collect and refine its data, but the final product that it produces is not available to the public and thus relatively useless to those without the appropriate clearances and unfettered access.

The TRITON report by Allen Vanguard[21] collates, corroborates and assesses terrorist incidents from around the world, congealing into the world's largest open source

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[18] http://www.start.umd.edu/start/announcements/announcement.asp?id=438
[19] http://www.wjla.com/articles/2012/12/2-virginia-tech-walk-on-football-players-charged-with-detonating-explosive-device-82690.html
[20] https://www.ida.org/researchareas/forceandstrategyassessments/irregular%20warfare%20planning%20and%20experimentation.php
[21] http://reports.hms-online.org/ViewProduct.aspx?ProductID=474

database of terrorist incidents. The database is proprietary and not publicly accessible, and although it is not classified like the IDA database, it is also used by JIDO and government organizations just the same.

The Worldwide Incidents Tracking System (WITS)[22], populated and published by the United States National Counterterrorism Center (NCTC) maintained the US Government's authoritative database on terrorist attacks compiled exclusively from open source data. It was publicly available, and used to provide an accessible, Internet-based database to a variety of consumers, but was discontinued in April 2012. It offered sorting and visualization functions that allowed it to filter out only IED events, among other characteristics. Because of its accessibility, WITS was one of the easiest data sources to use and offered investigators the luxury of repeatability that for-pay or otherwise closed systems cannot. WITS, however, used a more restrictive methodology for cataloging its events than most other databases as it did not consider attacks against willing combatants to be acts of terrorism and thus excluded them from the data set. Thus, many IED events in Iraq and Afghanistan were not captured. This resulted in extremely conservative estimates of worldwide terrorist activity and by proxy explosive violence from IEDs.

The RAND Database of Worldwide Terrorism Incidents[23] lists about 36,000 incidents of terrorism with coding and metadata details. Like the IDA data and the TRITON report, the RAND data are available through subscription and are searchable and interactive. Data exist from 1972 to 2009 with further data being collected, although nothing further than 2009 has been released.

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[22] http://www.nctc.gov/site/other/wits.html
[23] http://www.rand.org/nsrd/projects/terrorism-incidents.html

One of the most comprehensive, and yet most baffling sources of data are the so-called Iraq and Afghanistan War Logs released by the rogue information organization Wikileaks and reported on extensively by the New York Times[24], the UK Guardian[25], and many, many other news outlets. The Wikileaks data, a total dump of more than 90,000 mostly classified reports from a military reporting system, represent probably the most comprehensive and most accurate reproduction of IED events in Iraq and Afghanistan for the period of time that the data were collected because they were culled directly from soldier initiated reports on observed and experienced IED events. The largest classified leak in United States military history at that point in time, the documents were a treasure trove for researchers as they included date and time stamps for events, as well as grid references for location accurate to with one meter.

Unfortunately, the data carried with them significant ethical concerns. Because the data were classified at the time of disclosure and not properly declassified before entry into the public domain, they remained classified with all of the protections afforded to classified information. The DoD has directed all of its personnel, including associated contractors and academic researchers, not to access the data[26], and direct requests for unclassified or redacted versions of the dataset have been denied. While this potentially applies some level of protection to the information and the systems that it is accessed on, it eliminates a potentially important source from further consideration.

IED Trends

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[24] http://www.nytimes.com/interactive/world/war-logs.html
[25] http://www.guardian.co.uk/world/the-war-logs
[26] http://www.public.navy.mil/usff/Pages/wikileaks.aspx

States as political entities hold a monopoly on the legitimate use of physical force or violence (Weber, 1919). While IEDs do not necessarily threaten that arrangement since their use is almost always considered illegitimate (Moyes 2009), they do disrupt the order that states generally choose to exert over those that could use weaponry outside of social contracts in the tradition of Locke (1962) and Rousseau (1920).

The trend in the use of IEDs, especially by terrorist groups, is a symptom of that disorder. Nuclear weapons, for example, are difficult to acquire, difficult to control, and difficult to use. They exhibit severe logistical limitations. "There is, however, no limit to the ingenuity in improvising bombs, grenades and mortars. . . (Clutterbuck 1993)"

IEDs do not suffer the same limitations as nuclear, or even other larger platform-based conventional weapons. Their components cannot be tracked reliably, they do not exhibit readily traceable signatures like fissile material, and their cost is comparably negligible. For these and many other reasons they have become incredibly popular weapons for those that would disrupt order. This includes not only terrorists and their groups but drug cartels and criminal enterprises, as well.

IED events do not occur in a vacuum. They are the result of a specific set of contextual constraints that manifest themselves in violent, physical action. In Israel, for example, nearly 100 suicide bombings occurred between 1994 and 2003, most in direct response to Israeli aggression towards Palestinian interests (Niva, 2003). In Israel and the Palestinian territories, the suicide vest became the IED of choice just like the car bomb had in Northern Ireland.

In the United States, the predominant configuration is the pipe bomb. These are small metallic or plastic tubes commonly filled with black powder and outfitted with simple fuses. They were present in many of the marquee IED events in the United States including the Unabomber events, the 1996 Olympic bombing, and the Columbine High School violence in Littleton, Colorado (Oxley, et al 2001.) Pipe bombs do not, however, appear in any great numbers outside of the United States, although the spread of lethal knowledge concerning their design and use, mostly attributed to the publication of a manual for their construction in the English language terrorism periodical *Dabiq*, has led to an increase in their prevalence.

The cycle of explosive violence of the kind associated with IEDs is not new. Landmine warfare, a distinctive calling card of the battles of the early 20th century, permeated the existence of many people to the point that the indiscriminate nature of the devices and the difficulty in rendering them safe whether by identification and clearance or reduction became a global security issue (Matthew, et al 2006). That legacy of violence has carried over into the current IED problem set which is at once reminiscent of and more multifaceted than the landmine threat.

Unlike landmines, IEDs are not constrained to burial in dedicated fields. They can be emplaced anywhere, at any time, in any type of configuration imaginable to the IED maker. In 1920, a wagon cart loaded with dynamite was used as an IED in New York City presaging the car bombs so prevalent during the “troubles” in Northern Ireland (Davis, 2007) and beyond. Those devices, along with an array of sophisticated remotely triggered IEDs and even a homemade missile system described by Oppenheimer (2009) show the depths of ingenuity that shape IED trends and lead to global adoption of these types of weapons.

In particular, Jihadist groups like Al Qaida have adopted IEDs as tactical weapons with strategic implications to further their causes (Bales 2009). In a declassified National Intelligence Estimate from 2006, violent Jihadism was recognized as the primary threat to United States interests and its success a factor in the direction of global terrorism. IEDs play a major role in that success.

Trend reporting shows just how deadly IEDs can be. From just March to May 2012 there were 1,152 people killed in 758 IED events worldwide (Checcia, 2012). This included Vehicle Borne IEDs (VBIEDs) like the aforementioned Irish car bombs and suicide IEDs as well. Many of these events were claimed by Jihadist organizations and Al Qaida affiliates, but others were simply the work of criminals or insurgents. During just the first half of 2017, the IED Monitor published by Action on Armed Violence identified 7,784 deaths and injuries from IEDs. Most were civilians (Overton, et al 2017).

The trends in IED use do not exclude the United States. Underwater mines or boats outfitted with IEDs (like those that attacked the USS Cole) could threaten not only externally accessible ports but also internal waterways and shipping lanes (Truver, 2008). There is a considerable threat from Mexican drug cartels as well, as they have been known to use IEDs and have recently adopted the TTP of detonating car bombs as weapons of intimidation and assassination (Fimiani, 2011). As the cartels expand their geographic influence into the United States, the porosity of the southern border creates a legitimate VBIED threat in U.S. territory.

JIEDDO/JIDO

JIDO, the United States Department of Defense (DoD) organization tasked with synchronizing efforts to defeat IEDs across the globe, began as a small United States Army-led task force in 2003[27]. By 2006 it was elevated to a joint task force reporting directly to the Secretary of Defense. It was formally established later in 2006 via DoD Directive 2000.19E[28]. Since 2006, JIDO had been in the practice of releasing annual reports timed to the federal government fiscal year, although those reports ceased in 2010.

The reports described the contemporary IED threat, provided aggregated statistics on attacks, and offered modest predictions about the future. Because JIDO tracked all IED reports around the world, regardless of intent, scale, or scope, it was a more reliable source for aggregated statistical information than organizations that may only track terrorist activity or criminal activity. By its very nature it was dedicated to the study of the IED. The reports also included budget expenditures, and descriptions of so-called “Lines of Operation” that included counter-IED initiatives with titles like, “Attack the Network”, “Defeat the Device”, and “Train the Force” (JIEDDO, 2010). These lines of effort mainly describe the projects that JIDO assigned funding and resourcing to and served as a way of categorizing their effort in accordance with the WTI lexicon.

Since 2010, JIDO has not issued an annual report. Instead, in 2012 JIDO released a strategic plan to outline its efforts from 2012-2016 (JIEDDO, 2012b). This was likely done to account for the continued existence of the organization past the planned

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[27] https://www.jieddo.mil/about.aspx
[28] https://www.jieddo.mil/content/docs/20060214_DoD_Directive_JIEDDO.pdf

American withdrawal from Afghanistan (where the IED problem has been the most acute) in 2014. Because JIDO conceives of IEDs as a global threat, it must establish a strategic vision beyond the battlefields in Iraq and Afghanistan to ensure its continued relevance. The statements made by its Directors comparing IEDs to traditionally lethal components of warfare like artillery and claiming that IEDs will persist far into the future[29] reinforce this, as do studies of the longevity and efficacy of mass-casualty bombings (Quillen, 2002; Arnold, et al 2004). This foresight is prescient given the state of financial uncertainty surrounding many government programs, especially those with multi-billion dollar price tags operating under supplemental resourcing.

The establishment and operation of JIDO has been contentious. At least four separate United States Government Accountability Office (GAO) reports have cited JIDO as an organization without a proper strategic plan (2007), transparency (2008), visibility and coordination of its efforts (2009), or internal control (2010). In August 2012 the GAO reported that JIDO was still not exercising proper oversight over the DOD counter-IED mission (2012). Criticism has extended past the GAO and into the joint services, where student theses in the War Colleges have been published citing JIDO as a "roadblock" in the counter-IED fight (Ellis, et al, 2007) and proposing alternative decision models for proposal selection (Dawley, et al, 2008, and Willy, 2009).

Congress itself has also commented on not only the inefficiency of JIDO, but also its ability to accomplish the singular task of its original namesake, which was to defeat IEDs. In a report from the House of Representatives Committee on Armed Services

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[29] See https://www.jieddo.mil/news_story.aspx?ID=1496 and http://www.janes.com/products/janes/defence-security-report.aspx?id=1065970736 for example.

Subcommittee on Oversight and Investigations, it was concluded that despite JIDO's claims of limited the effectiveness of the IED as a weapon of strategic influence, it was unclear just how well JIDO was doing in accomplishing its main mission (2008). This is hardly surprising, as evidence has shown that there is a dearth of evaluation research on counter-terrorism interventions like JIDO, and what little there is shows that intervention strategies may actually increase terrorism events in the short term and possibly have no effect in the long term (Lum, et al 2006).

In 2015, after nearly a decade of work, JIEDDO was rechristened as the Joint Improvised-Threat Defeat Agency (JIDA), expanding the scope of its mission from just IEDs to all improvised threat, and cementing its place as a permanent combat support agency of the Department of Defense. Just a year later, the organization rebranded as the Joint Improvised-Threat Defeat Organization under the banner of the Defense Threat Reduction Agency (DTRA).

Defeating IEDs

JIDO is not the only organization interested in IEDs, their effects, and ways to eliminate them as threatening devices. A host of other government, industry, and academic entities have published on their attempts to defeat IEDs using a myriad of approaches. That IEDs are still ubiquitous speaks volumes about the level of success that they have had against this difficult, seemingly intractable problem. One can no more defeat an IED than one can "defeat" a bag of fertilizer, a bundle of wires, a plastic pen cap, or a garage door opener – all common components of IEDs.

In 2007 the National Research Council of the National Academies published a volume called *Countering the Threat of Improvised Explosive Devices: Basic Research Opportunities* that outlined in detail a number of directed efforts that could be undertaken to better understand and interrupt the effects of IEDs and the people that make and emplace them. The committee that drafted the volume was culled from universities like Yale and Princeton, private firms like Google and the Institute for Defense Analyses, and even the United States Postal Inspection Service.

They concluded that the best approach for countering IEDs around the world would be to limit the effectiveness of the people that employed them at various points throughout the threat and supply chain, from conception of the device through component acquisition and building, and finally to emplacement. The areas for research that they suggested such as the study of the relationships between human terrain[30]and the IED threat, or the need to use data acquisition, fusion, and analysis of varying information sources, have appeared in subsequent works on the subject.

The National Consortium for the Study of Terrorism and the Responses to Terrorism (START) published a workshop report in 2008 identifying the human and social forces at work in the spread of the IED threat. Citing the National Research Council report, the START report further identified the need for Spatio-Temporal modeling in identifying aspects of IED adaption, including comparisons of locations that have been targets of IED attacks with locations exhibiting similar terrain features. There have been many such studies performed since.

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[30] In the volume, human terrain is described as the political, social, cultural, and economic environment.

While many reports like the National Research Council and START reports have advocated for areas of study related to IED defeat, some groups have actually conducted that work and assessed their success. Because IEDs are composed of five main components, and because those components are often composed of many subcomponents and systems, there have been efforts to disrupt the supply chains of these critical items. Because of the nature of the items in question, which are often common household goods or dual-use in nature, this has been quite difficult.

The fertilizer that has been used to make the home-made explosives used as the main charge for many IEDs in Afghanistan and Pakistan has been targeted as a critical component worthy of interdiction. In 2010 a United States Senate Resolution called for the monitoring and regulation of ammonium nitrate in South and Central Asia as a way to control a legitimate item used in a majority of IEDs in the region (Goodman, 2010). Despite this Resolution, and despite hundreds of tons of ammonium nitrate seized by United States and Afghan troops, the number of IEDs using the fertilizer still increased[31].

The fertilizers and precursors used for making IEDs are often stored in weapons caches along with other illicit items like small arms or grenades. As such, locating and interdicting weapons caches is often seen as valuable in attempting to defeat IEDs by reducing their numbers and the places they might be stored in. From the perspective of the IED user, the best cache sites are those that are secure from interdiction, accessible to the IED user and his associates, and that provide easy distribution to emplacement sites (Shakarian, 2011). Identifying areas that fit these terrain considerations could possibly

[31] http://articles.washingtonpost.com/2012-08-18/world/35493152_1_ammonium-nitrate-afghan-troops-afghan-forces

help increase levels of IED caches discovered thus potentially decreasing the amount of IEDs that are finally emplaced and detonated, although that has not been reflected with any significance in overall attack levels.

Technical approaches to defeating IEDs have had limited success as well, and although Google lists hundreds of patents for devices designed to defeat IEDs, very few have had operational successes. This is partly because IEDs are so difficult to detect, both before and after they are emplaced. Detection of IEDs is based on detecting the component parts, generally by some type of signature inherent in the component itself. For IEDs using metallic parts, a simple metal detector will suffice, but the adaptive nature of IED builders has led to non-metallic IEDs that account for that tactic (Nakatsu, 2012). Explosive detection is often accomplished by vapors or traces, or by detection of bulk quantities by other methods like radar or x-ray (Schubert and Kuznetsov, 2006). Many methods of vapor and trace detection have been attempted, but because of low vapor pressure they are not adaptable to the stand-off distances required for safe interrogation of explosive items (Simmen, et al 2011). In fact, most vapor pressure detection methods for other organic compounds have proven unsuccessful for the explosives used in IEDs (Marshall and Oxley, 2008). Furthermore, they require some prior knowledge of a target area for interrogation, meaning that to detect an IED one must already know where it is likely to be. Outside of active war zones, this is often not the case. One promising technique utilizes common WiFi signals to detect so-called suspicious items, including IEDs, in baggage, but the application is limited to security checkpoint configurations and thus less appropriate for general emplacement areas (Wang, et al 2018).

One technological method that has had considerable success, however, was the jamming of RCIEDs which use radio transmitting devices like cellular phones or car alarm key fobs to send a signal to the IED to detonate on command. The United States Army ordered thousands of jamming devices for the RCIED threat in Iraq to cover the range of frequencies employed by RCIEDs[32], but areas without major, interested military presences with the resources to afford expensive equipment like jammers will still suffer from RCIEDs. This has been the case in places like Colombia where they are used extensively by drug cartels, and in the Philippines, Thailand, and Indonesia[33]. Even in areas where RCIEDs are present and jammers are called in to defeat them, simple models show that the groups emplacing the IEDs can adapt readily to the presence of that technology rendering it ineffective in very little time (Dayton, 2009).

Most technological methods have had limited success to the point that bomb-sniffing dogs and human visual inspection have been called more reliable (Erwin, 2010), and even moths and rats have been considered as bomb-sniffers (King, et al 2004). As such, a number of studies have been undertaken to enhance the effectiveness of visual detection of IEDs and landmine-type weapons in order to provide training, because IEDs must be detected before detonation lest they have lethal consequences (McNeese, et al 2017). Visual indicators enabling the location of buried explosive threats were identified (Schweitzer and Bodenhamer, 2007, and Szalma, et al 2011), and critical skills like vigilance and time-on-target for visual threat detection were further defined (Zimmerman and Mueller, et al 2012). Cognitive models were built (Ashworth, 2011) and computer-

[32] http://www.wired.com/dangerroom/2011/06/iraqs-invisible-war/all/

[33] http://www.oss.net/dynamaster/file_archive/051011/04e118e543b29b06a494b03a0e192cc8/OSS%20Remote%20IED%20Initiation%20Updated%20Final.pdf

based training was recommended for Unmanned Aerial System (UAS) operators (Cooke et al, 2010) based on success in increasing the performance of x-ray machine operators found in airports (Hardmeier, et al 2010). Still, the Army Research Institute, whose work in 2009 spurred many of the further attempts to understand visual search for IEDs, understood that some of the skills that helped identify IEDs visually could not be trained[34], despite the best efforts of researchers seeking to understand what made one individual able to see indicators of buried or hidden threats that another could not.

Aside from the technical limitations to IED defeat, there are social and contextual limitations as well. Technical solutions are expensive and time intensive. IEDs are cheap and adaptive. By the time an IED defeat solution is conceived of, built, tested, and fielded, the IED networks have likely already moved on to different device configurations that can thwart the new technology. In fact, groups that use explosive weapons co-evolve with the societies that attempt their defeat (Roach, et al 2005). For this reason and others, insurgent activity including IED use is considered to be a dynamic Red Queen activity where an adaptive Red Queen stays just steps ahead of a reactive Blue King – a regular mathematic relationship that offers insight into the patterns of IED groups (Johnson, et al 2011 and Johnson, 2012). Just like in the Lewis Carroll story from whence the concept draws its name, the two sides are engaged in a dynamic, literal arms race and it takes all the running they can do just to stay in place.

Illicit Information Sharing

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[34] See http://www.nytimes.com/2009/07/28/health/research/28brain.html?pagewanted=all, describing a limited distribution report.

Terrorists and others that use IEDs use the internet to recruit team members, collect information, and spread that information to sympathetic parties around the world with relative anonymity (Holt, 2012). They are enabled by information sharing technology in much the same way that the rest of the world is. Whereas documents like the *Terrorist Handbook* or the *Anarchist Cookbook* were mythical tomes whispered about in hushed tones before the dawn of broadband connectivity, now the recipes and methods for building explosive devices are as readily available as recipes and methods for baking cupcakes. Even the official Al Qaida English language magazine *Inspire* published a crude recipe for an IED under the headline "Make a Bomb in the Kitchen of Your Mom"[35] that was later cited as inspiration for the device configuration in the Boston Marathon bombings in April 2013[36] and several subsequent high-profile attacks.

In a way, the living archive of the internet is a necessary mechanism for the evolution of IED methods, especially when suicide bombings are considered. Whereas IED expertise could potentially be lost when suicide bombers detonate themselves, even if they were not integral to the construction of the device itself, the Web becomes a journal of their methods enabling evolutionary and incremental improvements over the IED versions that had come before (Kenney, 2010). The poor tradecraft that in the past would have been passed down through generations of traveling foreign fighters like an oral history is now archived forever for research purposes. Kenney further argues, however, that merely learning about making IEDs through reading about them online is

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[35] http://www.dailymail.co.uk/news/article-2219384/Federal-Reserve-bomb-plot-Quazi-Nafis-inspired-al-Qaeda-terrorist-magazine.html

[36] http://www.dailymail.co.uk/news/article-2313782/Dzhokhar-Tsarnaev-Boston-Marathon-bomber-admits-learned-build-bomb-Inspire-magazine.html

no replacement for the technical and experiential learning gained through physical acts, possibly explaining a number of high-profile interdictions and thwartings.

In addition, the so-called "Dark Web", the areas of the World Wide Web not accessible by search engine crawlers or bots because they reside in hidden databases, or behind paywalls or other security features have in fact become a rich source for the study of how IED information is shared (Chen, 2012, 2009, 2008a, 2008b). In this area of the web, social movement research can be conducted with respect to the flow of information between and across communities of IED builders and their associates.

Risk

Because IEDs are not manufactured to any standard, and since their targets can be so varied, there is uncertainty about their use and the amount of damage they will cause when initiated. To deal with this uncertainty, probabilistic risk models are necessary (Stewart, et al 2012). Risk can never be zero; there is always a chance that something bad will happen (Kennedy & Van Brunschot, 2009), and so risk must be assessed and managed. Just like the risk in crime can be assessed and managed, the risk in IEDs can be assessed and managed. Unfortunately, risk assessment and management has a cost, and resources cannot be allocated to risks ad infinitum. Risk and resources must be balanced (Kennedy & Van Brunschot, 2007).

To balance risk and resources it is imperative to have some insight into how, when and where risks may manifest. This is risk assessment. Risk models have already been applied to cases of terrorism (Cummins & Lewis, 2003). In the case of IEDs, this would mean predictions about how, when and where IED events would occur. Dahl

(2011) showed that insight into terrorist activities through intelligence gathering and traditional law enforcement initiatives was instrumental in foiling most thwarted terrorist plots. That insight would be gained through some structured, probabilistic technique.

Analytical Models

Understanding that the nature of the IED problem set does not lend itself to technological solutions or a “silver bullet”, and understanding that the traditional methods of interpolating data about IEDs – that is, human intelligence and signals intelligence – cannot account for the entire picture of the IED emplacement cycle, it stands to reason that a more considered application of collected data and analysis of those data might impart more meaning than information standing alone (Childress and Taylor, 2012). To that end, many models have been conceived of and built to illuminate the IED issue. Each model utilizes a set of assumptions and a set of data to determine if there is information about the problem to be gleaned.

Many models have attempted to understand the social context of IEDs, citing their nature as products of “human ingenuity and human social organization (McFate, 2005).” By understanding the human motivations and networks behind IED use, insights can be gained into the ways in which the devices are used and the permissive environments that enable them.

In a study of terrorist events using IEDs from 1970 through 2004 using data gathered for the Global Terrorism Database, LaFree and Legault (2009) arrive at a number of conclusions based on trends in their data: IEDs generally follow trends in terrorist activity although they are somewhat different than other terrorist bombings, they are not necessarily correlated to death rates in countries experiencing IED events, and that suicide IED events are on the rise. Beyond that, however, there are concessions that the data on IEDs are poor and there is still much work to do in understanding why IEDs are chosen by terrorists and others in their attempts to cause damage (beyond the fact that they seem to be effective).

Of particular note was the conclusion that IED efficacy is variable. Some IEDs in some places were particularly lethal while others in other places were not. The authors cite variations in the intended use of the devices – some are meant to be spectacular shows of force but not necessarily life threatening like fuel-enhanced explosions that create amazing fireballs but little else – but also the capacity for the local law enforcement or military presence to prevent or mitigate attacks. In addition, the level of competency of medical first responders (if any) may account for decreases in explosive device efficacy. Models assist in this type of work as well, and Raytheon has developed a system specifically designed to respond to the needs of decision makers in the wake of an IED event in a metropolitan area (Dawesar, et al 2010).

LaFree & Legault refer to the gains to be realized from using their and other data on IEDs to understand the social context of IED use and the circumstances behind their effectiveness. In particular, they refer to the work of Johnson & Braithwaite (2009, 2012) who use Geographic Information Systems (GIS) and space-time modeling to understand insurgency and counterinsurgency in Iraq. By using a novel spatio-temporal methodology, the authors are able to show that IED use mimics crime (and disease) in its tendency to cluster in space and time and then to decay. By studying IED use in Iraq against hardened targets and the counterinsurgency response to those IED events, they were able to observe elevated risk of repeat actions in a limited time window in places already used for IED emplacements. This was likely because of the constraints imposed on insurgent behavior with regards to time and space, but also on the resources required for IED emplacement.

The RAND Corporation, tasked with determining which scarce resources in Iraq could be dedicated to the counter-IED mission, turned to hotspot identification in order to gauge which areas of IED activity would benefit most from the considered application of snipers, quick reaction forces, and detectors (Keefe and Sullivan, 2011). This spatially oriented technique aligned events that had already occurred with the assumption that they were likely to occur again in the same places.

Other spatio-temporal models have attempted to reduce the complexity of the IED problem set by limiting the spatial characteristics of the model based on the observed characteristics of IED attacks. Benigni and Furrer (2008, 2012) do this by limiting the places that IED attacks can occur in their models solely to roads, because that is where most IED attacks actually occur. This reduction of complexity addresses what may be considered high-risk places for IED events but has more applicability to the problem spaces in Iraq and Afghanistan, which the authors were addressing directly, rather than to all countries.

Further models have taken the concept of limiting the IED risk space to the single dimension of roads and used it to develop optimized routing paths for IED reduction convoys called Route Clearance Teams (RCTs) whose mission is to traverse IED riddled roads to make them safe for further travel. Kolesar, et al (2008, 2012) use time series analysis of completed attacks to optimize routing for these scarce assets where IED risk was defined as the number of IEDs an RCT could expect to find on a given road based on historical patterns of attack and the rate at which insurgents could reseed those lanes of travel with IEDs once they had already been cleared. Royset & Reber (2009) apply a similar methodology to Unmanned Aerial Systems (UASs) tasked with the same mission, recognizing that the aerial platforms themselves were at limited risk due to their distance from the ground.

Counter-IED models are not completely limited to devices emplaced in or around roadways. Vehicle-Borne IEDs (VBIEDs) and suicide bombers can also be modeled when they depart from road networks. Binstock & Minukas (2010) show how multiple sensor inputs can be combined and modeled to enhance detection of individuals wearing suicide IEDs, and MacIntosh, et al (2010) describe an experimental setup of a number of counter-IED technologies to achieve the same result.

Sequence analysis and detection can be further used to help identify how constraints influence IED emplacements. There are a number of events that must take place in the journey that an IED makes from disassociated spare parts to casualty producing explosive device, including financial transactions to buy supplies and physical efforts like digging holes. Through data mining and modeling, sequences of transactional events that can possibly predict IED events can be discovered, although the particular sequences are dependent upon the specific environment and terrain in question (Stafford, 2009).

The National Ground Intelligence Center (NGIC), the United States Army production center for intelligence information, published a two-part series on constraint-based analytic procedures for investigating the social context of insurgencies that used IEDs in complex environments (2009, 2010). The study claimed that personal behavior choices, and in this context IED events, were the result of changes in social networks that influence individual choices based on constraints on capability and intent. These constraints comprise a social terrain whereby actions become more or less tenable; in this case, a social terrain of permissiveness enables IED activity. Thus, targeting those restraints on behavior becomes a more attractive proposition for defeating IEDs than targeting individuals themselves.

In addition, NGIC has been tasked with creating a GIS-based web repository that soldiers can use to visualize IED locations on the battlefield (Hutson, 2002) although that system has not been fielded. One such system that has been released, albeit with less tactical considerations than the proposed NGIC system and more of a public data analytics bent is the Basic Ordnance Observation Management System (BOOMS), which offers GIS based visualization of IED events (Murdock, et al 2012). At present the system only aggregates IED events from Iraq.

In permissive social terrains, the IED threat can develop and evolve on its own terms. In Afghanistan it was theorized that a so-called “Iraq Effect”, where foreign fighters were transporting lessons learned from the Iraqi battle space to Afghanistan, was behind the evolution of tactics. Barker (2011), in a study of events in Southern Afghanistan and Western Pakistan, scrutinized this. Rather than citing the influence of Iraq in particular, Barker found that TTPs accelerated due to improved information sharing (as described by Chen and Kenney) and a general coalescence of ideological or strategic objectives. This was supported by observations of increased IED violence in areas with significant populations (where mass bombings would affect more people) and areas heavily trafficked by coalition forces (where IED campaigns would have higher rates of military effectiveness) during the period of study.

Some types of modeling methods, such as Bayes nets, which are graphical representations of variable relationships that provide mathematical modeling capability, can account for both the technical constraints imposed on IED use as well as the social constraints (Whitney, et al 2009). By incorporating these constraints into a threat model, a process model, and a detection layer on the process model, technical and social precursors to IED activity can be identified and potentially interdicted. Further mathematical models have been able to predict general levels of violence and conflict volatility, although not specifically IED violence (Zammit-Mangion, et al 2012).

The model proposed by Whitney, et al, focuses on the IED group and the constraints imposed upon it by its physical and social limitations. There are other models (Brueckner, et al 2010; Brown, et al 2004) that look at the intended targets of the IED or the terrain surrounding potential targets to glean some information about the impending attack, because an attack cannot take place without a target and that target must occupy some physical space. By looking at historical patterns of target movement and the future presence of persistent targets of high value it may be possible to predict where some IED events may occur.

One method of modeling, Region-Based Geospatial Abduction, has been used to identify weapon cache sites related to IED events. Geospatial Abduction identifies when a likely set of feasible explanatory locations is compatible with domain knowledge about an issue. Using the method that they pioneered, Shakarian and Subrahmanian (2011) were able to infer unobserved geographic phenomena based on the observations and constraints of known events – in this case, cache sites coupled to IED emplacements in Baghdad, Iraq. While this method does not attempt to predict or prevent IED events themselves, it does establish a legitimate linkage between IED events and the terrain in which they occur by recognizing that the precursor materials for IEDs must by necessity occupy a space related to the final IED event.

A fault tree failure model to identify IED placement variables that could be used in countering IEDs was developed by Bennett (2009) and published in a redacted version to eliminate subject matter deemed sensitive by JIDO. While most of the useful information including the data analysis and subsequent conclusions were eliminated from the publicly available document, the discussion of the applicability of GIS and fault tree models to the IED problem reinforced much of what had already been published on the matter.

Porter and Reich (2012) attempt to use temporally weighted kernel density models to predict the next event in a series of criminal or terrorist events like an IED emplacement by building on the work of Johnson and Braithwaite (2009) among others and the observation that these type of events cluster in space-time. They were able to show that past events influenced the location of future events within temporal and spatial bandwidths, and drew on the work of Brantingham and Brantingham (1993, 1995) to speculate on the reasons why – specifically that perpetrators may have limited awareness of available targets or that attractive targets may cluster in space, respectively.

Combining the multiple methods of modeling for detection purposes can potentially increase their accuracy and decrease the number of false positives generated by detection related models. Johnson & Ali (2012) published a literature review of many papers regarding IED detection models to determine that combinations of different techniques coupled with detection technologies could have positive effects on detection levels by looping systems and incorporating redundancies. An entire special edition on modeling and simulation for Counter-IED systems was due to be published by the Journal of Defense Modeling and Simulation[37], a publication representing a growth industry within the DoD, in late 2012, although just one article was ultimately released, and not until the next year – again using a Bayesian network analysis to predict emplacements (Guo, et al 2013).

RTM

RTM is a spatial technique that applies contextual information relative to risky outcomes to estimate future risks, providing statistically significant predictions about risky behavior that are more precise than retrospective hotspot mapping (Caplan, et al 2011; Drawve, 2016). RTM is enabled by GIS in that it affords visual representation of variables correlated to risky outcomes. This allows for the exploration of visual narratives that tell the story of spatial influence – that is, the influence that characteristics of a location have on the location itself (Caplan, 2011.) Just as RTM has been applied to crime (see Caplan, et al 2012; and Moreto, et al 2013) and terrorism (see Rusnak, et al 2012; Rodriguez, 2010; and Onat, 2016), it can also be applied to the IED problem as a

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[37] http://scs.org/specialissues?q=node/174

phenomenon that intersects both. This is especially useful since resource allocation strategies for risk management that are based on places can be more efficient than strategies based on individuals (Kennedy, et al 2011), or in the case of IEDs, on the precursor materials and supply chains. RTM can then guide interventions based on environmental factors or conditions that are more aligned with the realities of defeat-minded organizations (Drawve & Barnum, 2017).

Although RTM by itself is potentially a more precise predictor of risky outcomes than hotspot mapping, there is utility in a combination of those techniques along with an integration of near-repeat analysis (Caplan, et al 2012) because “tomorrow’s crime incidents are likely to continue to occur at yesterday’s high crime areas (Kennedy, et al 2016).” A joint utility model would have particular advantages in assessing IED risk because IEDs exhibit risk factors that make them suitable for RTM, and because they are also prone to near-repeats (Johnson & Braithwaite, 2012), such as with the reseeding of previously used holes described by Kolesar (2012). Furthermore, it is possible that IED events may be part of microcycles, localized bursts of violence described by Behlendorf, et al (2011).

An RTM study of IEDs is beholden to the propositions laid out in *A Theory of Risky Places* (Kennedy and Caplan, 2012). Namely, that all places are risky although some are riskier than others; crime will emerge in areas of high vulnerability based on spatial influence; and the effect of risky places on crime is a function of that vulnerability throughout a specific landscape. That landscape, described as an “environmental backcloth” by Brantingham &Brantingham (1995) and further described by Barnum, et al (2017) as a kaleidoscope in which the spatial influence of place features pattern and interact across different locations, can be conceptualized as the permissive environment alluded to by counterterrorism practitioners when describing the totality of place-based influence that affects IED emplacements. Although the Brantinghams were referring to the environmental backcloth in the context of microplace analysis, where the influence of a neighborhood, for example, could impact the way in which crime clustered, the global environmental backcloth seems to exist as well, where countries exhibit certain socio-political or cultural characteristics that can influence IED risk. The RTM Manual (Caplan & Kennedy, 2010), The RTM Compendium (Caplan & Kennedy, 2011), and Risk Terrain Modeling: Crime Prediction and Risk Reduction (Caplan & Kennedy, 2016) offer specific methods to apply these propositions to spatially oriented problem sets utilizing a ten step process. The Global Risk Terrain Modeling (GRTM) Manual (Kennedy, et al 2011) further elaborates on applying RTM to global issues like IEDs. The proper application of this process comprises a good portion of the methodology of this study.

Conjunctive Analysis of Case Configuration

There are certain analytical techniques that can further elucidate the results and conclusions derived from RTM. Once is Conjunctive Analysis of Case Configuration, or CACC. A case-oriented rather than variable-oriented approach assessing multiple causes for the same outcome (Hart and Miethe, 2009), CACC explores relationships between the spatial influence of identified risk factors and the effects that they can have on criminal activity by categorizing the behavioral settings configurations in specific geographic areas and judging which were more influential on an outcome event. In this way, social contexts can be identified that predict behavioral outcomes (Caplan, et al 2017). For IED analysis, CACC and RTM can help to identify the minimum areas required for intervention against IED emplacement, which can preserve resources and promote efficiency.

Multi-Level Analysis

Identifying IED emplacements at the micro-level means investigating the potential additive and integrative effects of variables or risk factors at the macro-level, and a long history of empirical investigation shows that crimes concentrates at different spatial scales (Rosser, eta al 2016). Multilevel analysis in criminology has been investigated since the 1980s (Sampson & Wooldredge, 1987) and was further refined decades later (Wilcox, et al (2003) to show that criminal opportunities are present in both individual and place analysis. Lim & Chun (2015) describe criminal decision-making processes in which offenders are hierarchical in their target selection, moving from large areas of potential opportunity to individual level targets when they finally commit their crimes. In the case of IED emplacements, it then makes sense that multilevel analysis could help to explain IED events. Emplacers must be active in a general area based on their affiliation, if any, select a large area of operations where potential targets cluster in space and time based on their ideology or objectives, and then choose a specific target to effect taking into account the variables that contribute to the success of their chosen mission.

In developing the concept of an aggregate neighborhood risk of crime or ANROC, Drawve, et al (2016) worked toward the integration of macro-level social correlates to crime and violence with RTM procedures due to the relative lack of descriptive social characteristics in spatial risk assessment. It makes sense to aggregate these factors at the macro-level rather than the micro-level, as social risk factor data may not neatly align with or be relevant to micro-places.

Risk Factors for IEDs

An RTM study begins with the discovery of risk factors for the behavior in question. Identifying and evaluating risk factors is imperative so that maps and models can be built, because risky behaviors manifest near places that exhibit risk factors. Because IED events share so much in common with terrorist events, many terrorism risk factors are likely to be IED risk factors as well. However, simply using terrorism risk factors would miss the risks associated with IEDs that are more similar to crime risks, and so crime risk factors should be used in addition. This potentially leaves a rather large set of risk factors that is unwieldy to work with and not particularly insightful. The risk factors should be reduced to only the most important.

Krieger and Meierrieks (2008) identified a number of determinants of terrorism all rooted in national level socio-political and socio-economic phenomena like economic deprivation, modernization strain, lack of institutional order, and others. Okafor and Piesse (2017) extended their analysis to fragile states and found that specific targets like government establishments, religious centers, diplomatic centers, tourist areas, and private property attracted terrorist activity including bombings. Similarly, Piazza (2006) identified social cleavages, or grievance points, as critical to the formation of terrorism. This does not mean that individuals who are poor or otherwise deprived will become terrorists or support terrorism – quite the contrary, in fact, according to Krueger and Maleckova (2002). It does indicate, however, that an environment that promotes these determinants will have higher likelihood of terrorist activity and by extension IED attacks.

These determinants all coalesce to create a permissive environment for terrorism at the national level and, taken together, add up to what practitioners call “ungoverned territory” (Rabasa, 2007) or more commonly “state failure” (Rotberg, 2010; Acemoglu and Robinson, 2012) or fragility. These weak or fragile states enhance the potential for political violence (Schock, 1996).

The Fragile States Index (formerly the Failed States Index) published by The Fund For Peace[38] is an interactive report comprised of feature articles and a scored map depicting what a conflict assessment tool composed of 12 different qualitative and quantitative indicators determines to be fragile states. The Index ranks all the nations of the world according to a detailed methodology[39] after the ingestion and analysis of thousands and thousands of pieces of open-source information. The result is a graphical depiction of which states provide the most permissive environments for terrorism and IED use, among other ills. Each country is scored on a scale of 120 points based on the interplay of the 12 indicators, although the scores do not indicate any strength or direction in the relationships between the features.

Fragile states, in presenting a permissive environment for terrorism, contribute to the contagion effect. The contagion effect occurs when terrorists see the effects of other terrorist events and learn from them (Crenshaw, 2007), resulting in a situation where any destabilization in one country can cause collapse in a neighboring country (De Blij &

[38] http://fundforpeace.org/fsi/
[39] http://fundforpeace.org/fsi/methodology/

Muller, 1994). These learned behaviors then spread to other areas, enabled by technology and media until security norms erode and violence becomes routine and imitable. Bombings, in particular, exhibit strong contagion effects (Midlarsky, et al 1980). While there is some evidence that fragile states within terrorism hotspots are likely to exhibit terrorism contagion, the effect overall is rare (LaFree, et al 2017).

Giménez-Santana (2012), working under the auspices of the Rutgers Center on Public Security, defined risk factors to be used in RTM for fragile states as poverty rate, Gross Domestic Product per capita, GINI index, armed conflicts in neighboring countries, infant mortality, trade openness, militarization, state led political discrimination, institutional multiplicity, bad governance, political repression, political transition processes, social exclusion, gender inequality, lack of social cohesion, weak civil society, legacy of colonialism, and global economic shocks. Most of these characteristics are rolled up into the calculations for state fragility under the FSI.

While fragile states may provide an enabling environment for terrorism and crime, and thus for IED use, they do not completely explain the problem (Newman, 2007). Other variables are required for analysis.

Like terrorist attacks, every IED attack must have an intended target. The choice of targets is not random, but rather informed by deliberate decision making by a rational actor (Crenshaw, 1981). These decisions are often driven by information presented by the target itself, such as levels of protection (Sandler and Lapan, 1988) or propensity for retaliation. For example, Chechen rebels attacking targets in Russia and Chechnya would kill more civilians in Russia than in Chechnya to avoid losing popular support for their cause (McCartan, et al 2008). Likewise, in Afghanistan, the Taliban have repeatedly decreed that civilians should come to no harm as a result of their IED campaign against the International Security Assistance Forces (ISAF)[40]. Although this decree has never been realized in practice, it shows a deliberate thought process.

Targets for IEDs are often military, governmental, or civilian so anywhere military facilities are located, government buildings reside, or civilians gather could be an IED target. For example, during the "troubles" in Northern Ireland, the Provisional Irish Republican Army developed an arsenal of IEDs that it used against government and civilian targets alike (Tench, et al 2016). In reality, these types of targets constitute much of the planet. At the national level, every country will have government and military facilities and congregating civilians. This makes targets difficult to operationalize as a risk factor at that level of regard.

Government facilities are more attractive targets for terrorists and insurgents than for criminals (who would rather not have that type of attention) as their destruction contributes to the exhaustion of the economic, political, and psychological resources required to govern (LaFree, et al 2012), but they are ubiquitous. Every country has some sort of governance structure and some physical places where elements of that structure are located, usually around a capital city. This would mean that every country and every capital city were at risk of IEDs. At some level, of course, this is true.

Instead of operationalizing a risk factor that assumes government facilities as IED targets and thus assumes all countries, it would be better to instead assume that any active

[40] http://armedgroups-internationallaw.org/2012/08/21/mullah-omar-urges-the-taliban-to-avoid-civilian-deaths-a-cause-to-celebrate/

insurgency will use IEDs and build a risk factor around their presence. Thus, countries with active insurgencies or other bad actors aligned against the state are likely at higher risk of IED events than countries without.

Terrorist groups likewise will attack government structures, and so their presence and area of operations presents spatial risk. Where terrorist groups operate, we can expect to see IEDs. Therefore, countries with active terrorist or violent extremist groups will be at higher risk than those without. The United States Department of State, partnered with the Director of National Intelligence (DNI) maintains data on who they consider to be active terrorist groups around the world and where they operate[41].

This leaves military targets, which are attractive to terrorists (Tavares, 2004), insurgents (Thorton, 1964), and criminals (Carr, 1996), especially when the military activity threatens the criminal enterprise (Mili and Townsend, 2007). Thus, countries with ongoing military operations can be said to be at higher risk than countries without. In fact, countries with military deterrence programs for counter-terrorism and counter-IED actually drive innovation in terrorist TTPs including IED design which exacerbates the issue (Faria, 2006).

For the purposes of this study, ongoing military operations comprise both actions by a national military either at home (where military structures could be at risk of transnational terrorism) or abroad (where daily operations are at risk), and sustained violence by large, militarized parties. This includes militia violence, mobilized factions

[41] https://www.dni.gov/nctc/groups.html

engaged in intra-state violence, and paramilitary groups supporting any cause through violent action.

The Uppsala Conflict Data Program[42] (UCDP) annually collects data on armed conflicts and ongoing military operations around the world and makes those data available to the public. The data include distinctions like inter-state wars, intrastate conflicts, and instances of one-sided violence within nations. Militaries, insurgencies, terrorists, and criminals all find niches in these types of conflicts, and in each of these conflict categories there is the likelihood for IED use.

Countries at war abroad may experience IEDs as part of a political resistance movement at home. Countries battling within their own borders will see IEDs emplaced by insurgents, and there is a significant overlap between terrorism of the kind typified by explosive violence and civil wars in general (Findley & Young, 2012). In areas where there is one-sided violence IEDs may be the only asymmetric recourse of the oppressed (DeGregory, 2007). More than simply a permissive environment, active warzones create concrete opportunities for IED use and thus IED risk.

There are geographic correlates of conflict. Rough terrain aggravates state weakness because it is difficult and expensive to create and maintain infrastructure to govern remote, sparsely populated, and difficult to reach areas (Fearon and Laitin, 2003). Collier and Hoeffler (2001) find that there is a statistical relationship between rough terrain and conflict onset. In studying the severity of those conflicts, however, terrain was found to have no explanatory power (Lacina, 2006). Rough terrain and sparse populations

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[42] http://www.pcr.uu.se/research/UCDP/

did not correlate to more violence in part because there were fewer targets of opportunity. In Iraq, for example, IED violence was concentrated in cities (Townsley, et al 2008) and not in less governable areas like deserts because cities were where insurgents lived, where Coalition Forces (CF) patrolled, and where attractive, high value targets full of civilians, military, and government personnel and facilities were located.

Certain other characteristics of the IED problem set may not be useful if identified as risk factors. For example, there are many different types of weapons available to terrorists, insurgents, and criminals (Smith, 1993), but overwhelmingly the weapon of choice is explosive in nature. The choice of explosive weaponry and IEDs is driven more by the goals of the group action than by the availability of the weaponry (Jackson and Frelinger, 2008; Onat & Gul, 2018).

Although ungoverned territory and failed states may produce environments where weapons and the means to make them are more readily available, if a group has the desire to use an IED it will do so regardless of whether or not certain precursor materials are easy to obtain or not. When military or commercial explosives are not available, homemade explosives will suffice. A list of items identified by the United States Department of Homeland Security (DHS) Bomb Making Materials Awareness Program highlights a number of household items like injury cold packs or hydrogen peroxide that can be transformed into explosives[43]. For this reason, a risk factor based on availability of IED precursors is unlikely to have any great effect on risk calculation.

[43] http://www.dhs.gov/bomb-making-materials-awareness-program

IED components are available everywhere and at variable levels of cost and sophistication. Globalization has ensured a limitless supply chain for precursors and components. If controlling for a specific type of device this may be a useful distinction; to create a risk map specifically for RCIEDs at the sub-national level it would be critical to know where cell phone towers were located, or which shops sold mobile phones or electronics that were near possible target sites. At the national level, however, this distinction is less relevant.

Some work has already been done to determine the most important geographical risk factors for terrorist attacks including IED attacks at the micro-level. The acronym EVIL DONE, for example, conceived by Clarke and Newman (2006) describes potential terrorist attack locations in terms of their qualities of being Exposed, Vital, Iconic, Legitimate, Destructible, Occupied, Near, and Easy. Iconic and legitimate targets have been shown to be particularly enticing for IED attackers. Tominaga (2018) identified three risk layers for terrorist activity locations related to suicide IED attacks: physical geographic factors like rough terrain, geo-demographic factors like population density and poverty, and governance factors like the response capacity of state militaries and local governments. Berrebi & Lakdawalla (2007) found that politically sensitive areas in Israel were subject to IED attacks, but not other areas without the same considerations. Onat (2016) and Onat & Gul (2018) further described risk factors for terrorism to include places rich with civilian targets, like businesses, and places driven by the ideology of attackers, like military and government facilities, although the later ideological study was limited only to locations in Turkey. An earlier Turkish study identified civil service institutions, schools, tourist sites, transportation and telecommunications service facilities, businesses and army bases as targets (Öcal & Yildirim, 2010). A descriptive study by Guo, et al (2013) identified transportation targets like planes and buses, event targets like sports fields and churches, office-related targets like government buildings and police stations, housing targets like apartment buildings and motels, and institutional targets like universities or hospitals, with the most injuries and deaths occurring during IED events at office-related target locations.

Prior to determining which risk factors for IEDs should be included in the RTM study, it is important to note that different risk factors and different operationalizations of those risk factors will operate differently at different levels of analysis. At the national level, the presence or absence of a risk factor in the country in question would be sufficient to indicate risk from that risk factor for the entire country since continuous data is not being used. This is a binary situation. At the sub-national level, the density of risk factors could more likely explain risk than the mere presence or absence of a particular risk factor. Population density, for example, could show where potential targets aggregate and allow for a focusing effect. The density of government or military facilities could present a more target rich environment as well. Areas of operation of terrorist or insurgent groups, as well as areas in which armed conflicts are actively occurring likely present areas of higher risk. These areas can be distributed throughout or across wide areas without regard to national boundaries but would likely be too broad to be considered at the micro-level.

At the micro-level, risk is more likely to be characterized by the distance to or from certain risk factors, although density can also be important. An area immediately surrounding a government facility is likely at higher risk of an IED emplacement than some other facilities without official affiliation, and places where those types of facilities cluster are likely at higher risk than other areas, although there could be mitigating effects from protection and defense schemes for high value or iconic areas which could contribute to a displacement effect as attackers choose softer targets over those that are hardened by governments (Brandt & Sandler, 2010), although there is some evidence that hardened targets may still be attractive to terrorists and other IED emplacers due to the propaganda value derived from attacks whether successful or not (Hastings & Chan, 2013). Hsu & McDowall (2017) did not find evidence that hardened targets attracted more terrorist attacks, or that attacks against hardened targets produced more casualties, although their research was focused mainly on airports. Patrol routes used by military vehicles are likely at higher risk than civilian routes, and Braithwaite and Johnson (2015) identified coalition forces areas of operations, road networks, and heavily populated areas as attractors for insurgent IED attacks in Baghdad during the Iraqi insurgency between 2003 and 2011. Potential target sites within a certain range of known residences of IED makers or emplacers would be at higher risk than areas further away because there is likely a limit to how far emplacers are willing to transport explosives within their area of operations. All of these factors should be considered when determining how to build the model, because risk factors can be operationalized differently at varying levels of analysis in order to give a more complete, more valid picture of the risk associated with IEDs.

CHAPTER 3: METHODOLOGY

The methodology used to investigate the global risk of IEDs was Global Risk Terrain Modeling (GRTM). Because the illicit use of IEDs is by nature a criminal act, because criminal acts are associated with geographical risk factors, and because that risk can be modeled, it makes sense to employ GRTM. Researchers have attempted to use forecasting and modeling methods to predict IED risk at the subnational level using hotspotting and other techniques, but those techniques exhibit certain identifiable flaws that limit their utility. GRTM attempts to account for some of those flaws to offer a more valid model for prediction. Hotspotting, for example, only considers places where risky outcomes have occurred in the past and not places where they may occur in the future, thus limiting the predictive value.

GRTM was combined with aspects of multi-level analysis. This multi-level analysis comprised the creation and testing of hypotheses at three different levels of analysis: global, subnational, and street level.

Global Level:

H_1: There is a positive relationship between the composite risk score and IED events in 2015.

H_0: There is no relationship between the composite risk score and IED events in 2015.

For this hypothesis, the dependent variables were global IED events in 2015, and the independent variable was the composite risk score consisting of five sub-variables:

Presence or absence of a terrorist group operating in a country, presence or absence of interstate violence in a country, presence or absence of non-state violence in a country, presence or absence of one-sided violence in a country, and whether or not a country scored 90 points or more in the Fragile States Index for 2015. To test this hypothesis, several statistical methods were employed including statistical correlation assessments, ordinary least squares regressions, F-tests and T-tests, and a prediction profiler model.

Subnational Level:

H_1: Densely populated areas where terrorist groups operate in the riskiest countries (as identified by the global level analysis) are at higher risk of IED events than other places.

H_0: Densely populated areas where terrorist groups operate in the riskiest countries are not at higher risk of IED events than other places.

For this hypothesis, the dependent variables were global IED events in 2015 and the independent variable was a composite risk map of densely populated areas where terrorist groups operated in the riskiest countries, as identified by the global level analysis. To test this hypothesis, the steps of RTM were followed as indicated below.

Street Level:

H_1: Microplaces in cities identified in the subnational level analysis where certain risk factors cluster are at higher risk of IED events than other places in those cities.

H_0: Microplaces in cities identified in the subnational analysis where certain risk factors cluster are not at higher risk of IED events than other places in those cities.

For this hypothesis, the dependent variables were IED events in cities identified in the subnational analysis in 2015, and the independent variables were as follows: airports, bazaars, bus stops, cafes, embassies, government facilities, guest houses, hospitals, hotels, roads, malls, markets, media facilities (including places associated with newspapers, radio, or television), military facilities, mosques and other places of worship, police facilities, police stations (distinct from other police facilities like checkpoints and armories), restaurants, schools, stadiums, temples, tourist sites, and universities. To test this hypothesis, the steps of RTM were followed as indicated below.

This study assessed the global risk of IEDs at different scales and developed and tested hypotheses for each level of analysis, specifically the national, sub-national, and street level, by creating Risk Terrain Models for IED use using the steps outlined in the Risk Terrain Modeling: Crime Prediction and Risk Reduction by Caplan & Kennedy (2016). These steps are as follows:

- STEP 1: Choose an outcome event;
- STEP 2: Choose a study area;
- STEP 3: Choose a time period;
- STEP 4: Identify best available (possible) risk factors;
- STEP 5: Obtain spatial data;
- STEP 6: Map spatial influence of factors;
- STEP 7: Select model factors;
- STEP 8: Weight model factors;
- STEP 9: Quantitatively combine model factors;

- STEP 10: Communicate meaningful information.

As described in the literature on RTM, ArcGIS was used to build aspects of the model. The Risk Terrain Modeling Diagnostics (RTMDx) Utility, an application that automates many of the steps of RTM (Caplan & Kennedy, 2013) was used to process technical and statistical procedures. Spatial data such as shapefiles for the base world map are freely available online (especially from ESRI, the maker of ArcGIS), and georeferenced data in vector or raster format were obtained for each risk factor identified for analysis or built manually. Quantitative analyses were accomplished using Microsoft Excel and JMP.

Steps

Each of the GRTM steps was considered in order:

STEP 1: Choose an outcome event

The outcome event of interest in this case is an IED event, and the set of IED events for 2015 in the geographic area under consideration was the dependent variable in each hypothesis. An IED event occurs when an IED is emplaced and then either explodes or is otherwise discovered without exploding. IEDs that are emplaced but never discovered cannot be counted as data. They are unknown unknowns. The source of data for IED events was the Global Terrorism Database (GTD) from the National Consortium for the Study of Terrorism and Responses to Terrorism (START) at the University of Maryland. The GTD data used consists of all terrorist activity from 1970 through 2016 (at the time of analysis) but is sortable so that attacks may be filtered by weapon or attack type to include only bombings and other episodes of explosive violence. Furthermore, that data can be sorted by the level of certainty that the event was part of a terrorist attack that was intended to be political in nature, intended to affect those outside of the immediate victims, or be otherwise outside of the precepts of International Humanitarian Law. That is, if there is some question about whether the event was terrorism by definition, it can be excluded. Because IED events may not necessarily be terroristic in nature, all explosive violence events were included in this study, with the exception of a select few that were not IED related.

For this study, IED event data from the Global Terrorism Database for the calendar year 2015 were considered. This accounted for a set of 6,197 events. Outcome data for the calendar year 2016 were used to test the predictive validity of the model. This accounted for a set of 6,085 events. It should be noted that there was a single event in the database for 2015 without a geographic reference. This event was discarded as an outlier.

STEP 2: Choose a study area

There were three separate levels of study for which composite risk maps were created, and the results from the top-level investigations informed the sub-level studies. The first level of study took place at the global scale and risk was assessed for each country as a national level unit. The global extent is representative of the IED threat since all countries are at some risk of IED use either directly or by virtue of the contagion effect from violence around them; terrorists and other bad actors do not make it a habit to respect national borders in under-governed areas. Furthermore, organizations tasked with defeating the IED threat operate at a global scale. Providing policy prescription to them based on this type of risk assessment would not be relevant if it were not conducted at that level.

The global base map of the countries of the world obviously covers the entire area of interest and the GTD dataset includes all countries that experience IED events, so both the base extent and the outcome data are at the appropriate levels. Risk factors are similarly conceptualized because some data are not available below national levels or are not easily operationalized as such.

The second of the three levels of study was subnational to the extent that risk factor data was available and could be operationalized. The countries that were identified as highest risk in the national level map were further analyzed in this second level map so that the study had a funneling or filtering effect. The second level map identified clusters of risk that were more intelligible than simply identifying which countries presented ordinal levels of risk. In this way, it allowed some analysis of which parts of the riskiest countries exhibited the environmental factors that were most representative of IED risk and directed investigation into the third level map.

The third level risk map – dependent again on availability and operationalization of the data – analyzed two micro-areas with street level data similar to that presented by Caplan, et al (2011) for the crime of shooting in the city of Irvington, New Jersey or other published examples of the RTM construct. These two areas were selected based on the prevalent risk clusters from the second level maps with concessions made for areas that had more presentable data. For example, cities like Baghdad, Iraq or Kabul, Afghanistan may have more readily available data due to the ongoing activity surrounding the conflicts in those areas even if they may seem to present the same risk as an underreported area like Manila, Philippines.

Presenting three separate sets of risk terrain maps showed the applicability and scalability of RTM to global phenomena like IED events, and also the ways in which relevant risk factors can be operationalized to better represent risk in the study extent. In addition, selecting three separate spatial scales illustrated the different ways in which IED attacks may operate in each of them. At the national level the presence or absence of IED risk was driven by different factors than at the city level. The presence of bad actors within national borders may indicate that a country is at risk of experiencing IED violence, but at the micro-level the house that a bomb maker lives in and its proximity to attractive targets would provide more relevant information. These extents somewhat mirror the three distinct levels of influence that IED violence has for perpetrators or groups: strategic, operational, and tactical.

STEP 3: Choose a time period

The time period of study for the risk terrain map was the year 2015. Data were available for all pertinent risk factors for that year, and data were likewise available for the outcome events. In addition, this created the opportunity to test the predictive validity of the map using outcome data from 2016, which were also available. Choosing to look at risk factors for 2015 was meaningful. IED events were occurring in many countries in 2015 and were being recorded and studied, and much more georeferenced outcome data was available than in previous years due to changes in the GTD methodology for collection and reporting.

The time period of a year likewise offered more generalizability than a shorter time frame and accounted for seasonality trends that wouldn't be captured with a time window of less than a year. This is especially important since IED events exhibit a seasonal component in their use. Afghanistan, for example, continues to exhibit definitive fighting seasons timed to the local weather patterns.

Risk factors for IED use are also well entrenched and difficult to change in short periods of time, ensuring that those factors are likely to persist into the prediction period. The relative permanence of terrain features if a considerable strength of RTM.

Since national level indicators are good predictors of risk in the long term (Barton, et al 2008), the use of 2015 factors should provide a good test of predictive validity for future years as long as geographic conditions do not appreciably change. This is important to consider in areas where conflict rapidly changes the terrain. Military installations may come and go, and seats of government may relocate as well. Since these are risk factors for IED use, they must be accounted for.

There are some considerations that must be made for the temporality of the studies at different levels of analysis. At the national level, the presence or absence of risk factors is likely slow to change, and thus the validity of the model should hold over greater periods of time. The social cleavages that lead to the types of conflict that invite explosive violence are often long gestating and resistant to quick reaction. Wars may start and stop quickly, but the preconditions for them are often prevalent far in advance of mobilization. While national level conditions may change rapidly from time to time, such as in the swell of instability surrounding the Arab Spring, these are generally exceptions.

At the sub-national level, too, there is some resistance to radical change in the area of consideration and the location of risk factors. Government and military facilities are likely resistant to relocation unless forced to do so, but the uncertainty of governance in areas embroiled in conflict makes this more likely than in less fragile states. Population densities are not fixed, but migration of target dense areas require some impetus that is likely the result of macro-level external forces. The exception, of course, would be emergency relocation or refugee fleeing in the event of active conflict, which is especially important given the nature of IED violence as an act associated with war and conflict itself. In fact, these forced migrations or relocations may exacerbate the social cleavages that aggravate conflict, leading to a vicious cycle. This is especially evident in Syria, where large scale migrations to escape violence have rapidly altered demographics. Thus, sub-national risk factors are more transitive than national level risk factors even if they do not change every single day.

At the city level, risk factors are likely quicker to change, and can in fact change day to day or hour to hour depending on how they are operationalized. While the physical locations of certain landmarks that may attract IED emplacements such as national, state, or local government facilities may not change, some types of military installations or check points may be hastily established or disestablished. Likewise, markets or bazaars that attract large crowds may have limited engagements whether at regular intervals or not. Furthermore, the groups that use IEDs likely move quickly throughout their areas of operations as a tactical consideration, so as not to make themselves easy targets for reactive forces. Bomb maker hideouts or residences can change quickly, as can the routes that military or police patrols use.

STEP 4: Identify best available (possible) risk factors

This step, perhaps the most important step in RTM outside of building and presenting the actual risk map, consisted of compiling and then analyzing a set of variables that were most significantly correlated to the IED threat. This was accomplished by means of the literature review already conducted, since empirical research had already identified a number of correlates of terrorism, insurgency, and crime. All of these have been shown to be related to the IED threat in different ways, and each set of risk factors at each level of analysis formed the set of independent variables considered for each tested hypothesis.

In the case of IEDs, the most important correlates seem to be based on presence of so-called “bad actors”, availability of targets, and permissive environments for violence, or what could be simply conceptualized as good guys, bad guys, and a place for them to come together. This conceptualization was present in the literature. In Clarke’s discussion of situational crime prevention (1983) it was described as a condition in which a criminally disposed individual, a vulnerable target, and an appropriate opportunity to offend come together. Even though all of these variables have been shown to be related to the IED threat directly or by proxy, not all were instructive in creating the final map (although none were discarded until data manipulation had occurred because risk factors can be operationalized in different ways so that factors that do not appear to be related to outcomes initially may in fact be when reconceptualized.) For microlevel analysis with appropriate outcome events, this all takes place within RTMDx and is transparent to the normal utility user.

Unlike the presence of IED targets which were prevalent (but not equally distributed) everywhere, not every country had groups that used IEDs. That placed the countries that did at greater risk. While there was still some risk of lone wolf style attacks, that risk was not as great as the risk of IED use by groups that have both the capability and intent to use IEDs, and who have used them in the past. The groups that were most likely to use IEDs are terrorist groups, active insurgencies, and drug trafficking organizations and other large-scale criminal enterprises. Countries that have these groups operating within their borders are at higher risk than those that do not.

Permissive environments create safe havens for terrorists, opportunities for insurgencies to form and grow, and ungoverned territories for criminals and drug traffickers to operate without repercussions. They create situations that are ripe for violent conflict, which is increasingly characterized by IED use. Fahey & LaFree (2015) showed that states that experienced instability, states with higher population density, and states with higher levels of urbanization were at greater risk of terrorist (including explosive violence) attacks, although there was some variation across the sample. Low socioeconomic development also attracted terrorism (Coccia, 2017).

Permissive environments are created when states fail or are in danger of failing (characterized as fragility), and when the scourge of war visits upon them. Thus, fragile states and those that are living through conflict are more likely to experience IED events than states with strong governance that are free of conflict. Conflict can be characterized as classical interstate war, civil war or intrastate conflict, or one-sided violence perpetrated by a government against its people. Each of these unique situations provides a different scenario in which IEDs can be used. They can be legitimate weapons of war, tools of insurgencies, and asymmetric weapons of the oppressed. Each scenario carries with it some risk.

STEP 5: Obtain spatial data

Since this risk terrain map will be used to predict future risky places, a recent base map of the countries of the world was used to ensure that the map is as representative of the world it will portray as possible. Since data for 2015 were used, a map of the world as it appeared in that year was appropriate. Countries that did not exist were excluded from study, like South Sudan, as were countries with no data.

A polygon shapefile base map of the countries of the world in political relief was available free online from NaturalEarthData.com[44], which offers vector and raster maps for GIS practitioners. A 1:10m cultural vector map depicting 197 countries was selected for completeness and ease of use. Other maps were available from a number of different sources including the United States National Geospatial-Intelligence Agency and ESRI, the maker of the ArcGIS software. National level basemaps should all be similar and any projection issues they exhibit were corrected for within ArcGIS using endogenous tools.

For subsequent study levels, political basemaps showing subnational divisions were used. Again, the NaturalEarthData.com map was useful, as well as the World Street Map[45] from ESRI, which included street level data that was required for the micro-level map.

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[44] http://www.naturalearthdata.com/downloads/10m-cultural-vectors/

[45] http://www.esri.com/software/arcgis/arcgis-online-map-and-geoservices/map-services

For each level of the study under consideration (national, sub-national, and micro) the factors that were included were thematically similar, although the ways in which they were conceptualized and operationalized was adjusted.

For the national level model, a spreadsheet was created and imported into ArcGIS that linked the presence or absence of the selected risk factors to the country in question. These risk factors were added together to create the composite risk map. The ad-hoc method of risk factor selection was used for the sub-national level based on the lessons learned from the literature review, and the same method was used for the street level analysis although those factors were screened by RTMDx for model creation based on their significance.

Military facilities, government facilities, and civilian populations have been identified as targets of terrorism, and a risk terrain map at the sub-national level would benefit from risk layers identifying their placement. However, at the national level and at the global extent, these targets are homogenous. Each country has government facilities, military presence (with very minor exceptions), and population centers. This would create a risk layer where each country was assigned the same amount of risk which would not be instructive. Ranking by relative numbers of these facilities would not necessarily be instructive, either, if no ordinal relationship was demonstrated.

Likewise, there are proximity factors that are characteristics of terrorist activity that cannot be used in a risk terrain map at the national level. Terrorist events usually take place nearby where they were planned and where the weapons used were acquired or built. Without georeferenced maps of terrorist hideouts or IED manufacturing facilities, however, this information is not relevant. While those maps may exist in classified military reporting, they certainly are not available to the public if they do. Some concessions can be made to “back-out” possible locations that may be useful, but the practice may be difficult, time consuming, and inefficient.

Roads and major intersections are correlated to IED use (Mohler, et al 2018), and again, at the subnational level this would be useful information to have. However, at the national level roads are not relevant. All countries have roads of some sort, and they exist along a continuum from dirt paths to superhighways. At the subnational level each type of road would likely have its own associated risk factors. Here, it all looks the same.

Rough terrain has been correlated to the onset of violence, but it has a negative correlation to the sustainment of violent activity since there are relatively fewer targets for violence in the sparsely populated areas characterized by rough terrain. Where there are no targets, there cannot be IED events, and so rough terrain may not be an appropriate risk factor for this model.

The risk factors that were relevant, however, are those here. These are the presence of bad actors, presence of targets, and permissive environments where they come together. Each risk factor has sub-factors beneath it, and each represents a separate amount of risk.

Bad actors are terrorist groups. Permissive environments are fragile states, states at war with other states, states involved in civil wars, and states waging war against their own people. Targets are any areas or populations that could be susceptible to IED emplacements, where the most densely populated areas present the most targets. These risk factors were selected on an ad-hoc basis based on the impressions from the literature review, but they can also be tested for empirical validity against the outcome data. This created a final list of risk factors that are thematically associated with the outcome event as referenced in the literature, but that also have some statistically significant relationship. Again, RTMDx provided this feature.

STEP 6: Map spatial influence of factors

For each level of study, the operationalization and mapping of the risk factors varied. In brief, at the national level risk factors were either be present or not present. This allowed dummy variables to be used and created a system that does not need to be weighted or adjusted. Each risk factor was either represented as a “1” when the factor is present in the country or a “0” when it is not.

The risk values were directly attributed to the country polygons and there was no need for distance or density calculations. Risk factors were valued on a binary scale where “1” represented high risk and “0” indicated not-high risk. This standardized the risk values across all of the risk factors.

Each factor was operationalized so that only the highest risk countries were represented as high risk and received a score of “1” for each factor. For the presence of bad actors, if a country had a terrorist group operating within its borders it received a score of “1”. All others received a “0”. For permissive environments, only countries in the top quintile in the Fragile States Index were counted as being the highest risk. They received a “1” and all others received a “0”. States in conflict received a score of “1” if the particular type of conflict was present in the country and a “0” if it was not. This accounted for interstate wars, intrastate wars, and one-sided violence.

At the sub-national level, density of risk factors was more important for determining relative places where IED risk resided. As such, density maps for risk factors were used at the sub-national level. With cell sizes of 100km by 100km, each cell will be representative of a very large city and visually indicated where IED risk clusters.

It should be noted that the selection of 100km by 100km grid squares is not entirely arbitrary. 100km by 100km is roughly the size of the city of Paris, which offers some level of quick visual comparison, and is also the reference size for the Military Grid Reference System (MGRS) which is used for military location reporting and thus is included in many militarily sourced incident reports about IED events. The quick calculation of Risk Terrain Models is somewhat limited by computing power, and grids of 100km by 100km represent a sweet spot between efficient use of processing time and fidelity of data. As such, grids of this size have been used in previous studies and are operationally relevant.

Even though consideration has been levied against the choice of grids of that particular size, the choice still suffers from the modifiable areal unit problem, in which bias can be introduced when spatial boundaries are districted according to some chosen (perhaps arbitrary) criteria (Openshaw, 1984). Here, because data are being visualized over areas that are not aggregated into districts but rather are being grouped according to a grid that is roughly the size of a large city, the model should show risk at the sub-national area focused on city-sized locations that allow for further investigation, such as a city-level analysis even if they are not representative of actual city boundaries. Because the intention of the sub-national level model was to identify areas for further analysis, the modifiable areal unit problem is mitigated against, although it can never be solved.

At the micro-level, density functions could also be calculated, but distance functions were more illustrative of the places where risk existed and could be worked with in the finer granularity that street-level data affords. For example, government facilities were considered to be risky places for IED emplacements, and it made sense to operationalize the areas of highest risk that corresponded to government buildings as about 50 meters in distance from the building itself, which roughly corresponds to the safe stand-off distance for outdoor evacuation from an IED weighing 50 pounds[46]. For common distance-based operationalizations of RTM risk factors at the micro-level that are keyed to half-block increments, this was appropriate.

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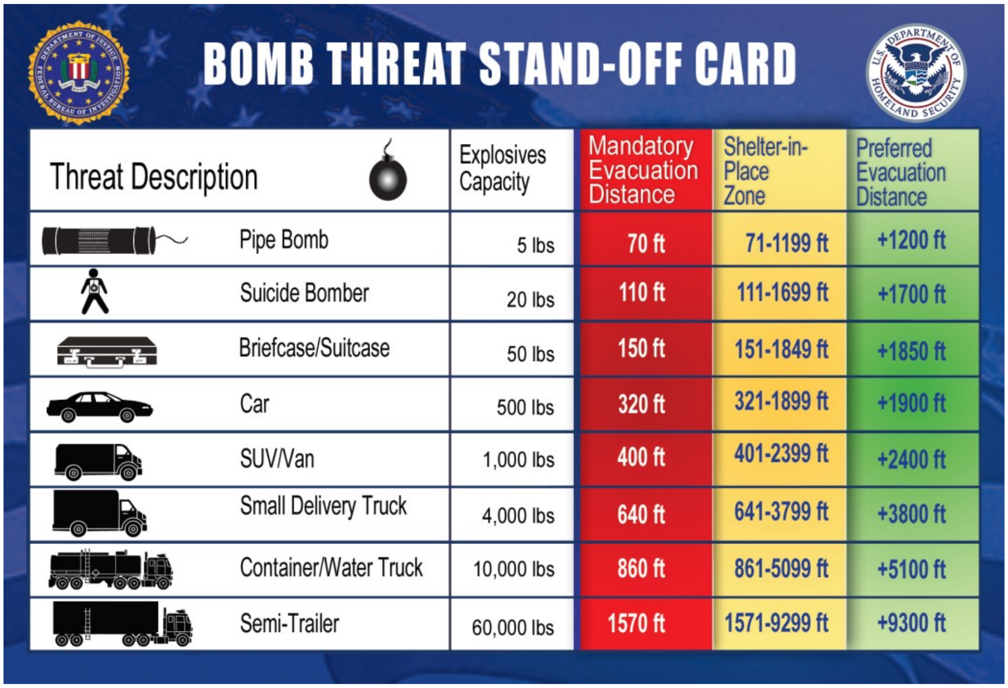
[46] https://www.dni.gov/files/NCTC/documents/features_documents/2006_calendar_bomb_stand_chart.pdf



BOMB THREAT STAND-OFF CARD

Threat Description	Explosives Capacity	Mandatory Evacuation Distance	Shelter-in-Place Zone	Preferred Evacuation Distance
Pipe Bomb	5 lbs	70 ft	71-1199 ft	+1200 ft
Suicide Bomber	20 lbs	110 ft	111-1699 ft	+1700 ft
Briefcase/Suitcase	50 lbs	150 ft	151-1849 ft	+1850 ft
Car	500 lbs	320 ft	321-1899 ft	+1900 ft
SUV/Van	1,000 lbs	400 ft	401-2399 ft	+2400 ft
Small Delivery Truck	4,000 lbs	640 ft	641-3799 ft	+3800 ft
Container/Water Truck	10,000 lbs	860 ft	861-5099 ft	+5100 ft
Semi-Trailer	60,000 lbs	1570 ft	1571-9299 ft	+9300 ft

Figure 3: Bomb Threat Stand-off Card (source: National Counterterrorism Center)

Similarly, some risk factors that may not seem to be applicable at one layer may be applicable at another, depending on how they are operationalized. For example, rough terrain at the national level may be indicative of ungovernable territory or a permissive environment and so it could be included as a risk factor in the national level risk map. At the subnational level, however, rough terrain may not directly correlate to outcome data because IED targets may not be present in great numbers in rough terrain in the same way that they may be in clustered in cities. However, certain distances from rough terrain may correspond to increases in IED emplacements because the devices may be constructed in ungovernable terrain and then transported to nearby populated areas for employment, as long as that transit distance is not untenable for the perpetrator.

STEP 7: Select model factors

At the global extent, the model factors that were selected were those deemed to be most relevant to strategic level of analysis. These were factors related to macro level influences on national level politics, like the presence or absence of bad actors, whether or not wars were occurring, and how fragile the country in question was deemed to be. In total there were five relevant risk factors.

At the subnational level, the riskiest countries as determined by the global level analysis were used as a risk factor unto themselves. This satisfied the criteria for permissive environments as dictated by the literature. The risk factor for targets was represented by a map of global population density, and the risk factor for attackers was represented by a map of terrorist operational areas. There were three relevant risk factors for this level of analysis.

For the street level analysis, risk factors were pulled from Google Earth Pro queries and compiled into maps in ArcGIS based on their georeferences. These risk factors were again drawn from the empirical literature, and represented attractors like schools, markets, cafes, government or military facilities, and other place-based features that could attract IEDs. At this level, the most relevant risk factors were chosen by RTMDx.

STEP 8: Weight model factors

At the national level, risk map layers were not be differentially weighted because there was no data on the relative influence of any one factor over another. They were simply being represented by the presence or absence of each factor. Each risk factor carried the same weight as a function of the operationalization. Risk factors that were present were considered high risk and represented by a value of “1”. All other areas were not considered to be high risk and were represented by a value of “0”.

Weighting did not occur at the sub-national level due to unavailability of relevant data. At the micro-level, weighting was accomplished by statistical procedures in RTMDx.

STEPS 9: Quantitatively combine model factors

Risk values associated with risk factors were added to the ArcGIS attribute table and added using the field calculator function to arrive at final composite risk values for maps at the national and sub-national level. This technique is demonstrated in the GRTM manual and was fairly straightforward since there were no weighting issues to account for. Countries with missing data were excluded from the final map at this point. RTMDx built appropriate composite maps for the micro-level analysis.

STEP 10: Communicate meaningful information

The final risk values arrived at in Step 9 were symbolized using graduated colors corresponding to the number of risk factors selected for the map. Highest risk areas were colored in red, with orange and yellow shades represented less high-risk areas and green shades representing areas that were not high risk. The map conformed to the appropriate standards for communicating information with maps and rightly included scales, legends, titles, North arrows, and all of the associated content of quality maps. At the subnational level, a large map showing the areas of highest risk was created based on the same procedure listed above, and a zoomed in inset map was also created to show finer detail since the riskiest places all clustered in the same general region. Risk maps for the street level analysis conducted in RTMDs were automatically built by the tool, but street level risk maps for an alternative analysis without outcome data (which could not be calculated in RTMDx as a result) were built by hand in the same manner and conforming to the same standards as the previous two maps.

Testing the validity of the map at the global level (which is optional under RTM but was included in this study since outcome data were available), was accomplished using regression analysis. Tools were available in the ESRI suite of products, and Microsoft Excel performed ordinary least squares regression as well. The Prediction Profiler, a tool in the JMP statistical analysis suite offered as a part of SAS, can also build predictive models based on input data. A specific set of instructions for performing one type of test for predictive validity is available at the Rutgers RTM website[47] but there are many types of tests that can be applied based on the type and distribution of the data in the map. If spatial autocorrelation exists, the ESRI suite of software has tools that can both identify it and calculate the necessary spatial lag correlates to account for it. At the street level, RTMDx offers assessments of predictive validity for micro-level analysis, with the general caveat that availability and quality of risk factor data are critical for prediction accuracy (Kocher and Leitner, 2015). The Predictive Accuracy Index (PAI) for RTM analyses can also be calculated based on the formula described by Chainey, et al (2008), which is depicted below. Using this technique, the hit rate for outcome events is determined by taking the number of events occurring within the predicted area over the total number of events, and the area percentage is determined by taking the predicted area

[47] http://www.rutgerscps.org/docs/StepsOf_TestingValidity_AndWeighting.pdf

over the total area of the study extent. The higher the PAI, the more predictive the analysis. RTMDx now has the ability to calculate PAI.

$$\frac{\left(\frac{n}{N}\right)*100}{\left(\frac{a}{A}\right)*100} = \frac{HitRate}{AreaPercentage} = \text{Prediction Accuracy Index}$$

Figure 4: PAI Formula

Strengths and Weaknesses of the Study

Although there have been some GRTM investigations of terrorism, this study was the first RTM study undertaken concerning IEDs specifically. There have been multiple RTM studies conducted both for practical (Caplan, et al 2011) and training purposes[48]. There have also been multiple attempts to model IED events from many different disciplines using many different techniques as discussed in the literature review. There has never been an attempt to combine the two. Furthermore, while there have been multi-level and conjunctive analysis studies conducted with RTM inputs, there has never been one conducted at this scale that attempted to infer relationships between the levels of analysis for a single outcome event of interest.

The selection of RTM as a process for studying IEDs presented several different strengths. First, RTM is a proven technique that has been used to assess risk for similar

[48] See the sample cases in the RTM manual and GRTM manual for examples.

topics of interest. It was pioneered as a criminological technique that has applications past crime modeling, and the unique position of the IED threat at the junction of terrorism, insurgency, and crime made RTM an appropriate choice for this study.

Second, RTM is a technique that accounts for some of the shortcomings of modeling techniques that only assess one dimension of a problem. The IED threat has multiple dimensions, and the opportunity to adjust the model to fit several different risk factors presented opportunities for a more illuminating model. For example, IED models that only assessed past IED events and created hotspot maps may miss the threat of future events in places that have not yet experienced IED violence. RTM can account for this, and one of the premier strengths of the technique is the ability to predict with statistical validity future events in places where outcomes have not yet occurred. Assigning risk to countries that have not yet experienced IED events, but are likely to in the future, was one of the biggest strengths of this study.

Finally, this study provided predictions about national level risks that will prove useful for policy planning and for direction of resources, and which may provide leading indicators for IED violence. For example, if a country begins to exhibit some national level risk factors for IED emplacements, there may be a period of time before that actual violence occurs in identified risky areas which could allow for target strengthening or other place-based security approaches. Other studies of the topic may provide data useful for academic curiosity, but this one can have practical applications immediately.

This study suffered, however, from data limitations. A map that assigns risk at the national level has practical applications for large scale planning and policy, but not for small scale intervention or policing. Telling, for example, the government of the country of Nigeria that it is at high risk of experiencing IEDs may be of value to an aid group planning an intervention or a military planning to mobilize, but may be less useful to a policeman trying to plan his route for the day. Once those aid groups or militaries are on the ground, they will no longer be able to benefit from the conclusions reached here at that level of analysis. Substantial subnational level data would enable a study that would be more useful at a local level, but those data do not exist in usable forms or are restricted. The inclusion of subnational and city level maps in this study attempted to show how the RTM technique could be applied given more reliable data for risk factors. Without vetted, reliable, replicable data, however, the final result suffered slightly.

The data about IED events are likewise flawed. IED data are difficult to capture on a global scale because of the non-standard criteria for reporting and the limits to data discovery when information is not centrally located, although the GTD has attempted to alleviate this in recent iterations. Even the Wikileaks data culled from classified reporting by individuals actually involved in IED blasts suffered from a lack of standardization, duplicate entries, and missing information. With the drawing down of combat operations in Iraq and in Afghanistan, the reporting standards (where they existed at all) for IED events have been lost. Even the International Security Assistance Forces (ISAF) in Afghanistan have conceded that their data on enemy initiated attacks, including IEDs, are inherently flawed and will become increasingly more so due to the change in reporting responsibility from ISAF to indigenous Afghan units[49].

[49] http://www.wired.com/dangerroom/2013/03/afghanistan-data/

Furthermore, most databases containing information about IEDs are primarily interested in the study of terrorism and may miss IED events that do not fit that definition. There is no universally trusted clearinghouse for all IED event data with detailed reporting standards and any study attempting to use data on IEDs will suffer as a result.

CHAPTER 4: RESULTS

This study considered three levels of analysis: global, subnational, and street level analysis using various applications of the RTM framework and methodology. The primary temporal frame for the analysis was the year 2015, with outcome data from 2016 used to test predictive validity.

Outcome Events

The outcome event at issue was the IED event, where each IED event was defined as a discrete, intentional act of violence (or the threat of imminent violence via an emplaced IED) using an improvised explosive weapon. IED events were collected from the Global Terrorism Database for the years from 2010 to 2016, inclusive, by filtering the database to those years and further filtering the data set to include explosive weapons in the field "weapon subtype" by selecting only those weapons categorized as "Bombs/Dynamite/Explosives". Outlier events that did not meet the NATO definition for an IED were discarded, although there were very few and they were often military grade munitions in the form of hand grenades or landmines used in the traditional manner. Each of these IED events was geocoded and placed as a point on the world map.

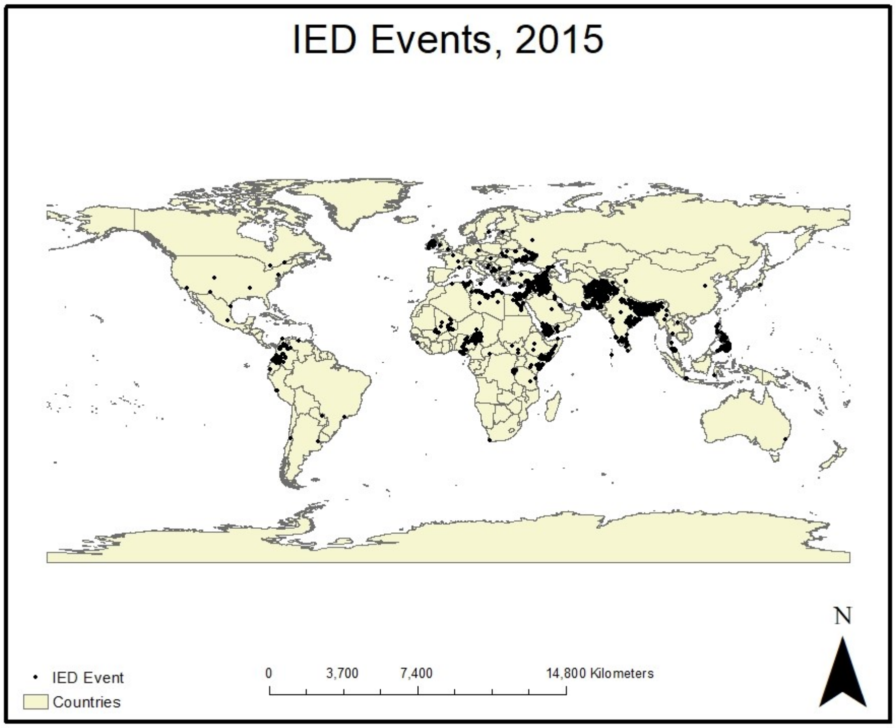


Figure 5: IED Events, 2015

Although the GTD data were comprehensive for the collection methodology used, there were some limitations. Legitimate warfare activities and activities of sovereign states in conflict were excluded because the database only collects data on events that it considers to be terroristic in nature. As such, less-attributable Russian activities in Crimea and Eastern Ukraine, for example, were excluded, as were Syrian barrel bomb incidents. This naturally limits the total amount of IED events for consideration, but the database accounts for doubt in reporting by including a field for events that may be doubtful in fulfilling its strict definition of terrorism. These events were included in the analysis, as IED events can sometimes take place outside of the strict definition of terrorism, such as with criminal enrichment acts or simple vandalism not aimed at any political objective. Simply stated, if an IED event was included in the GTD, it was included in the analysis.

In 2015, the year of analysis for this study, there were 6197 IED events, with a national mean of 35 IED events and a very large standard deviation of about 173 events indicating significant variation across countries included in the study.

IED 2015	
Mean	34.815
Standard Error	12.983
Median	0.000
Mode	0.000
Standard Deviation	173.209
Sample Variance	30001.225
Kurtosis	103.053
Skewness	9.388
Range	2037.000
Minimum	0.000
Maximum	2037.000
Sum	6197.000
Count	178.000
Confidence Level(95.0%)	25.620

Table 1: Descriptive Statistics for IED Events in 2015

At the global, or strategic level, IEDs tended to cluster in highest risk countries identified by compositing global risk factors. Of the 6197 IED events in 2015 counted by the GTD, 3872 were in countries with a risk score of 5, or highest risk. This accounted for 63% of IEDs in just 5% of the countries assessed. By including countries with risk scores or 5, 4, and 3, the proportion of IED events captured jumps to 90% in just 15% of the world’s countries. Shifts in the amount of assessed risk are directly related to shifts in the amount of IEDs a country experiences.

Boundary Data

The boundary data for the global analysis comprised the total set of sovereign states on the NaturalEarth world map, a vector shapefile attributed to NaturalEarth.com representing a 1:10m cultural map of admin level 0 countries. There were 247 countries represented on the map, and each was coded with attribute variables enabling further analysis, although just 178 countries were considered in the analysis due to the availability of risk factors for them.

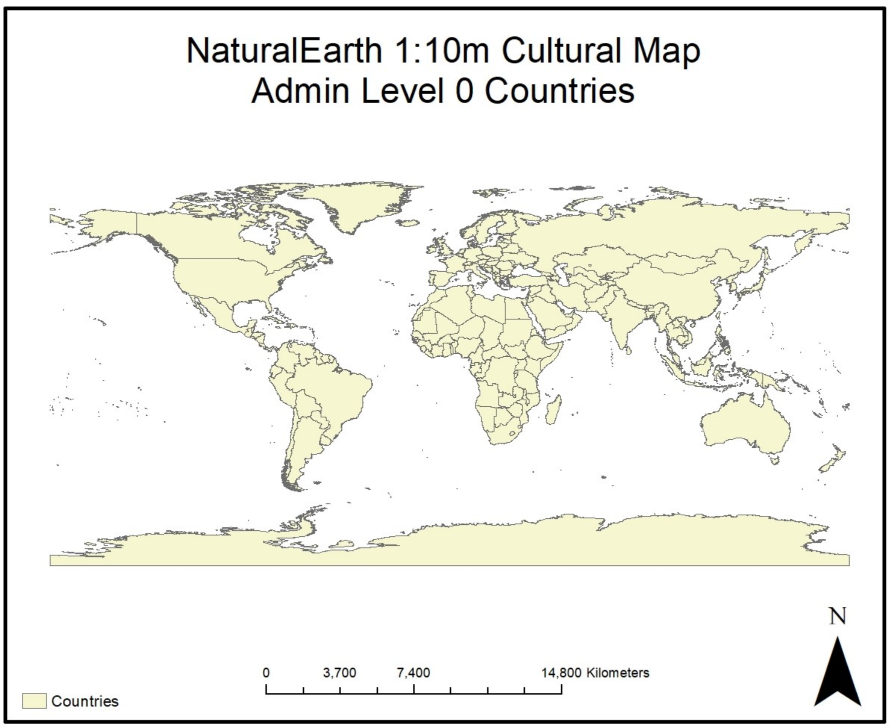


Figure 6: Global Base Map

The NaturalEarth map was created by volunteers, is in the public domain, and requires no attribution or citation. As such, there are some limited issues with authoritativeness. Disputed borders, for example, are attributed according to de facto status where the controlling party on the ground is given credit for the territory. This could limit the accuracy of the analysis when IED events occur near disputed borders, such as in the Kashmir region between India and Pakistan.

The same world map was used for the subnational level analysis, but with dissolved internal boundaries since the analysis at that level did not consider sovereign borders.

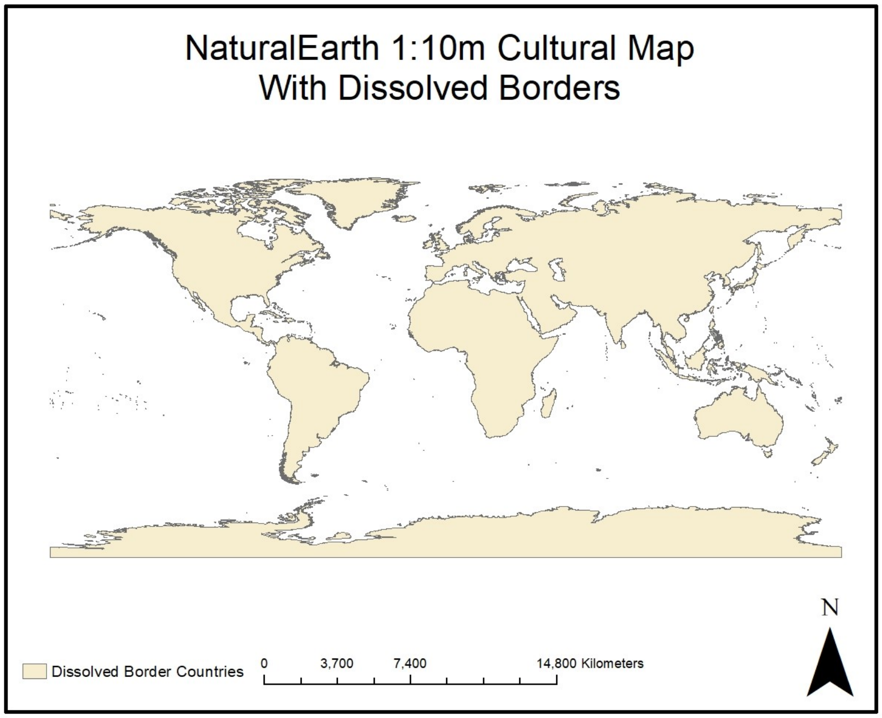


Figure 7: Global Base Map without Internal Boundaries

At the street level, two separate boundary layers were considered. The first was a city boundary map of Kabul, Afghanistan. This boundary was again extracted from a

NaturalEarth vector map, this time from a subdivided dataset of populated places.

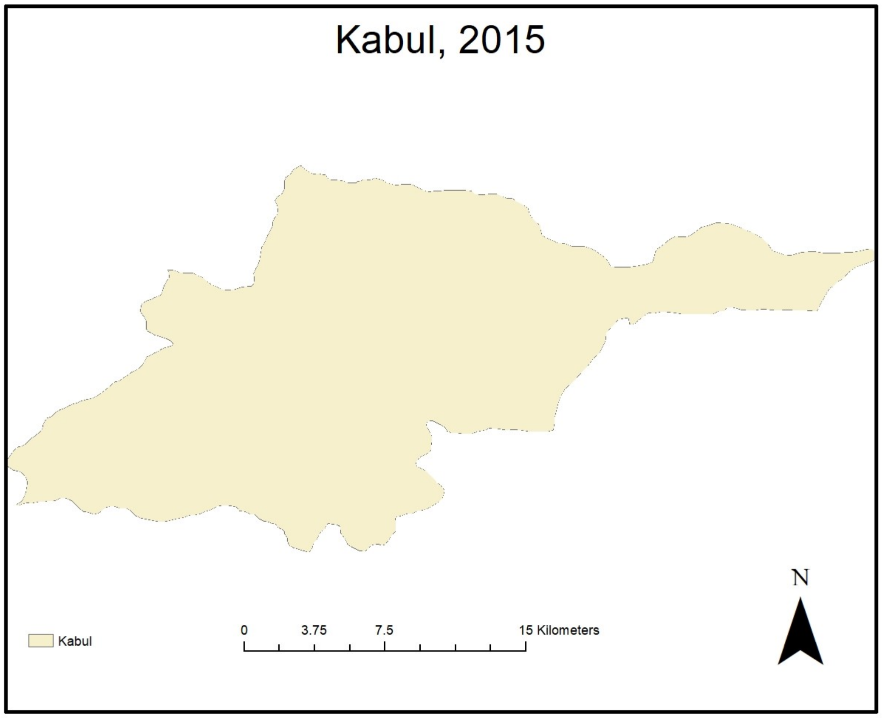


Figure 8: Kabul Base Map

The second was for the city of Casablanca, Morocco, also drawn from the same NaturalEarth vector map in the same manner.

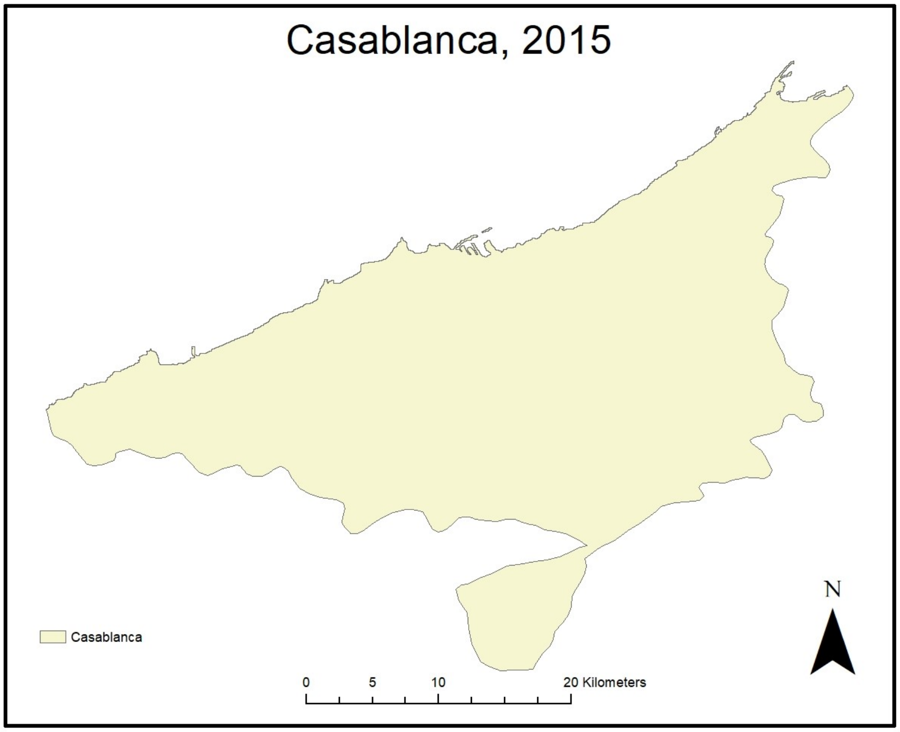


Figure 9: Casablanca Base Map

Kabul and Casablanca were chosen as paired cities due to their similar size, population, and population density. Kabul was assessed to have a population of about 3.41 million people ("Afghanistan", 2013) in an area of about 275 square kilometers, whereas Casablanca was assessed to have a population of about 3.36 million people ("Morocco: Grand Casablanca – Settat", 2014) in an area of about 230 square kilometers. This city pair represented two cities of similar size and population with similar risk factors in terms of crime attractors, but with drastically different composite risk scores to illustrate the difference between the effects of areas of high risk and areas of not high risk at the global level on the creation of street level risk maps.

Risk Factors

Risk factors varied in conception and operationalization across the three levels of analysis. At the global level, risk factors were collected and operationalized as binary constructs indicating the presence or absence of a particular risk factor in a particular country. At the subnational level, risk factors were collected and operationalized as continuous raster and vector polygon data across the entire globe and represented as raster layers on a world map. At the street level, traditional crime attractors were gathered from Google Earth in dimensions assessed to be most related to IED events according to the literature review.

Global Risk Factors

There were five global risk factors assessed to create the highest risk of IED events, the compositing of which would create a scale of risk from 0 to 5 where 5 represented countries assessed to be at highest risk of IED events and 0 represented countries assessed to be not at highest risk of IED events.

The first risk factor was the presence or absence of a terrorist organization operating within the boundaries of a sovereign state as judged by the annual U.S. Department of State Country Reports on Terrorism. The annual Country Report on Terrorism is a congressionally mandated publication required by Title 22 of the United States Code, Section 2656f, whereby the Department of State must report on terrorist activities around the globe by 30 April each calendar year regarding terrorist events that occurred in the previous calendar year. Chapter 6 of each annual report is titled “Foreign Terrorist Organizations” and is a listing of named foreign organizations engaging in specific terrorist activity that threatens the national security of the United States as defined by certain U.S. laws. Each entry for each named group contains a section on location or area of operation that list the country or countries in which the group operates, which makes for simple coding of the binary variable. Countries that had an active, named terrorist group operating within their borders as designated by the annual report were coded as “1” and all others were coded as “0”. There were 39 countries in 2015 that had terrorist organizations operating within their boundaries.

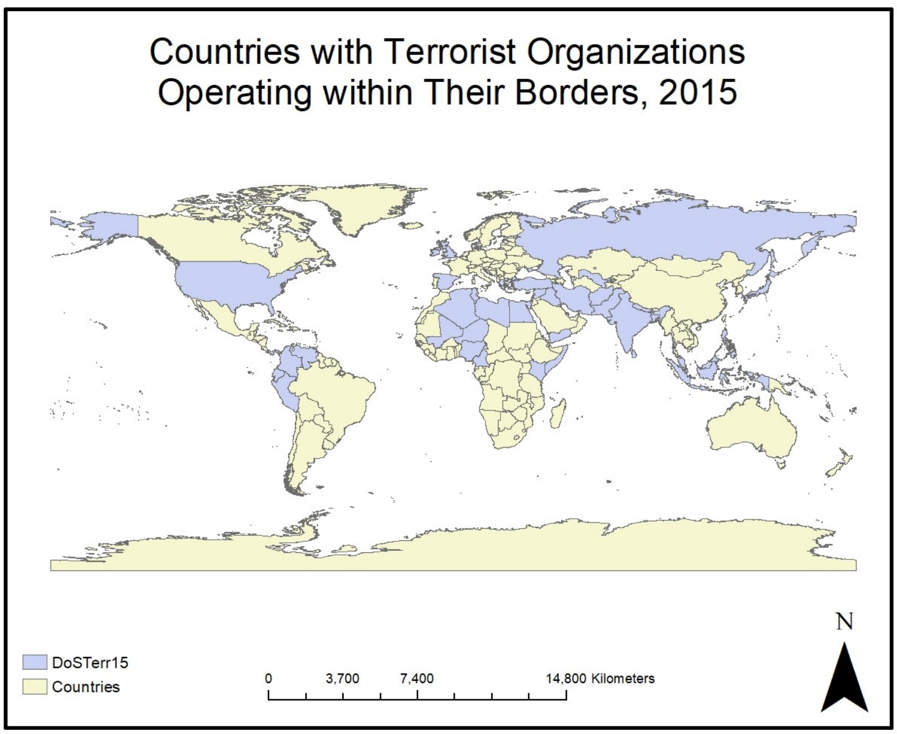


Figure 10: Countries with Terrorist Organizations Operating Within Their Borders, 2015

There are some limitations to the use of this variable. First, the definition of a Foreign Terrorist Organization is somewhat limiting. Groups that do not directly threaten U.S. interests are excluded which leaves some domestically focused groups that may use IEDs out of the analysis. Domestic U.S. groups not controlled by a foreign entity are also excluded from the analysis. There may also be significant lag in the identification and naming of groups because the decision to name a group is inherently political; naming denies members of these groups access to the U.S. financial system and as such is a deliberative process that must be considered by legal entities and legislative bodies. This can introduce significant lag such that active groups perpetrating IED violence may not be officially named in successive calendar years even though they are active.

The second, third, and fourth risk factors are measures of violence drawn from the Uppsala Conflict Data Program, a free collection of more than 40 years' worth of data collection on organized violence around the world compiled by Uppsala University in Sweden. All data for the three risk factors were drawn from the UCDP Georeferenced Event Dataset, which describes individual acts of violence across a number of different conceptual groupings. For this study, the three operationalized risk factors were interstate war, where an armed conflict with at least one state actor and at least 25 deaths took place within the borders of a state during the calendar year (n=31) ; non-state conflict, where an armed conflict with at least 25 deaths took place within the borders of a state during a calendar year where none of the parties was a state actor (n=15); and one-sided violence, where violence against civilians resulting in at least 25 deaths and perpetrated by a government or other formally organized armed group took place within the borders of a state during a calendar year (n=31). For each risk factor, satisfaction of the criteria resulted in a risk score of "1" and all others were coded as "0".

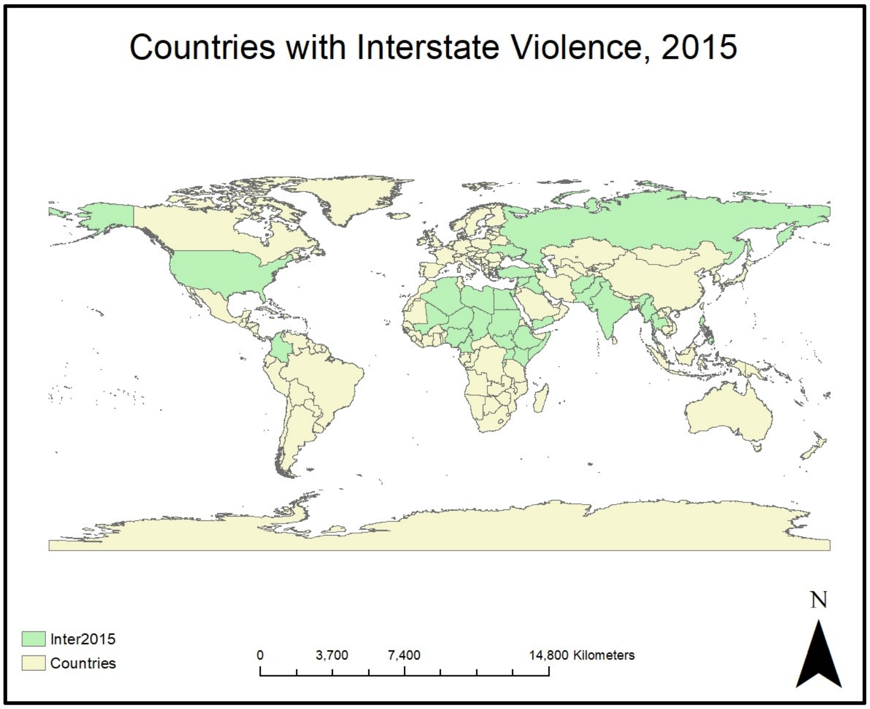


Figure 11: Countries with Interstate Violence, 2015

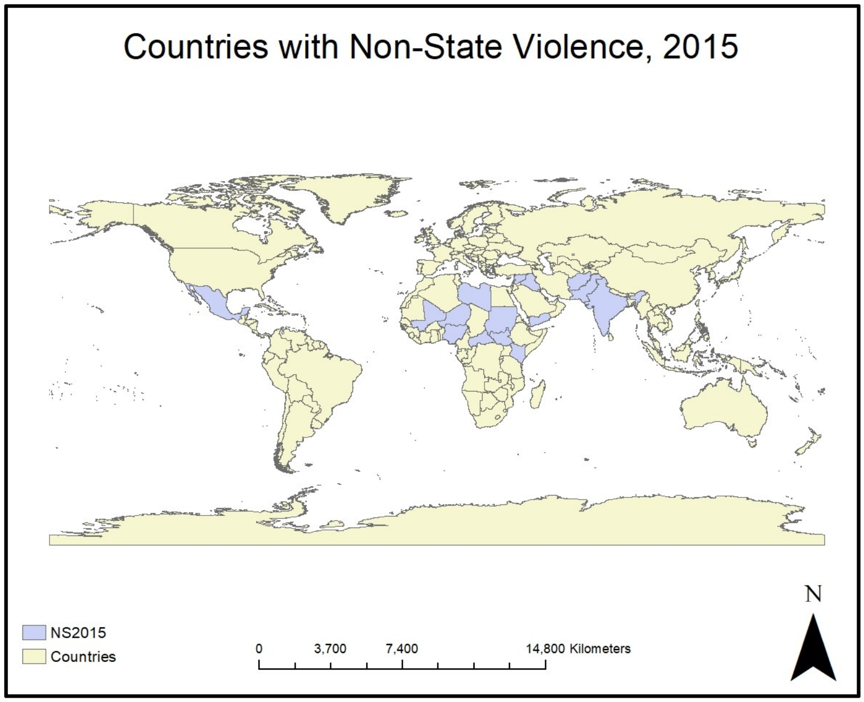


Figure 12: Countries with Non-State Violence, 2015

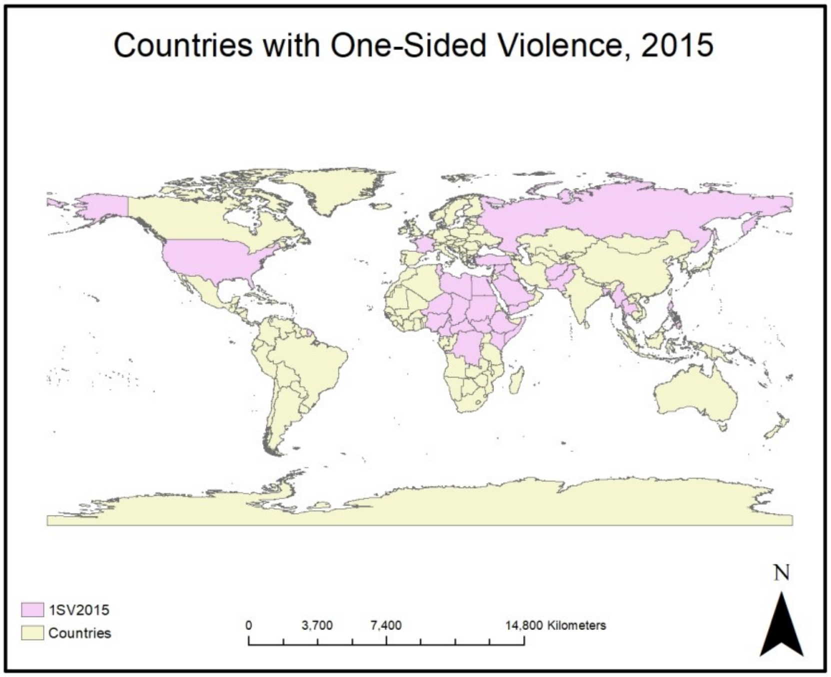


Figure 13: Countries with One-Sided Violence, 2015

As with the Department of State reporting, there are some limitations to these data and their operationalization for this study. The cutoff limit of 25 battle deaths to define armed conflict is arbitrary; similar collection attempts have used higher or lower numbers. Similarly, the geographic operationalization is tenuous. When two states are involved in interstate conflict, only the state where the conflict is physically taking place is given credit for the violent acts. This potentially creates situations where a dyad, or pair of opposing conflict actors, are not fairly assessed for risk. Again the United States is probably unfairly represented in this assessment: during the period of study, the United States was involved in at least two conflicts that could be considered interstate wars, but because the conflict action took place in Iraq and Afghanistan and not in the United

States, the threshold is not triggered and the risk is not counted. This creates a situation where political violence in the United States using IEDs as a protest against involvement in foreign wars – which counted in the outcome dataset from the GTD – is not properly credited with in the risk score.

The final global risk factor concerns the states at highest risk of fragility according to the Fragile States Index compiled by The Fund for Peace. The FSI is a composite measurement of twelve variables meant to coalesce into an easily digestible score representing a state's ability to manage internal and external pressures. The twelve variables, called "Indicators" each represent a component of competent governance that a state must manage. States that cannot manage these indicators are assessed to be vulnerable or fragile. Fragility, in this operationalization, becomes a proxy for a permissive environment. States that are more fragile are considered to be permissive environments, which puts them at higher risk of IED violence.

Each state is assessed on a scale of 1 to 10 for each of the twelve indicators where 10 is the highest or worst score for each indicator. The twelve scores are combined to create a composite score ranging from 0 to 120 where 120 is the most fragile state. The FSI assessed 178 countries in 2015. For this study, the top quartile of possible scores (representing the top quintile of actual scores), or those states scoring 90 or above in composite value, were assessed to be at highest risk and were coded as "1". All others were coded as "0". There were 38 countries that scored 90 or above.

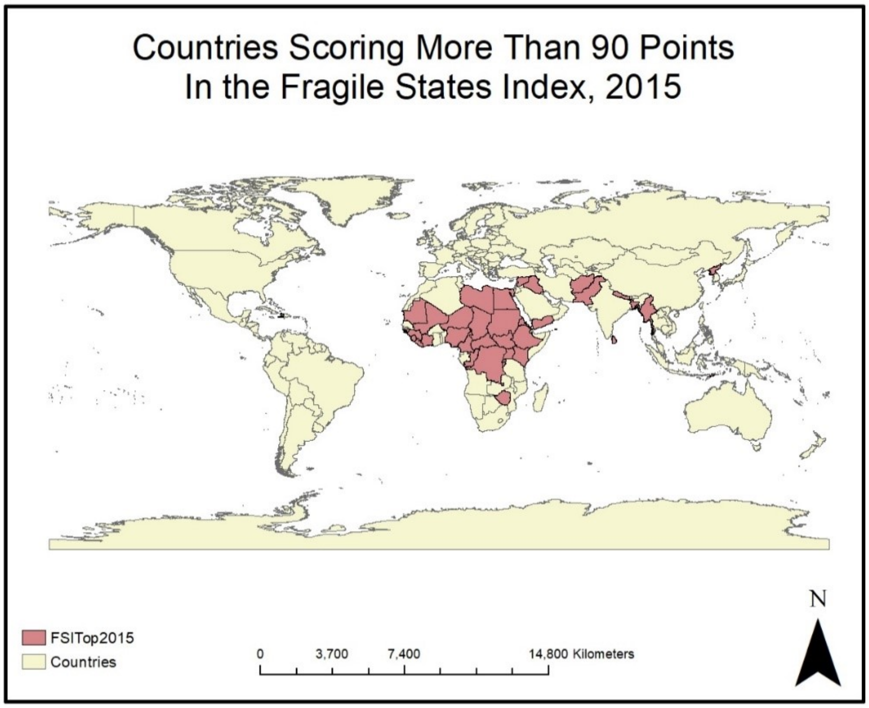


Figure 14: Countries Scoring More Than 90 Points in the Fragile States Index, 2015

When each of these binary risk values were combined, they created a composite risk score on a scale of 0 to 5 for each of the 178 countries assessed by the FSI where 5 represented countries at highest risk of IED events and all other scores represented countries not at highest risk of IED events.

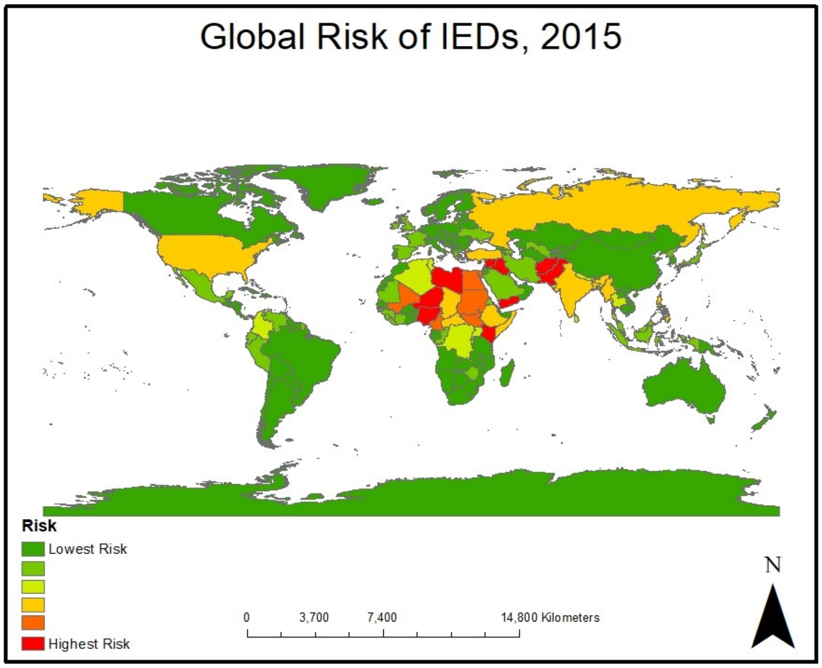


Figure 15: The Global Risk of IEDs, 2015

The countries that scored 5 in composite risk (n=9) became a risk layer for subnational analysis, creating a link between the two levels of assessment and performing a filtering function to allow analysis of only the highest risk countries.

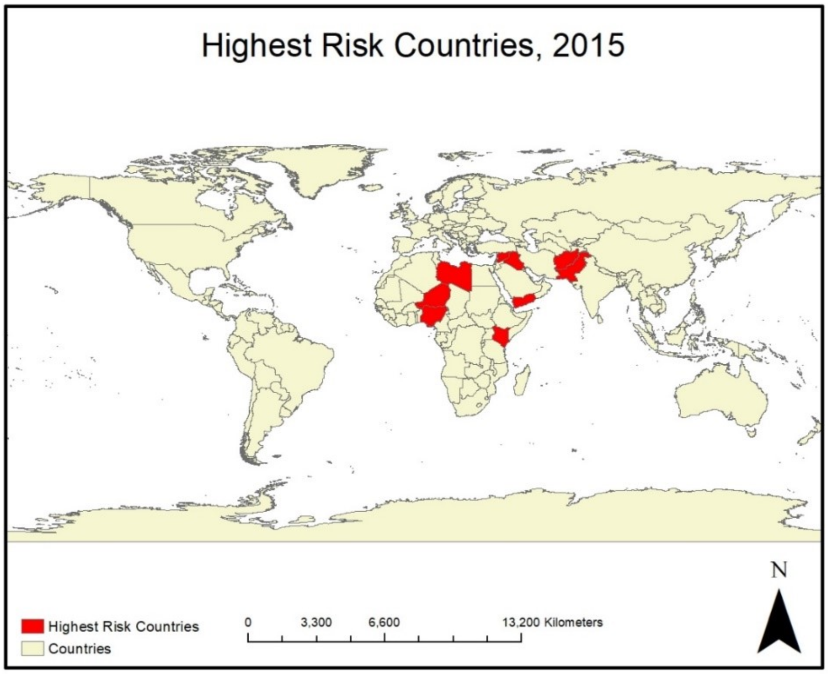


Figure 16: Highest Risk Countries, 2015

It is quite simple to see that all of the highest risk countries are located in and around the Middle East and North Africa, an area characterized by state fragility, shortcomings of governance, violent instability, and vulnerability to social stresses.

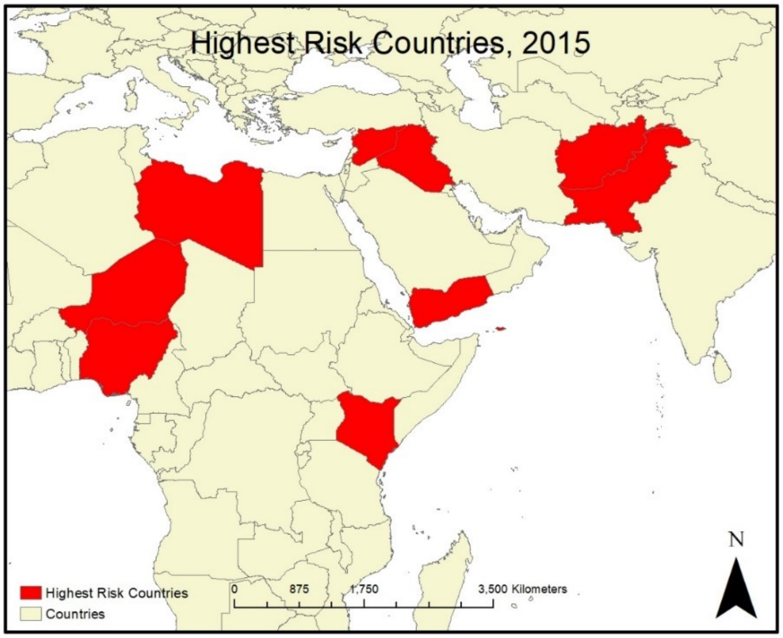


Figure 17: Highest Risk Countries (Detail), 2015

Individually, none of the assessed risk factors was strongly correlated with IED events, but taken together in a composite risk assessment, the correlation gets stronger.

Risk Factor	Correlation
FSI2015	0.2
FSITop	0.3
DoSTerr	0.3
Inter	0.4
NS	0.4
1SV	0.4
Risk	0.5

Table 2: Correlation of Risk Factors to Outcome Events

Although initially suspected to be a good proxy for permissive environments, a significant contributor to IED events according to the literature review, the Fragile States Index did not in fact act as a strongly correlated risk factor. Even limiting the analysis to just the top scoring countries in the FSI only produced a weak positive correlation marginally higher than the FSI alone. Countries with terrorist organizations operating within their borders were more strongly correlated, and the individual violence measures from the UCDP were even more strongly correlated than that, but it was only by compositing all of the risk factors into a final risk score that the measure was moderately positively correlated with IED events. It was this strength that signaled the significance required to include the composite risk score as a factor in the subnational analysis, and an ordinary least squares regression showed statistical significance ($p<0.01$).

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.582							
R Square	0.339							
Adjusted R Square	0.335							
Standard Error	69.516							
Observations	177.000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1.000	433149.756	433149.756	89.634	0.000			
Residual	175.000	845672.493	4832.414					
Total	176.000	1278822.249						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-6.387	6.105	-1.046	0.297	-18.436	5.662	-18.436	5.662
IED2015	35.507	3.750	9.468	0.000	28.105	42.909	28.105	42.909

Table 3: Ordinary Least Square Regression for Risk Score and IED Events, 2015

An F Test to compare variances across samples was completed to verify that sample variances were different, which they were.

F-Test Two-Sample for Variances		
	IED 2015	*Risk*
Mean	34.81461	0.865169
Variance	30001.23	2.038215
Observations	178	178
df	177	177
F	14719.36	
P(F<=f) one-tail	0	
F Critical one-tail	1.281377	

Table 4: F-Test Two Sample for Variances for Risk Score and IED Events, 2015

This F Test was then used as the basis for a two-sample t-Test for samples with unequal variances. In this case both tests for one and two-tailed tests were significant ($p<0.01$)

t-Test: Two-Sample Assuming Unequal Variances		
	IED 2015	*Risk*
Mean	34.81460674	0.865168539
Variance	30001.22532	2.038214943
Observations	178	178
Hypothesized Mean Difference	0	
df	177	
t Stat	2.614919627	
P(T<=t) one-tail	0.004847305	
t Critical one-tail	1.653508002	
P(T<=t) two-tail	0.00969461	
t Critical two-tail	1.973457202	

Table 5: t-Test: Two-Sample Assuming Unequal Variances for Risk Score and IED Events, 2015

A generalized Poisson regression model formed using the Prediction Profiler tool in JMP[50] delivered a prediction interval where countries with assessed risk scores of 5 could expect to experience between 303 and 840 IED events in any given year of assessment, with a point estimate of 503 IED events. The risk score variable created the simplest, most elegant model, where that variable was highly confounded with the other risk factors and the outcome events. Other factors offered less explanatory strength, and while the noisiness of the data prevented very strong models from being built, the general trends were immediately evident from the visualization.

[50] https://www.jmp.com/support/help/14-2/profiler.shtml

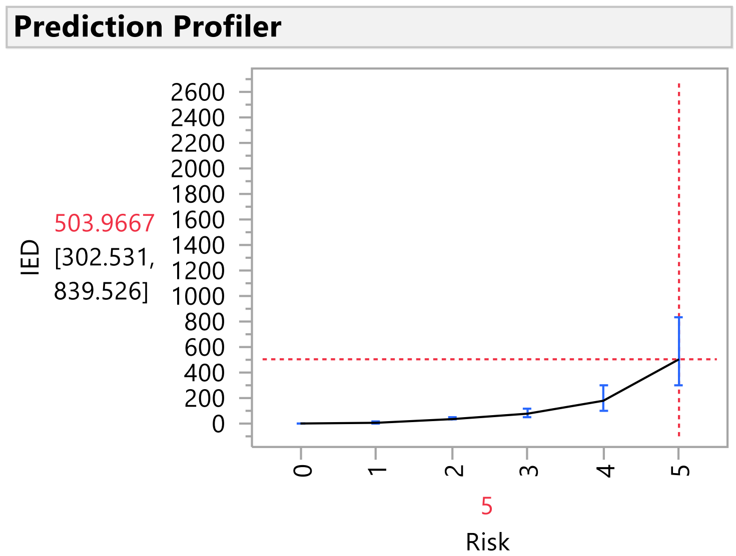


Table 6: JMP Prediction Profiler for Risk Score, 2015

An ordinary least squares regression run against IED event outcome data from 2016 indicates predictive validity for this technique, meaning that the composite risk scores calculated for 2015 can predict with statistical significance the countries that will have the most IED events in 2016 ($p<0.01$). Interpretation of the R square value indicates that roughly 34% of the variation in IED events can be attributed to the risk score, which is in line with average values for studies of this type (Weisburd & Piquero, 2008).

SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.582				
R Square	0.339				
Adjusted R Square	0.335				
Standard Error	59.069				
Observations	177.000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.000	313377.654	313377.654	89.816	0.000
Residual	175.000	610592.481	3489.100		
Total	176.000	923970.136			

Table 7: Ordinary Least Squares Regression for 2015 Risk Score and 2016 IED Events to Determine Predictive Validity

Based on these multiple analyses and visual inference from the composite risk map compared with the location of outcome events, the null hypothesis that there is no relationship between the composite risk score and IED events in 2015 can be rejected. The higher the risk score for a country, the more likely it is to experience IED events.

Subnational Risk Factors

There were two additional subnational risk factors assessed to be related to IED violence based on the literature review, with the general concept that IED events would cluster in permissive environments that allowed IED targets and IED emplacers to come together in physical space. These risk factors were densely populated areas and areas of operation for terrorist groups, which were added to the previously established risk factor of highest risk countries from the global analysis.

Densely populated areas were drawn from the Gridded Population of the World (GPW) version 4 study of population density (version 4.11, specifically) compiled by the National Aeronautic and Space Administration (NASA) Socioeconomic Data and Applications Center (SEDAC), a NASA data center hosted at Columbia University. The GPW data set used for 2015 consisted of estimates of population density – operationalized as the number of human persons per square kilometer – based on census data and population registers. The counts were then built into a 30 arc-second grid cell raster map symbolized with a color gradient where darker colors represented more densely populated areas. This raster map was overlaid onto the Natural Earth vector basemap and then reclassified to show only areas with population densities of 190 persons per square kilometer or more, representing the densely populated areas of the planet where potential targets may cluster. These areas were designated as the highest risk areas and reclassified with an attribute score of 1 while all other areas were reclassified with an attribute score of 0 representing not highest risk.

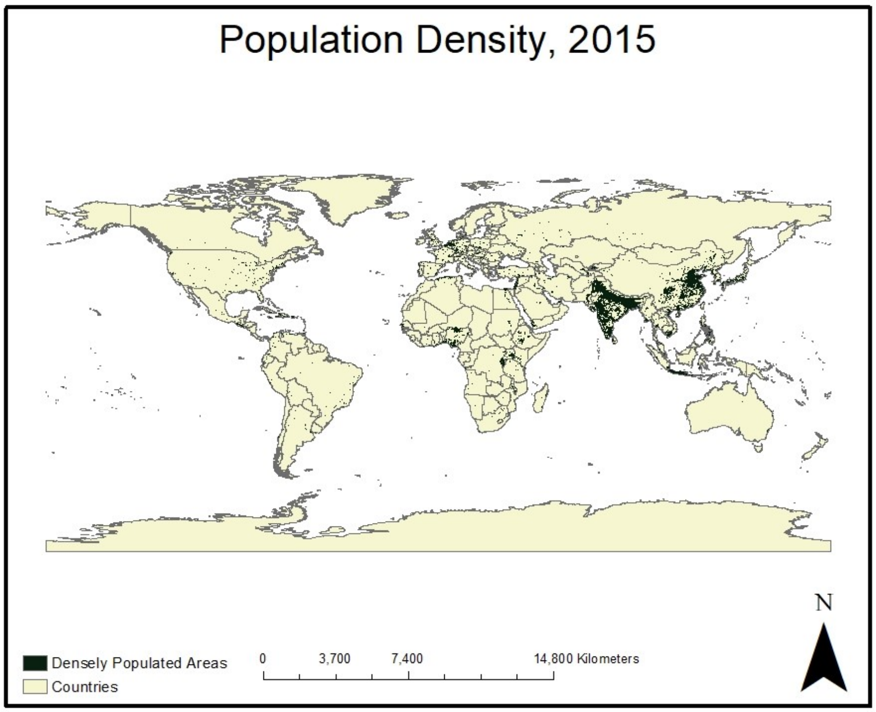


Figure 18: Population Density, 2015

Areas of operation for terrorist groups were derived from official Director of National Intelligence (DNI) assessment maps located at the public-facing DNI website[51]. These maps were drawn from assessments of operational areas derived from Foreign

[51] https://www.dni.gov/nctc/groups.html

Terrorist Organization designations by the U.S. Department of State in conjunction with U.S. Intelligence Community assets under the direction of the DNI.

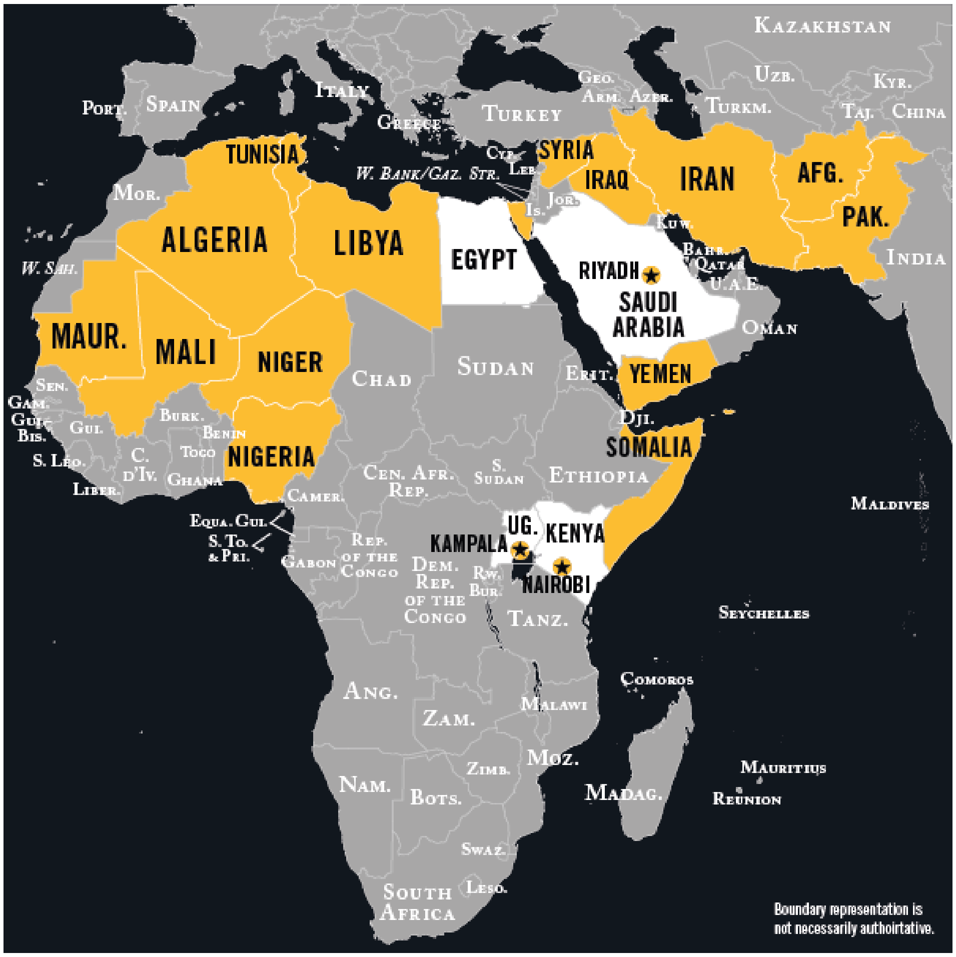


Figure 19: Example of Terrorist Operational Area Map for Al-Qa'ida (source: National Counterterrorism Center)

The maps purport to show contiguous areas of operation for designated terrorist organizations across the world (as above, with Al Qaida), but are limited due to the nature of the information used to draft them. For example, operational areas for many organizations are classified as the total territory of a sovereign state if the DNI assesses that the organization may operate in any area of that state. Other areas for different groups are drawn as polygons with various levels of fidelity (as below, with the Lord's Resistance Army).

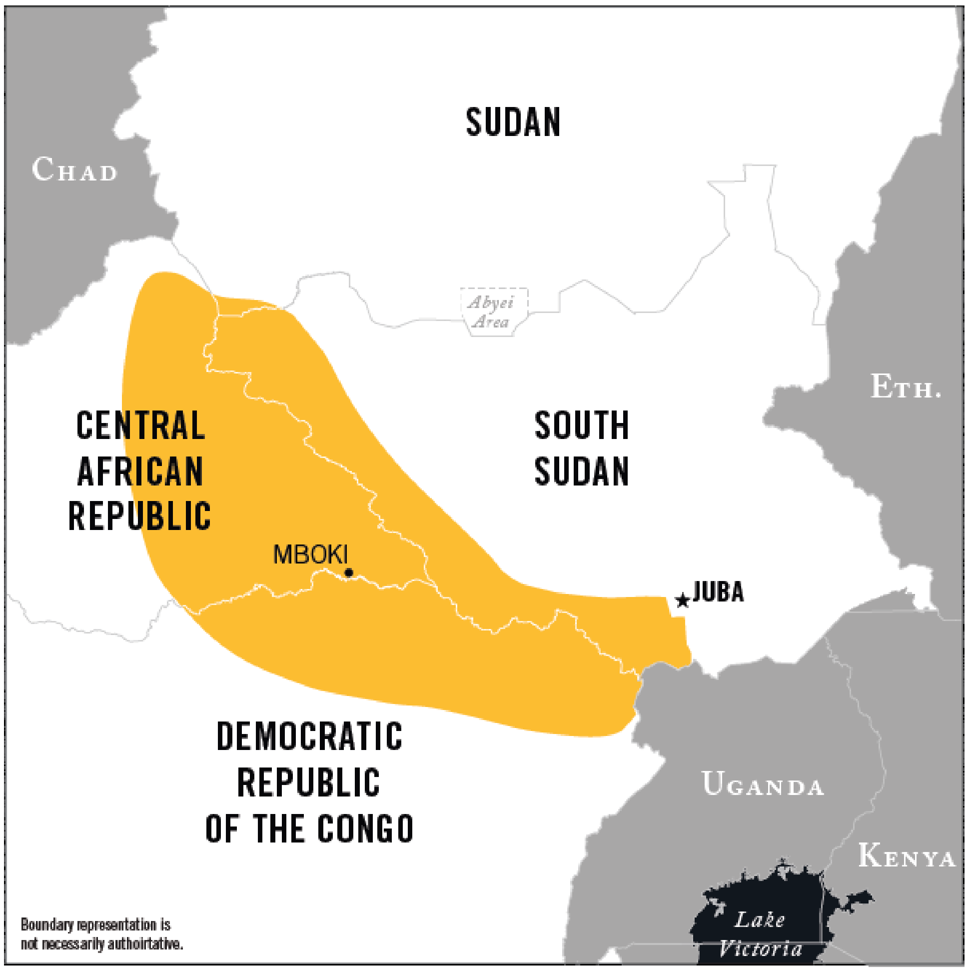


Figure 20: Example of Terrorist Operational Area Map for Lord's Resistance Army (source: National Counterterrorism Center)

The maps do not represent all designated terrorist organizations; there are no maps for any organizations operating in North or South America, for example, and there are no specific timelines associated with the operations of the groups depicted on the maps, although the groups represented were active in 2015. As such, some groups like the ELN in Colombia, which were particularly active in IED emplacements during the study period, were not represented. Some other groups may also have been more or less active in the ascribed areas over the duration of the study. Nevertheless, there are few usable, official designations of terrorist operational areas that exist outside of the DNI maps, which were transposed using a combination of district level polygon selection from the Natural Earth district level vector maps and freehand drawing in ArcMap. These areas were designated as the highest risk areas and reclassified with an attribute score of 1 while all other areas were reclassified with an attribute score of 0 representing not highest risk.

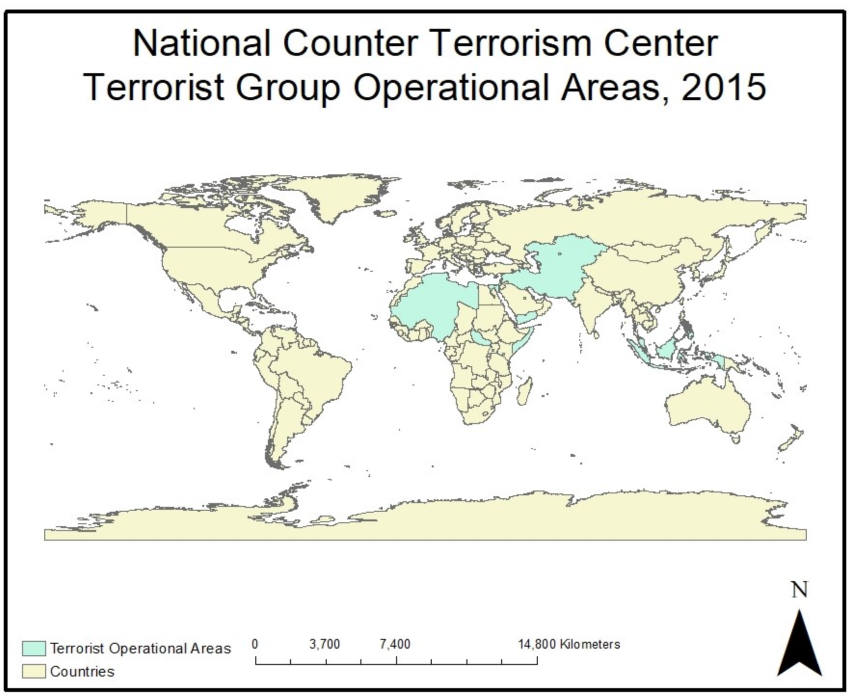


Figure 21: Terrorist Group Operational Areas, 2015

Once again, it is plain to see the concentration of risky actors in an around the Middle East and North Africa, although there is a significant terrorist presence in south Asia as well.

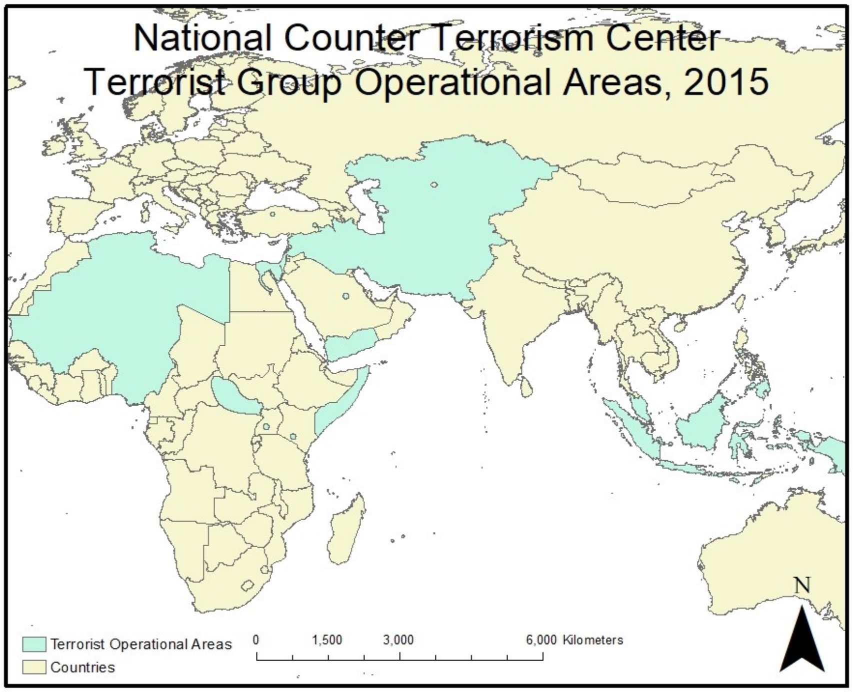


Figure 22: Terrorist Group Operational Areas (Detail), 2015

Once all subnational risk factors were appropriately operationalized and classified, they were composited into a risk map representing areas of highest risk for IED events with cell sizes of 150km, which was consistent with previous studies from the literature review. This risk map was a composite of all of the binary layers for the identified subnational risk factors and the previously calculated layer identifying highest risk countries. When composited together, the resulting risk map identified areas on a scale from 1-3 where 3 represented highest risk areas where dense populations lived within terrorist operational areas, all within previously identified high risk countries. These subnational areas of highest risk then became the selection areas for street level studies, and it was plain to see that many large cities with known IED problems were captured by the subnational analysis.

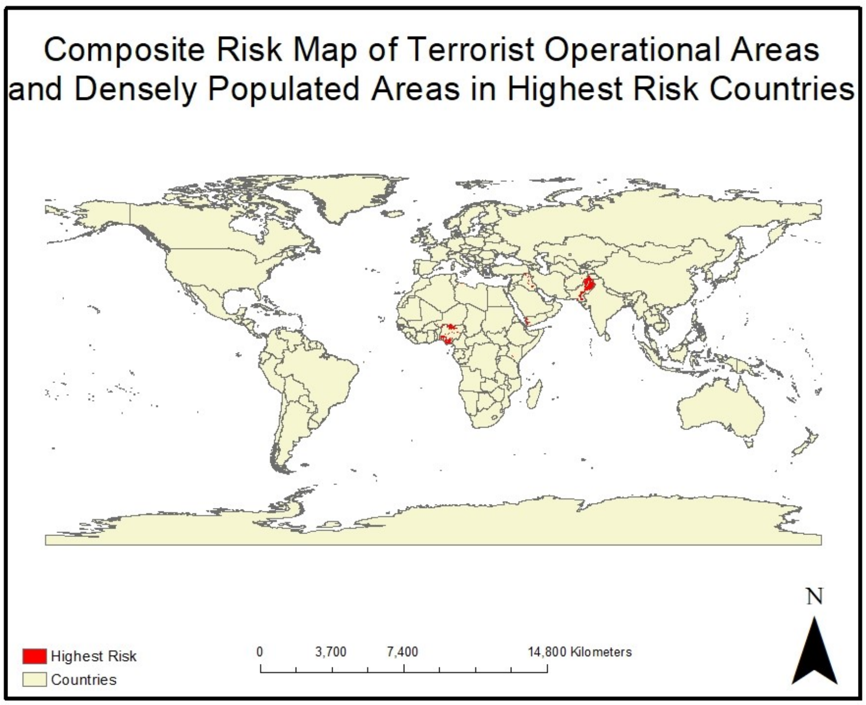


Figure 23: Composite Risk Map of Terrorist Operational Areas and Densely Populated Areas in Highest Risk Countries, 2015

Here there is significant clustering in the area between Afghanistan and Pakistan, as well as in Iraq, Nigeria and Yemen. There is also a small cluster near Tripoli.

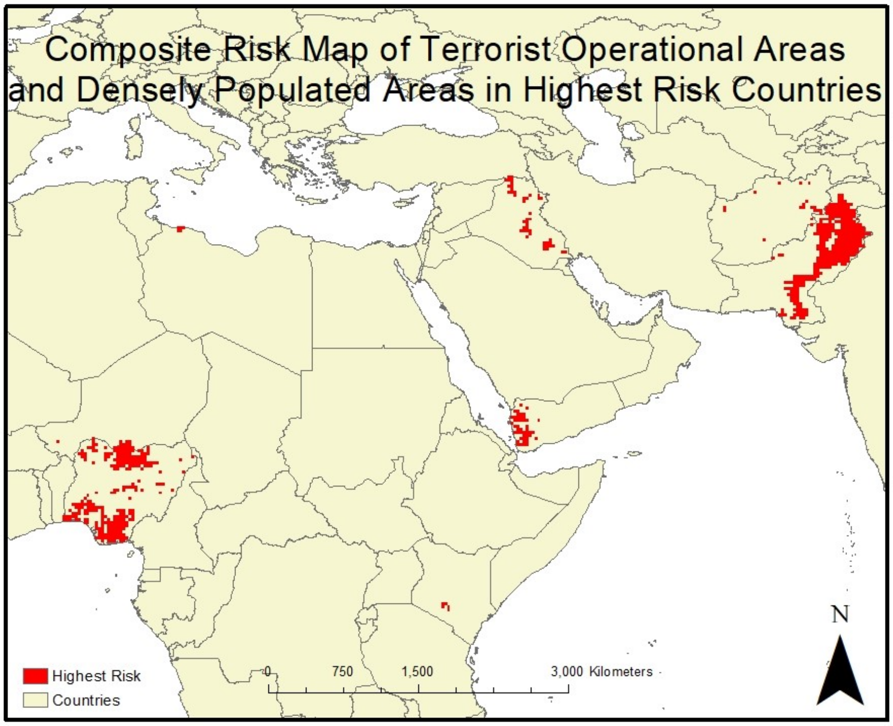


Figure 24: Composite Risk Map of Terrorist Operational Areas and Densely Populated Areas in Highest Risk Countries (Detail), 2015

It is important to note that RTMDx was unable to build a relevant risk map using any combination of study parameters. Initial attempts using the entire map of the world as a boundary took many hours to process. All global IED events in 2015 were used as outcome data and risk factors for global densely populated areas and the operational areas for terrorist organizations were assessed, but no relevant model could be found. Changes in place size and operationalization of risk factors were also considered but proved unsuccessful. Follow on attempts used just the highest risk countries as a boundary, and all outcome events and risk factors were clipped to that boundary, but again the utility could not produce a relevant model. Again, place sizes and operationalization were reconsidered, but without prevail. Based on this outcome, the null hypothesis cannot be rejected outright, although there is still some evidence that the general concept is mostly valid.

There are many potential reasons for this failure. Looking at the raster maps it is plain to see that the analysis suffers greatly from MUAP, especially at these larger scales. Even the zoomed in map of Afghanistan shows clustered areas of risk around Kabul, but the risky areas do not cover the entire area of Kabul proper, which they should. There are also challenges with the risk factors and the subsequent maps created from them, especially the maps of terrorist operational areas. Those maps are speculative at best and suffer from a lack of fidelity specific to generalizations about terrorist operations. Furthermore, with just two risk factors it is exceedingly difficult to derive a relevant risk map, especially across such a large area. Nevertheless, the ad hoc method of risk map creation supplies the necessary data and fulfills the intended function of the intermediate level of analysis, which is to further define general areas of interest for further microlevel study.

Street Level Risk Factors

Once global and subnational level analyses were completed, the highest risk areas identified by those processes were down-selected to two separate cities to build a street level risk terrain model using RTMDx for an area of highest risk and a manually generated risk terrain model for an area of not highest risk in order to illustrate the differences between risky and less risky places that were otherwise similar in size, population, and density. This comparison was intended to show the difference between the empirical soundness of an analysis using RTMDx for actual outcome data and the predictive potential of a traditional risk map in an area without outcome data given the possibility of changes in the global risk level in the future.

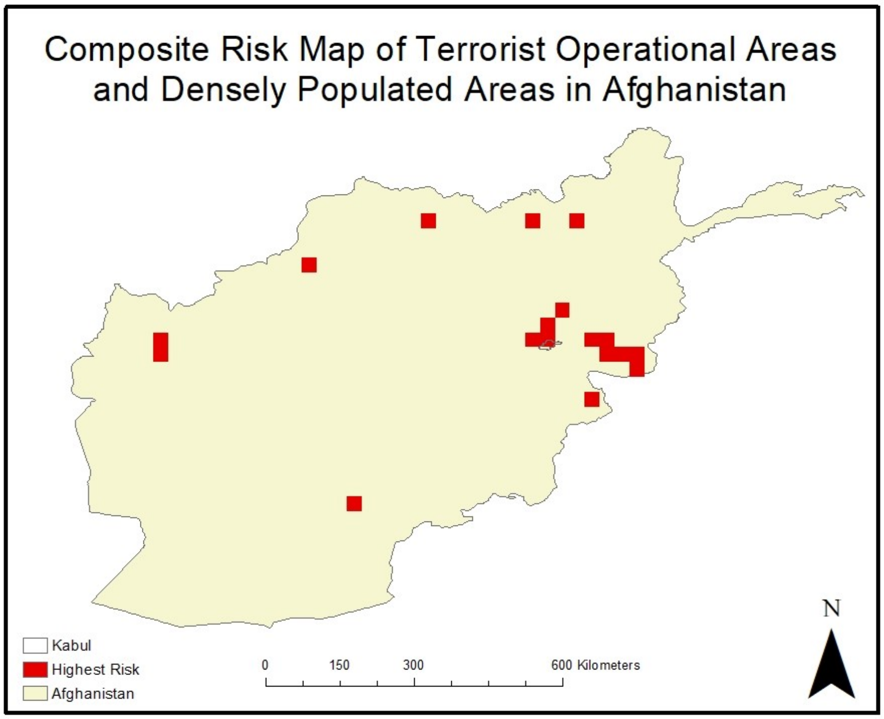


Figure 25: Composite Map of Terrorist Operational Areas and Densely Populated Areas in Afghanistan, 2015

The city of Kabul, the capital city in Afghanistan, was selected to illustrate the utility of street level RTM for IED events. Again, drawing from the literature review, a series of 23 risk factors were identified that could attract IED events and create risky microplaces. These places were: airports, bazaars, bus stops, cafes, embassies, government facilities, guest houses, hospitals, hotels, roads, malls, markets, media facilities (including places associated with newspapers, radio, or television), military facilities, mosques and other places of worship, police facilities, police stations (distinct from other police facilities like checkpoints and armories), restaurants, schools, stadiums, temples, tourist sites, and universities. Generally speaking, the risk factors were broadly categorized as government, military, or civilian places that could potentially be targeted by or attract IED events.

Risk layers were created using the technique described in the Risk Terrain Modeling Blog[52] where exhaustive subject searches were conducted in Google Earth Pro to find similarly categorized places in the area of interest. Those places were then saved into a KMZ file which was converted to an ArcGIS layer consisting of points, and the layer was exported to a projected shapefile. The only exception was the risk factor layer for roads, which was clipped from a larger shapefile of all Afghan roads from the Humanitarian Data Exchange, a collection of data sets under Creative Commons licensing cultivated by the United Nations Office for the Coordination of Humanitarian Affairs – Centre for Humanitarian Data.

In the case of Kabul, RTMDx found a relevant risk terrain model for IED events in 2015 using the risk factors for Government Facilities, Malls, and Schools. With a standard value of 100 meters and a place size of 50 meters, RTMDx created 207,684 distinct places with Relative Risk Scores (RRSs) ranging from 1, indicating the lowest level of risk assessed by the utility, to 2876.218 at the upper end of the analysis for an aggravating model. This means that a place categorized as highest risk would be more

[52] http://www.riskterrainmodeling.com/blog/risk-factors-for-those-in-need-of-risk-factors

than 2876 times as risky as a lowest risk place with an RRS of 1. The mean RRS was 1.379 and the standard deviation was 20.508, with just 88 places (or 0.04% of the study area) greater than two standard deviations from the mean. This data allows for a safe rejection of the null hypothesis. Areas where certain risk factors cluster are at higher risk of IED events than other places.

Risk Factor	Operationalization	Spatial Influence	RRV
Kabul - Mall.shp	Proximity	100	21.189
Kabul - Government.shp	Proximity	100	13.879
Kabul - School.shp	Proximity	100	9.781

Table 8: RTMDx Output for Relative Risk Factor Value in Kabul, 2015

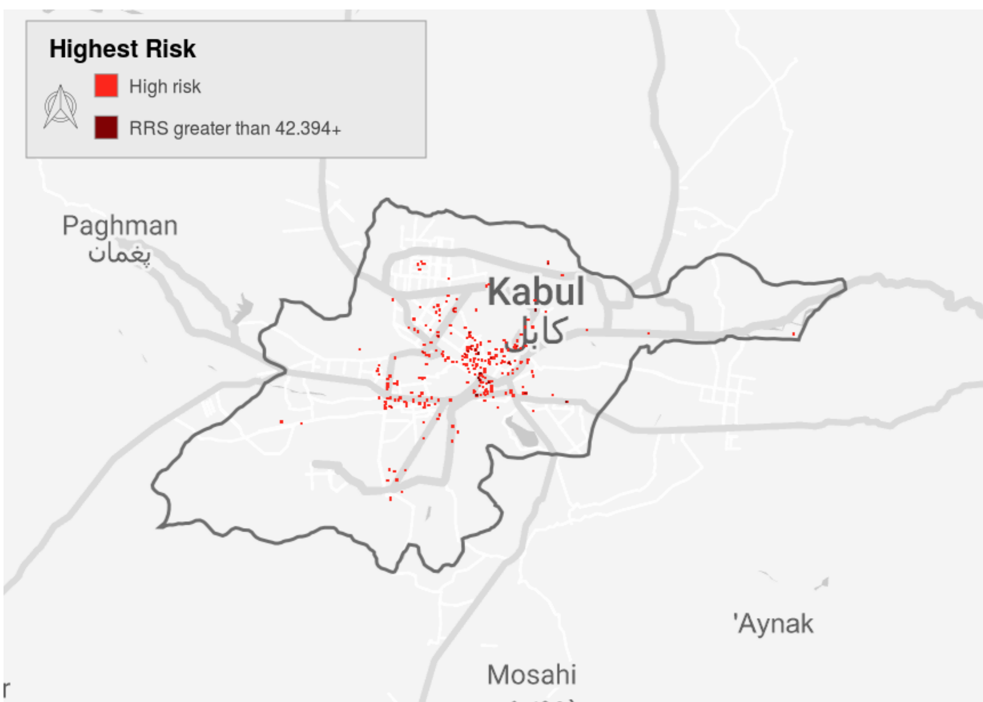


Figure 26: RTMDx Output Map for Highest Risk Places in Kabul, 2015

A map showing all relative risk scores illustrates where risk clustered in the city around the assessed risk factors.

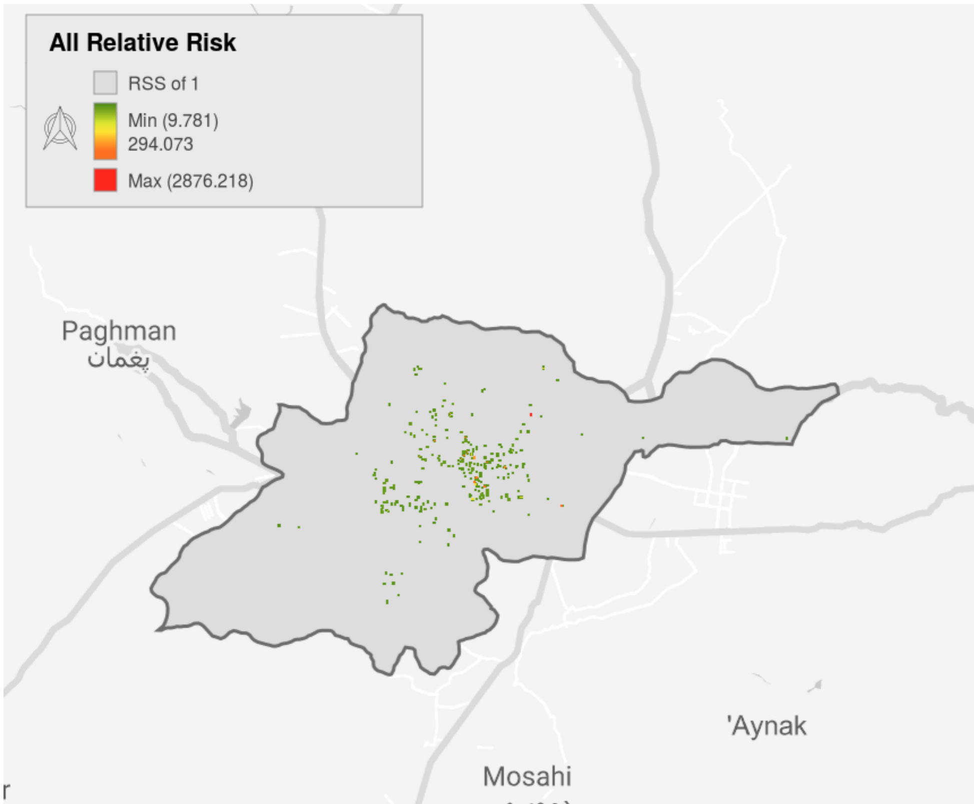


Figure 27: RTMDx Output Map for All Relative Risk Scores in Kabul, 2015

This analysis makes sense considering the lessons learned from the literature review. IED emplacements are known to target military, civilian, and government places where soft targets or vulnerable populations congregate. Government facilities in Kabul comprise both government and military targets where IED emplaces can exert violent influence, and both malls and schools have large, unprotected clusters of vulnerable human targets, especially during busy times of day.

A predictive validity assessment of this analysis using PAI returned a hit rate of .3276 using real outcome data for 2016, where 19 IED events occurred in areas assessed to be at highest risk (determined using the Spatial Join function in ArcGIS and corroborated in RTMDx) against 58 total IED events in Kabul. The area percentage was .0499, or just about 5% of the total study area, as expected for RTMDx output of highest risk cells. This returned a PAI of 6.55, which compares favorably to other crime mapping techniques.

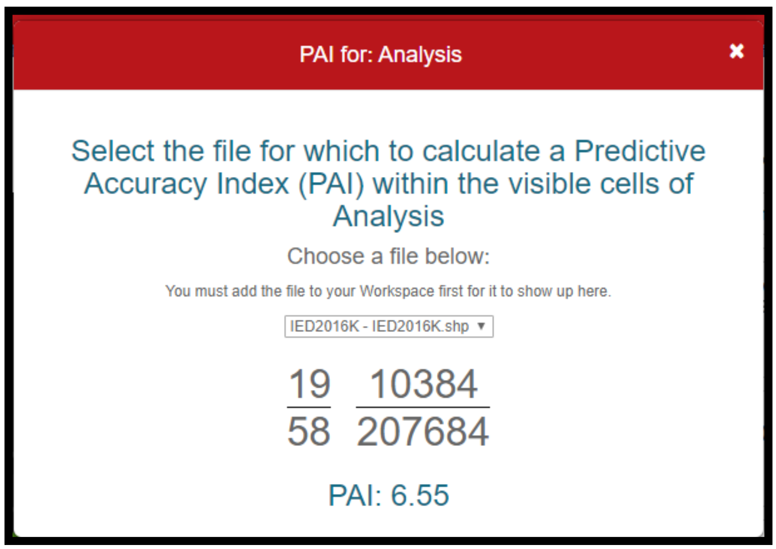


Figure 28: PAI Output from RTMDx

The same risk layers were created from the same risk factors using the same techniques and sources for the city of Casablanca, the capital city of Morocco, which had a global level composite risk score of 0 for 2015 and experienced no IED events, but which shared common environmental attractors and exhibited similar characteristics to Kabul like area, population, and population density. These layers were built in order to manually compile a risk map outside of RTMDx to show where risky places for IEDs would be if Morocco began to fall under the influence of global level risk factors and ascended to highest risk status to create a permissive environment.

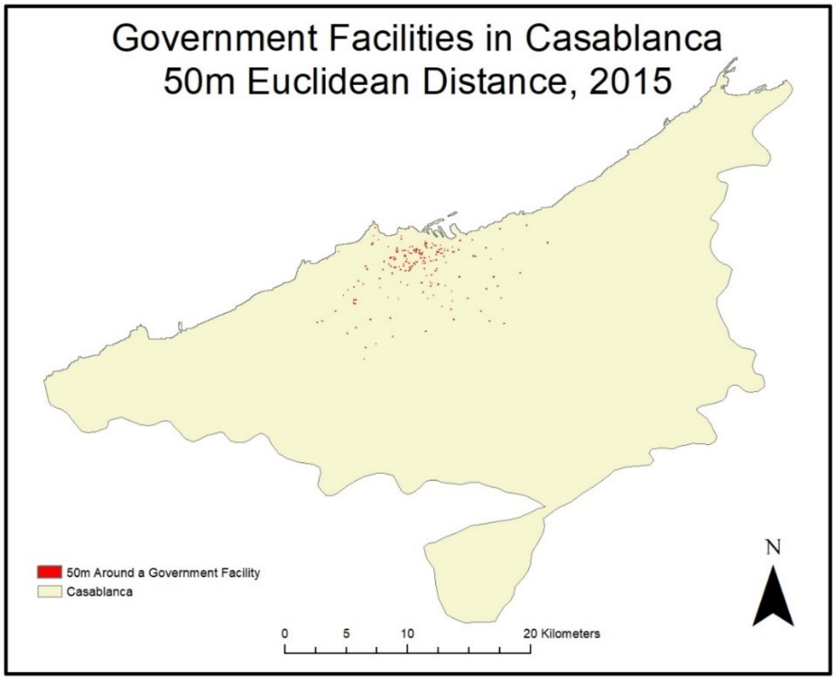


Figure 29: Area 50m Around Government Facilities in Casablanca, 2015

Based on the output from the Kabul model in RTMDx and the basic geographic and demographic similarities between Kabul and Casablanca, the same risk factors and operationalization were used to build the map layers to be composited. Here, the Euclidean distance tool was used to create a layer with vulnerable areas identified 50 meters around government facilities pulled from Google Earth Pro using the same technique as with the Kabul risk layers.

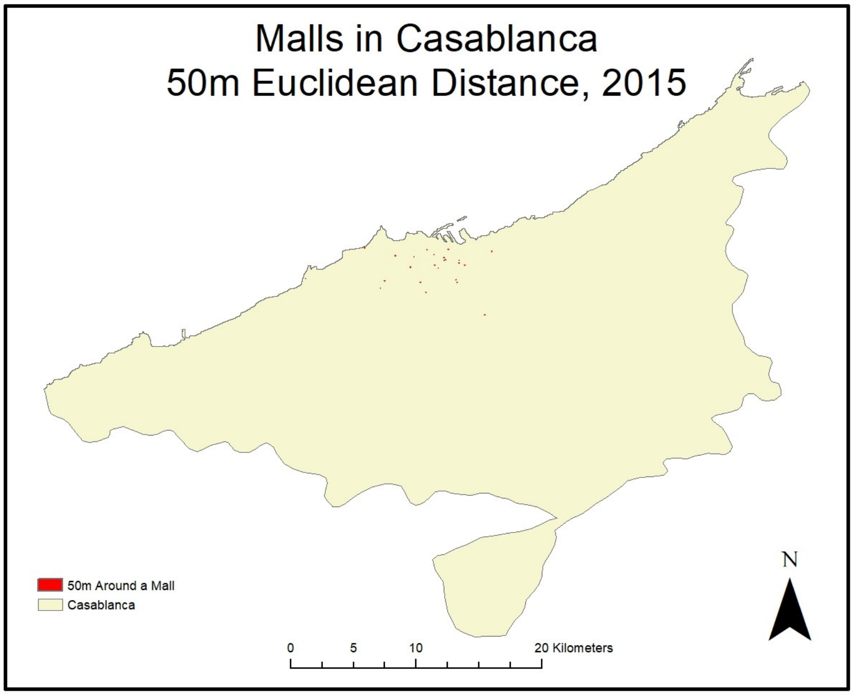


Figure 30: Area 50m Around Malls in Casablanca, 2015

The same standard was used for malls and a spatial influence of 50 meters.

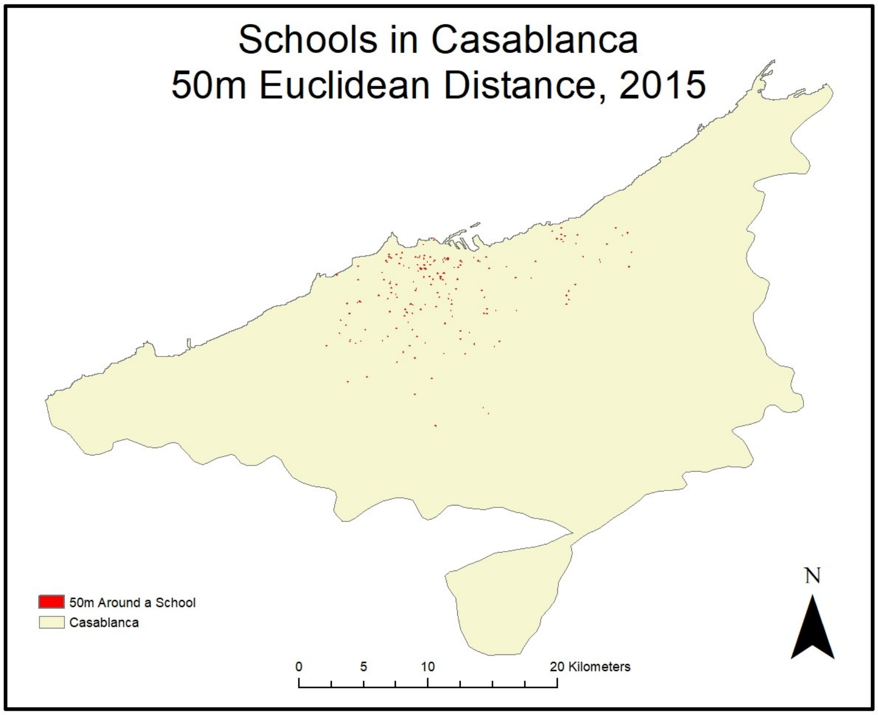


Figure 31: Area 50m Around Schools in Casablanca, 2015

Finally, the same 50 meter influence area was used for schools.

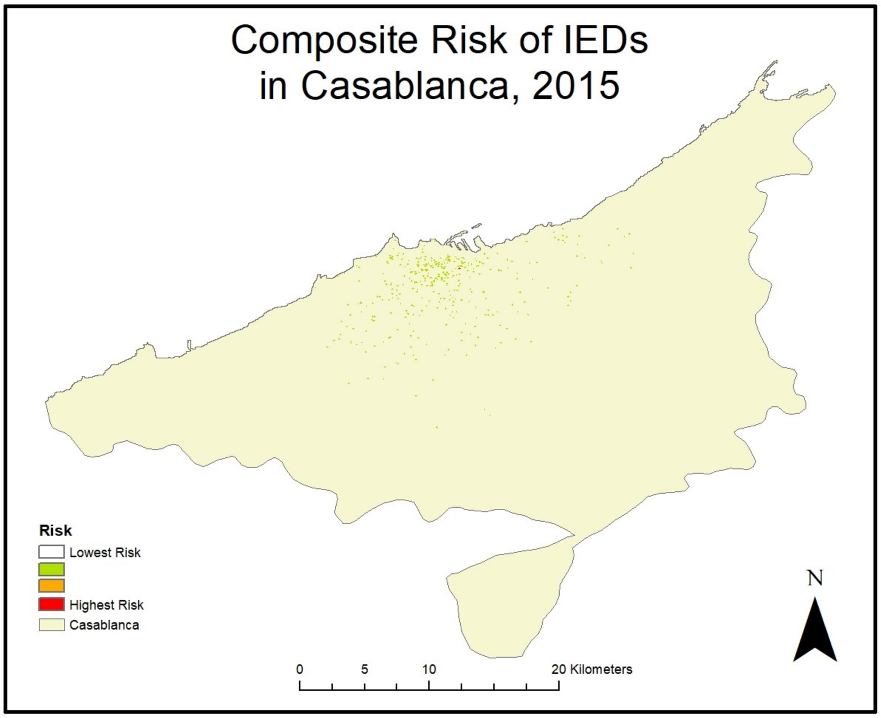


Figure 32: Composite Risk Map of IED Risk in Casablanca, 2015

Compositing the layers together in the raster calculator produced this risk map, identifying areas of highest risk where IED events could occur in places with higher relative levels of vulnerability based on the intersection of the spatial influence of government facilities, malls, and schools. Since most activity in Casablanca is clustered near the business center at the heart of the city by the sea, a zoomed in map is provided for further elucidation.

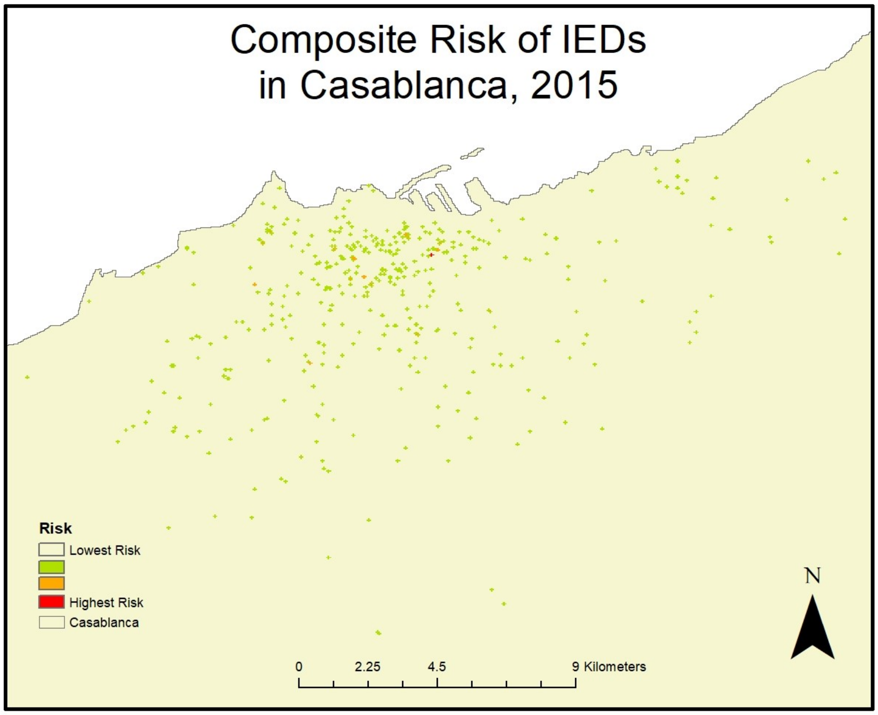


Figure 33: Composite Risk Map of IED Risk in Casablanca (Detail), 2015

CHAPTER 5: SUMMARY AND CONCLUSIONS

The present study sought to assess the risk of improvised explosive devices at the global, sub-national, and street level according to the methodological tenets of RTM. Because many IED events are terroristic in nature, and because of the inherent criminality of both terrorism in general and IED events specifically, RTM is an appropriate construct for this study. Furthermore, the proactive focus of RTM as a predictive tool makes it ideal for the study of IED events in environments where the anticipation of a risky encounter with an IED can mean the difference between life and death. A well-considered spatial risk assessment for IED events at each level of analysis presented in this study can direct resources toward the most significant areas of interest saving time, money, and potentially lives.

IEDs are weapons with strategic, operational, and tactical effects. Strategically, they can influence national will during conflict and create environments of terror during times of peace. Operationally they can shape battlefields and reconfigure resource allotments for peacekeeping or policing, and tactically they can kill, maim, and destroy either indiscriminately or with great precision. To understand the scope and scale of the IED problem strategically, operationally, and tactically requires an analytic approach that considers each of these three levels of analysis and assesses risk across them in a meaningful way. This multi-level analysis allows analysts and policymakers, military operators, and law enforcement or emergency responders to drill down to the level of analysis that is most pertinent to them, and to make policy or resourcing adjustments accordingly. This creates a necessary narrowing effect; the world is simply too large and too complex to watch every 50-meter grid square all of the time.

Accordingly, this study is the first of its kind. It is the first attempt to apply RTM to the IED problem and the first RTM-based study to integrate multi-level analysis with direct linkages from the global extent to street-level microplaces. It established risk factors at the global, sub-national, and street level that were statistically significant and predictive of future IED events and expanded the scope of the RTM methodology to quantify the correlative effect of macro-level environmental factors on the amount of IED violence in a country. The comparison between the paired cities of Kabul and Casablanca illustrated the differences between the effects of those macro-level risk factors on whether or not an area with similar street level crime attractors experienced IED events. These techniques are innovative and add to the existing literature around RTM and its subdisciplines.

The study also helped to characterize the circumstances under which IED events take place at all three levels of analysis. At each level there was existing literature that described situations in which a country, region, or city might experience IED events. This study organized and visualized those situations. At the global level, the riskiest countries for IED events were fragile states with terrorist groups operating within their territory that were experiencing state-level violence. A risk score compositing five factors was able to explain 34% of the variation in IED violence at the global level. At the subnational level, the study was able to illustrate the most enticing regional areas for IED events based on population density and terrorist group operational areas. At the street level, 23 different microplace risk attractors were assessed in RTMDx with government facilities, malls, and schools making up the most relevant risk factors. Again, this is consistent with the existing literature at all levels.

This attracting model can be described simply: The riskiest places for IED events are permissive environments where targets cluster together and where attackers operate.

Fragile countries that have governance challenges are often embroiled in conflict, and the governance vacuum created by conflict can lead to permissive environments for terrorist groups to operate. Permissive environments create macro-level risky places for IED activity at the global extent, and there is more to the assessment of a permissive environment than just geography. Where dense populations cluster in permissive environments, and where those dense populations can be targeted by malicious actors, there will be risk of IED events. Narrowing down the risky places from the global, to the subnational, to the micro level allows for more efficient targeting of malicious actors and the more careful allocation of resources to truly vulnerable places. The symmetry between the description of permissive environments at the global level and the traditional criminological concept of the environmental backcloth is not unnoticed. Each concept describes a similar thing, and this technique marries them together.

Permissive environments are preconditions for terrorist activity (Crenshaw, 1981), and insurgency (Fearon & Laitin, 2003) and the weapon of choice of terrorists and insurgents in those environments is the explosive device (Enders & Sandler, 2004 and Kalyvas, 2006). Permissive environments in which these devices could be used are characterized by state fragility and war (Coggins, 2014), and this study found that a combination of state fragility, inter- and intra-state war, one-sided violence, and the presence of terrorist groups was associated with increased risk of IED events.

The study of terrorism in particular is similar to the study of crime, because both activities are inherently illegal in nature (LaFree & Dugan, 20014). As such, techniques used to study crime can be used to study terrorism, and by extension, the tools of terrorism - like IEDs. IED events are likewise inherently criminal events (Brehm, 2012) and are deserving of the same rigorous methodologies as the study of crime. The study of IED risk in particular is of interest to those that must live, work, or operate in areas that may be characterized by IED events.

Risk can never be zero as there is always a chance of a negative outcome (Kennedy & Van Brunschot, 2009). Risk also varies across space and time, and IED risk has specifically been shown to cluster in space and time (Johnson & Braithwaite, 2009, 2012). One technique to study the risk of criminal events that vary across space and time is RTM (Caplan, et al 2011). This study showed that RTM can be used to study a single outcome event across different geospatial levels of fidelity to arrive at relevant risk models for that outcome event type. Here, IED events were assessed across global, subnational, and street levels.

At the global level, the permissive environments presented by fragile states experiencing violence and terrorism approximate the environmental backcloth described by Brantingham & Brantingham (1995) to denote the vulnerability of specific environments to crime. The countries that have permissive environments for IED events then become the boundary layer for the study of IED events at the subnational level.

At the subnational level, the places where targets and attackers come together in that boundary layer represent the areas of highest risk unbound by national borders. There are targets everywhere because there are people everywhere. The more densely populated an area is, the more targets there are relative to the terrain. There are not attackers everywhere, but there are in some places. In the places where targets and attackers occupy the same terrain, the risk of an attack is higher. This study plotted the places where dense populations coexisted with terrorist operational areas, which led to the identification of certain cities that were at higher risk of IED events, such as Kabul, Afghanistan.

Those cities that were at higher risk of IED events based on the previous two analyses were then candidates for street level analysis using RTMDx, an application that automates many of the steps of RTM. In order to build risk models in RTMDx, a series of risk factors for IED events was developed based on the existing literature. Soft civilian targets like markets or schools were often associated with IED violence (Brandt & Sandler, 2010), as were government and military targets, mostly for their propaganda value (Hastings & Chan, 2013). This study developed 23 risk factors for the city of Kabul across the broad categories of government, military, and civilian target types. RTMDx returned a risk model where government facilities, malls, and schools were at the highest relative risk of IED events occurring within 50 meters, the safe-separation distance for a typically sized IED.

A city with similar demographic characteristics to Kabul was chosen for an alternative analysis to determine which micro places could be at highest risk in a city that had all of the same risk factors at the street level but did not experience any of the risk factors associated with IED events at the global level. This city, Casablanca, Morocco, did not return a relevant risk map in RTMDx because it experienced no outcome events during the period of study, but a manual risk map built using the traditional RTM procedures showed the areas of highest risk based in the utilization of the same street level risk factors that were associated with IED events in Kabul. In this way the study showed that although the microterrain of Kabul and Casablanca were similar, the macro environment was different and there was no permissive environment in Morocco to create vulnerability to IED events. In this way, the global risk factors that are associated with permissive environments represent a sort of switch that can turn IED events on or off in a specific location.

This technique creates context and shows how conditions at one level can affect conditions at another. Although Kabul and Casablanca are very similar in both size and makeup, one city is in a high-risk country while another is not. The city in the high-risk country routinely experiences explosive violence from IEDs, and the city in the lower risk country does not. This difference can be quantified using RTM, as shown in this study. By starting at the macro level and drilling down to the micro level, analysts using this technique can identify areas of interest without running multiple analyses or long running time series experiments. In this way, the global level risk assessment works as a sort of indicator or switch, turning IED risk up or down as the risk number rises or falls over time. Furthermore, the technique of using matched city pairs can help to identify potential problem areas at the micro level before they become security challenges.

Limitations

As with any topic worthy of investigation at this level, there were a number of limitations encountered in the conduct of this study, and many areas of potential future research that were discovered along the way.

The most confounding limitations were those of data availability and integrity. When IEDs are directly affecting the daily operations of the United States Department of Defense, the data collected and analyzed are exquisite and there are many organizations that attempt to collate those data. When strategic concerns shift national focus away from counter-IED operations, the resources previously dedicated to the cataloging of IED events dissipate. Countries that are experiencing IED events are unlikely to collect and share IED data for many of the same reasons that they cannot effectively fight IED violence. They lack either the means of the will, or both. While valiant efforts have been made by organizations like the University of Maryland with their GTD, the limits of their collection methodology mean that many IED events could potentially go unreported or underreported if there is any inclination that they may not be related to the institutional definition of terrorism.

There were also limitations to the availability and integrity of the risk factor data used for the separate analyses. At the global level, the individual risk factors were barely correlated with the outcome events, and the composite risk score was only moderately correlated. A stronger set of risk factors might have returned better correlation. Likewise, although the variation explanation from the regression analysis was near the average for other similar studies, there was still room to grow, and it is not reasonable to assume that all relevant risk factors were available for analysis.

At the subnational level, the inclusion of just two risk factors, while relevant based on the literature review and the theme of interaction between victims and offenders in space, was a serious limitation. A stronger set of risk factors might have returned a valid model from RTMDx. The two analyzed risk factors served their purpose of directing further analysis to areas of interest, but a reconsideration of the total subnational model with more risk factors might have provided a stronger link between the levels and allowed for a more rigorous statistical analysis, and may have allowed for weighting or other techniques to improve the quality of the analysis. It is important to note that the use of more relevant risk factors at the subnational level and assessments of different place sizes could increase processing times considerably, weakening the return on investment for using this approach in time sensitive analyses.

The risk factor for terrorist operational areas was especially problematic. The risk layer was built by hand using graphical maps provided by the National Counterterrorism Center that were not georeferenced in any way. They were also not necessarily representative of all of the terrorist organizations represented by the yearly State Department designations. As a result, some organizations could have been under- or overrepresented, or not represented at all in the analysis. A better source for geographical references to terrorist operational areas could have improved the analysis. Some more rigorous terrorist operational area maps were available, but they were built using the georeferenced data from the GTD which would have resulted in a bit of circular logic for this study. It is possible that more detailed maps were available from official government sources, but those were not appropriate for use here given the potential security classification.

At the street level, the use of the Google Earth Pro method of feature extraction to build risk factor shapefiles was limiting. Because vetted, cultivated datasets of georeferenced attractors were not reliably available, this method of collection was the most expedient and complete. Still, it is almost a certainty that some places were not captured, misaligned, or even double counted despite the implementation of control mechanisms. With 23 different risk factors, just three were found to be relevant enough to create a model. At each level, the lack of standardization could have potentially weakened the analysis, and more complete data might have changed the outcomes, although there is no indication that the overall analysis would have been considerably different.

Future Research Opportunities

At each step of the process in developing the present study, opportunities for future research presented themselves. There were many different types of techniques that could have allowed for different types of data analysis to take place that could strengthen the overall understanding to the IED problem and the phenomenon of multilevel linkages in spatial risk assessment. Future studies could redirect the analysis across levels based on different temporal scales. The time period of one year for study was not entirely arbitrary; most national level data considered for the study were aggregated and reported on yearly, and at the global level the factors that contributed to IED risk changed slowly if at all. For this reason, it would be pertinent to expand the scope of the study to analyze IED events over multi-year periods to assess if there were risk-based triggers for increases or decreases in observed outcomes. For example, trends could be observed in time series over decades or more (the GTD data are available back to the 1970s, and although they are not all georeferenced in that vintage, the global level analysis does not need that level of granularity) to see if changes in the macro environmental attractors affect long term changes in IED events. A cursory attempt to check for significant changes over time revealed Libya to experience direct increases in IED violence as the risk score rose from 2010 to 2016, but that seemed to be an outlier and more study would be required to form a cogent hypothesis.

It would also be pertinent to conduct a more serious investigation on the effects of contagion at the global and subnational levels. At the microlevel there did not seem to be any theoretical basis for further investigation. IED events were more related to the direct environments in which their emplacers operated, and there was no indication that they could spread beyond the direct influence of bombmakers and their areas of operation. At the global and subnational levels, however, there was some existing literature that seemed to suggest that neighboring country or region risk could grow as the risk developed over time in a country or region of interest. This would require a slightly more complicated model, but the assessment would be practical and feasible.

At the street level, there could be opportunities to study transience in risk factors. One of the strengths of RTM is that it can reliably assess risky microplaces because terrain features like schools or government facilities have long lifespans and do not move easily. However, an interesting study could be made from the assessment of environmental attractors that do move and how the spatial risk assessment changes as they transit through the studied space. This example arose from the curious case of a small number of IED events that occurred in Kabul that did not seem to be related to any risk factor in particular but nevertheless clustered in space over the course of 2015 and

2016. It turned out that these events were assassination attempts against a government worker that rode a specific bus to and from work every day. Pattern of life analysis by the IED emplacers led them to attack the bus he rode at different places along its route at different times according to their perceived capabilities. The attacks did not come against a bus stop or his residence or his point of debarkation, but against the route itself. It would not necessarily be instructive to assess all bus routes as a risk factor since the attracting feature was not the bus itself but the presence of an individual with a very specific association. This level of fidelity is not likely available in any publicly curated aggregation, but could nonetheless lead to interesting outcomes if a study were found to be plausible.

Finally, a series of street level analyses using exquisite data from sources other than those publicly available (such as classified military reporting), and using an automated system for developing risk terrain models similar to RTMDx but with an artificial intelligence layer applied for real time analysis in a tactical military system would be enticing. Such a system could be integrated with military sensors on route clearance vehicles, for example, or in a heads-up display for a soldier performing dismounted reconnaissance. This would allow for continuously updated risk maps updated in real time and overlaid onto a visual representation of the real world during actual operations, resulting in such fine scale output that it could potentially show a soldier where to step or not step based on a continuously adjusted confidence level projected as part of the display. With developments in machine learning algorithms and processing power pushed to the tactical edge, a system like this performing RTM analysis with actual tactical data could be designed and built.

Closing

Even without the initiation of the future concepts described above, the present study contains significant information to suggest implications for policy and practice. At the global level, the association of macro risk factors based in the human terrain of a country with IED events allows for policymakers and governance structures to see warning signs of impending violence. As a country trends toward fragility, and as it sees the infiltration of terrorist groups, and as it experiences violence of one kind or another, it can reliably expect to experience IED events in short order. Recognizing these larger risk factors can direct the resource managers to focus intervention attempts on the subnational level to find areas of interest to defend, which then allows further focus on susceptible cities where street level analyses could be conducted using RTMDx to find appropriate models. In those models lie the critical areas that must be defended, and because of the predictive validity of the methodology, policymakers could be more confident in their RTM based proscriptions than with some other techniques.

In areas that are not subject to risk at the national level, the identification of similar cities with potentially similar risk factors can show where new defensive city designs could be focused when planning public spaces, or where additional intelligence assets might be focused to identify IED event planning prior to emplacement. Further study of those defensively designed spaces could show whether or not replacement or redirection effects were legitimate for IED violence.

In sum, IED events are criminal in nature and can be studied using criminological techniques like RTM. In assessing IED risk at the global, subnational, and street levels, there were direct links between the risk factors at each level that informed the maps or models at the level directly beneath it. Global risk factors that approximated the traditional environmental backcloth showed how permissive environments were associated with increased levels of IED violence. At the subnational level, certain areas where targets and attackers came together created rich environments for IED events, which led to the identification of cities that could be studied using RTMDx. The identification of a paired city that was similar to a risky city but without the macro level risk factors present reliably did not experience IED events but showed where IED events could occur if the macro level risk factors were present. This created a holistic analysis environment that demonstrated the interdependence of the three levels and the use of RTM as a construct to link them all together in a meaningful way.

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