SPATIO-TEMPORAL MODELLING OF INSURGENCY IN IRAQ

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ABSTRACT

In the wake of 9/11, counter-insurgency operations have taken primacy in many states' policy agendas. In this chapter we provide an overview of the Iraq conflict and review existing theory regarding insurgent targeting strategies. In particular, we focus on how attacks might be organized in space and time given the resources available to insurgents, and the spatial and temporal constraints that shape their behavior. Using data for a six month interval of time, we then examine space-time patterns of two types of attack; IED and non-IED. The results indicate that both types of attack cluster in space *and* time more than would be expected if their timing and location were independent. Simply put, following an attack at one location others are more likely nearby within a short interval of time, but the risk of attack within the vicinity diminishes with time. Importantly, the precise patterns vary by attack type suggesting that they are generated by different types of insurgent strategy and that different counter-insurgent tactics will be appropriate for different types of attack.

INTRODUCTION

Counter-insurgency operations have been catapulted to the forefront of many states' policy agendas in the wake of 9/11. While it is not historically unprecedented for major powers to focus their attention upon such operations,[1] there is a general belief that they have now overtaken more conventional forms of conflict in states' security priorities. This represents a relatively recent shift and, accordingly, uncertainty obscures successful identification of the most appropriate application of military force in countering the increased threat from insurgent activities. This uncertainty is manifest most vividly within the membership of the coalition-of-the-willing, where fierce debates rage as to the wisdom and impact of continued military presence in Iraq. More generally, a great deal of uncertainty surrounds the prospects for security and prosperity in Iraq during and beyond the period of foreign occupation. It is yet to be definitively established whether or not, for instance, the incremental surge in US forces on the ground from the spring of 2007 has permanently lowered levels of insurgent violence nor what will be the effect of UK withdrawal—planned to begin July 2009. What is certain, however, is that while violence continues there is little chance that credible, stable, consolidated democratic institutions will emerge to facilitate confident citizen participation in government.

These debates are all the more pertinent now that Barack Obama—a strong advocate of setting a timetable for withdrawal—has been elected 44th President of the USA, replacing George W. Bush—himself an advocate of the stay-the-course doctrine. One reason for the prolongation of the "stay-the-course"/"timetable-for-withdrawal" debate is the lack of accurate empirical evidence identifying factors that exacerbate or mitigate the severity of insurgent activities on the ground.

[1] For instance, the United Kingdom in Malaya and the United States in Vietnam did just this in the mid-Twentieth Century.

Accordingly, great value ought to be attached to advances in the understanding of ongoing insurgent campaigns against coalition troops. Of particular interest are details about Improvised Explosive Devices (IEDs), which have, since late 2004, become the greatest threat to the military on the ground in Iraq .

In this chapter we build on previous work (Townsley, Johnson and Ratcliffe, 2007; see also N.F. Johnson, 2006) concerned with the spatio-temporal distribution of insurgent activity. In line with the approach suggested by advocates of situation crime prevention (e.g. Clarke, 1997), and recognizing that different types of insurgent activity may be influenced by different factors and reflect different targeting strategies, we analyse patterns for different types of activity seperately. Here, we focus on IED attacks and compare these to patterns of non-IED insurgent attacks.

In what follows, a brief review of the literature identifying insurgent strategies among non-state actors is used to identify a series of consistent expectations. These largely centre upon the claim that insurgents are highly likely to allocate their scarce resources purposefully in periodic and clustered patterns so as to maximise their prospects for taking control of new territories and winning the public relations competition. Accordingly we employ a procedure initially developed within the field of epidemiology (Knox, 1964) - refined by research within the Situational Crime Prevention literature (e.g. Johnson and Bowers, 2004; Johnson et al., 2007; Townsley et al., 2003) - to test the hypothesis that space-time patterns of insurgent activity resemble those of a contagious process—occurring closer in space and time than would be expected assuming that the timing and location of events were independent. The testing of this key hypothesis is designed to provoke the derivation of additional hypotheses regarding operational practices within insurgent campaigns and counterinsurgent responses. Example hypotheses are addressed in the concluding remarks of the paper.

INSURGENT STRATEGY

We employ a simple definition of insurgency that identifies it as the use of force by a non-state actor hoping to coerce a Government to affect some policy change in deviation from the status quo.[2] Importantly, we consider the terms terrorism and insurgency largely interchangeable, though we recognise that traditionally they have been dealt with as two distinct forms of non-state actor challenges to the central Government; with the former refering to attacks against "innocent" civilians and the latter being associated with attacks against the officials and military assets of the Government. For instance, while the United States' Department of State specifies in its definition of terrorism, that violence is "…perpetrated against noncombatant targets…" (US Department of State 2003, p. xiii), the United States' Department of Defense (DOD) chooses to define terrorism more generally as "the unlawful use or threatened use of force or violence against individuals or property to coerce or intimidate governments or societies, often to achieve political, religious, or ideological objectives" (White 2003, 12). We choose to treat these two terms as synonyms because we would claim they are both driven by a desire to affect policy change and, in the case of Iraq, there is a growing tendency for campaigns to employ violence against both sets of targets: of the 118,246 insurgent attacks between June 2004 and August 2007, 85,284 targeted Coalition Troops, 21,725 targeted Iraqi Security Forces, and 11,237 targeted civilians.[3]

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[2] For more comprehensive treatment of the variety of definitions offered for "terrorism" and "insurgency" in the broader social science literature, see Schmid & Jongman (1988) and Hoffman (2006).

[3] Figures come from the U.S. Department of Defense's "Measuring Stablity and Security in Iraq" report to Congress from December 2008.

A range of recent studies have detailed rationalist explanations for the employment of insurgent violence that do not rest solely upon the existence of (what is commonly perceived as being irrational) fanaticism (see, e.g., Crenshaw, 1998; Wilkinson, 1986; Hoffman, 1998; Pape 2003, 2005; and Kydd & Walter, 2006). Martha Crenshaw, for instance, characterizes insurgency 'as an expression of political strategy…' in which the resort to violence is viewed as '…a willful choice made by an organization for political and strategic reasons, rather than as the unintended outcome of psychological or social factors' (1998, 7). We identify four common themes among these strategic arguments, each of which overlaps significantly, ultimately reiterating the claim that insurgency can be characterised as a struggle between government and non-state actor over control of territory and public opinion. Moreover, each implies that attacks should be non-random and at least loosely coordinated so as to maximize impacts.

Exhaustion Strategies

It is commonly recognised that insurgents are militarily and politically weak actors who lack sufficient strength in numbers to enable them to compete against the political leadership through legitimate processes and whose tool-kit for countering politically powerful actors, with whose authority they fundamentally disagree, is, therefore, restricted to violent means (see, also, Lacquer, 1977; Bell 1978; Crenshaw 1981, 1998; Carr 1997). 'Generally, small organizations resort to violence to compensate for what they lack in numbers. The imbalance between the resources terrorists are able to mobilize and the power of the incumbent regime is a decisive consideration in their decision-making' (Crenshaw 1998, 11). The reality of this power asymmetry tends to point insurgents toward strategies of exhaustion (see, e.g., Kydd & Walter, 2006, and Lapan & Sandler 1993). These strategies involve focusing scarce resources upon small, (winnable), isolated, periodic uses of force. In aggregation it is hoped that such a strategy will exhaust the opponent's abilities (money, lives) or (more likely) will/morale. The success of exhaustion strategies depends upon being able to strike the right balance between maneuver (fleeing) and engagement (fighting). In other words, it is suggested that insurgents aim to employ strategies that are likely to optimize the impact of limited resources and the spatial and temporal constraints (Townsley et al., 2007) that limit their activity.

Morale-Building Strategies

Violence can also be employed to prepare the ground for mass revolt, inspiring resistance by example by demonstrating the vulnerability of the government coming under attack (Hewitt 1993, Marighella 1969). Metz (2003) argues that insurgents rely upon being able to highlight the inability of the government to guarantee peace and stability for the broader population. Whilst traditional views might characterize the course of insurgency as a steady escalation of violence until the insurgents have built a military force to match and defeat the government, the Iraqi case differs insofar as it resembles the Palestinian struggle where violence can be used to target a potentially weak-willed foreign occupier, increasing tensions between the domestic population and the occupier, ultimately designed to compel withdrawal (see, e.g., Wilkinson 2000, Pape 2003, 2005). In particular, this strategy is aimed at demonstrating to sympathetic audiences that the movement stands a chance of victory in its struggle against a status quo power and, therefore, that continued support is not in vein. Accordingly, this logic also implies a strategy in which resources are expended in bursts that maximise exposure but minimise the likelihood of capture.

Public Relations Strategies

Insurgent violence is also identified as having a useful agenda-setting function within a broader population that is not necessarily sympathetic to the movement (see, especially, Thornton, 1964). 'By attracting attention it [violence] makes the claims of the resistance a salient issue in the public mind. The government can reject but not ignore an opposition's demands' (Crenshaw 1998, 12). The public relations battle against the Government can be thought of as existing at three levels. First, there is a need to draw attention to the goal of the movement with a view toward attracting new recruits. For Bueno De Mesquita (2005) this results in attempts to demonstrate that the insurgency is not futile; to demonstrate that the insurgency can harm its targets and that it has some prospect of success.

Second, there is a broader (not necessarily supportive) population within the state that could help swing the balance in the ongoing struggle between Government and Insurgents—as they could provide implicit support by not opposing the use of violence for broader aims. The dominant discussion in the literature in this respect refers to the strategy of *outbidding*, whereby competing factions utilise isolated violence to muster support (see, e.g., Bloom 2005, Crenshaw 1981). Third, there is the population of the state committing forces to counter insurgency that can also be swayed in opinion, it is argued, if they feel the ongoing costs of the insurgency are too high. As with the *exhaustion* and *morale-building* strategies detailed above, it is expected that insurgent attacks will be non-random and that some effort will be made to optimize limited resources that are subject to spatial and temporal constraints, once again maximising exposure whilst minimising the potential for capture.

Provocation Strategies

Finally, it is claimed that the employment of violence may serve to provoke a harsh government retaliation which would undermine the Government's democratic credentials and that could, therefore, serve to alienate the masses, pushing them toward supporting the resistance organization opposing the government (see, e.g., Thornton 1964, Fromkin 1975, Crenshaw 1981; McCauley 2006; Pridemore & Freilich, 2007; LaFree, Korte, & Dugan 2009). Most recent discussions of this strategy have identified the vulnerability of liberal democracies, in particular, to violence so designed (see, e.g., Wilkinson 1986, Pape 2003, 2005).

In summary, each of these broad categories of strategies highlight the fact that insurgents face a significant power asymmetry and must, therefore, allocate their scarce resources so as to *exhaust* their opponent's morale by demonstrating their weakness and/or authoritarian tendencies, while building morale among their own supporters. Consequently, it is anticipated that attacks will cluster in time and space, so as to magnify their occurrence.

There is a paucity of research concerned with the spatial[4] distribution of insurgent activity that has used point (rather than regional) level data, let alone that which considers patterns in space *and* time (though Berrebi & Lakdawalla 2007 and N.F Johnson, 2006 offer welcome exceptions; see also Cothren, Smith, Roberts & Damphousse, 2008; Rossmo, Harries & McGarrell 2008). However, the limited research that has examined patterns of insurgent activity using point level data does

[4] For an excellent example of research which examines changes in patterns of insurgency over time, see N.F Johnson (2008).

provide support for the hypothesis discussed above. For example, using three months of data concerning IED attacks in Iraq, Townsley, Johnson and Ratcliffe (2007) demonstrate that attacks cluster in time and space more than would be expected if the timing and location of events were independent.

The Townsley et al. (2007) paper focused on only one type or attack (IEDs) but raised more questions than it answered. Consequently, in the current study we provide a replication and extension of the Townsley et al. work. Before presenting the analyses, we provide a little more detail about the Iraq conflict and the use of IED and non-IED attacks by insurgent actors.

FREQUENCY AND LOCATION IN THE IRAQI INSURGENCY

The insurgency in Iraq took hold almost immediately after America's successful completion of a conventional campaign against Hussein's military forces. This insurgency appears to have grown in size and violence in the near five years that have passed since the conventional campaign was completed, to the point at present where it is comprised of a myriad organizations united only by their mutual desire to undermine the transitional government in Iraq and oust the foreign occupying forces of America and her coalition of allies. These groups have employed suicide bombings, IED attacks, kidnappings, murders, sniper techniques, and mortar attacks.

IEDs are booby traps—disguised, victim-triggered devices, often in form of roadside bombs. There is a long tradition to the employment of such weapons by insurgents and terrorists including in Malaya, Vietnam, Northern Ireland, and Sri Lanka. It is likely that they have become so prevalent in Iraq as a result of the expertise gained by fighters in the Iraq-Iran war of the 1980s and the availability of explosives, especially mines from that time.

As of November 17, 2008, IEDs had claimed 1812 of the 4197 hostile Coalition troop fatalities in Iraq, having increased year-on-year since the invasion in March 2003, representing, for instance, 70% of monthly casualties (among those killed in action) in 2005, up from 26% in 2004 (Ryu 2005). IEDs are now, therefore, the single largest cause of America's losses in battles.[5] While it had been hoped that early symbolic victories (e.g., the death of Saddam Hussein's sons and the capture of Hussein himself) would abate the killings, in fact it was soon recognized that insurgents were becoming increasingly well organized—combining ambushes, the employment of rocket-propelled grenades (RPGs), the placement of IEDs, and small arms fire. Accordingly, massive budgetary allocations have been allotted to projects safeguarding troops on the ground and specifically targeting the threat from IEDs (Miles 2005, 2006)—including $1.2bn between 2003 and 2006 allotted to reinforce and armour humvees against their deployment (Garamone 2004).

In March 2006, Bush claimed that terrorists were employing IEDs because they lack strength to tackle America's conventional forces: "After the terrorists were defeated in battles in Fallujah and Tal Afar, they saw they could not confront Iraqi or American forces in pitched battles and survive, and so they turned to IEDs, a weapon that allows them to attack from a safe distance without having to face our forces in battle." (Smith 2006.) At least anecdotally, it appears as if insurgents have, in fact, proven to be very successful in overcoming American countermeasures. For instance, they have built bigger bombs in reaction to America's armoring of humvees; and they have employed remote detonation devices that can be used up

[5] Casualty data are available at www.globalsecurity.org and www.defenselink.mil.

to 2km away in response to the increasing number of captures/killings of bombers by Americans (Ryu 2005).

INSURGENCY DATA

The advances presented in this study depend upon access to rich data detailing the evolution of the insurgent campaign. Such data is (understandably) hard to come by. In this instance, we have a comprehensive dataset detailing all incidents, representing a variety of acts (committed by insurgent forces against Iraqi and Coalition forces), that were reported to Multi-National Force-Iraq (MNF-I) through daily Significant Activity (SIGACTS) Reports. This "unclassified" data, available for the period January-June 2005, was made available by the Reconstruction Operations Center[6]. These data, treated as "sensitive", have been employed elsewhere within academic communities, such as in articles describing the utility of geographic profiling techniques in the search for Insurgent hideouts. [7]

Our primary focus in this study concerns spatial and temporal patterns in insurgent activity. In future work our aim is to uncover their correlates. There are a total of 7,409 attempted IED attacks in the first six months of 2005, of which 3,882 successfully exploded and 3,527 were deployed but failed to explode and were subsequently found and cleared by Coalition forces. Visual inspection of the data plotted on a map clearly demonstrates that attacks have taken place in many areas of Iraq but with a heavy concentration around Baghdad, and into the Anbar and Ninewa Governorates to the east and north of the capital, respectively. Considering attacks, there were a total of 5,537 recorded incidents that were not classified as

[6] This Center is run by the Aegis Specialist Risk Management Group on behalf of the MNF-I. Details: https://brief.aegisiraq.com

[7] Examples of work on Geographic Profiling of insurgent activities can be found online at: http://www.nta.org/docs/Geoprofiling.pdf / and http://www.tec.army.mil/publications/GeoProMilCap.pdf

IEDs; these include mortar, rocket, surface-to-air, sniper, and small arms attacks, as well as ambushes and grenades. Intuitively, the most significant distinction between the IED and non-IED categories of attacks is that the latter involve an immediate engagement between insurgents and counter-insurgents, whereas the former are spatially- and temporally-remote activities which, whilst often more capital intensive, are arguably less labour intensive.

The chapter proceeds as follows. First, we describe and employ procedures for identifying space-time clustering patterns in insurgent activities. Second, we present a series of tables and graphs to detail the patterns these procedures uncover. Third, we conclude by discussing the possible policy implications of these findings and offer a series of hypotheses regarding potential correlates of the observed patterns.

METHOD AND RESULTS

Identifying space-time clustering

Analyses were conducted to determine whether (for both event types: IED and non-IED attacks) events occurred close to each other in space *and* time more than would be expected if timing and location were independent. The method used was a variant of that developed in epidemiology to test for disease contagion (see Knox, 1964; Besag and Diggle, 1977). It has been detailed elsewhere (Johnson et al., 2007), so only an overview will be provided here.

For a given data set, each event is compared to every other, and the geographic distance and time elapsed between each pair of events computed. This generates ½ n(n-1) comparisons. A contingency table which summarises the results (e.g. how many events occurred within 500m and 14 days of each other) is populated. The dimensions (i.e. the spatial and temporal bandwidths used) of the contingency table are selected to provide a sensitive analysis of the hypothesis tested, whilst ensuring that the observed cell frequencies are adequate for reliability. One might select a temporal bandwidth of one day to provide detail, but at this level of resolution, the cell frequencies may be too small. To ensure validity of inferences made, a range of space-time bandwidths was used. Since the same general pattern emerged for each combination, only those using intervals of 7 days and 500m are reported.

The contingency table generated to summarise the observed distribution is then compared with what would be expected if the timing and location of events were independent. To do this, the process described is repeated but using permutations of the data set in which the date on which the crimes occurred is randomised (or shuffled) across events[8]. As a full permutation is virtually impossible for even a moderately sized data set, a Monte Carlo (MC) simulation is used to draw a random sample of 99 permutations. The results of the MC simulation are then compared with the observed distribution, and the frequency with which each cell value for the observed distribution exceeds those for the permutation test recorded. The number of times that the observed cell frequency exceeds those generated by the MC simulation provides an estimate of the statistical significance of the results for that cell. For example, if an observed cell frequency exceeds those generated by the MC simulation only 50% of the time, this would indicate that the observed value would be expected roughly 50% of the time even if the location and timing of insurgent

[8] As the location of events is preserved, risk heterogeneity – the fact that some places and some periods of time are more risky than others - is accounted for in the analysis.

activities were independent. However, if the observed frequency for a particular cell exceeds the values generated during the MC simulation 95% of the time, then this would indicate that the observed result would be unlikely to occur under the null hypothesis. Formally, the statistical significance (see North et al., 2002) of an observed value for any particular cell is computed using Eq. (1).

$$p = \frac{rank+1}{n+1} \qquad (1)$$

Where *n* is the number of simulations, and *rank* is the position of the observed value in a rank ordered array for that cell

An indication of the size of the observed effect (or Knox ratio) can be derived by dividing the cell frequency for any particular cell by the median value generated by the MC simulation. To illustrate, a value of one so derived would indicate that the observed frequency for a cell was that expected under the null hypothesis. A value of two would indicate that twice as many events occurred within a given space-time proximity of each other as would be expected according to the null hypothesis. In the event that attacks (IED and non-IED) are clustered in space *and* time, the Knox ratios for the cells with the shortest space-time intervals will be above one, indicating that relative to expectation according to the null hypothesis, there is an over-representation of events close in space *and* time.

It is important to note that the approach to analysis takes account of the fact that some locations will be more attractive or accessible to insurgents than others, and that activity may be more intense at some points in time than others. The question of central importance is whether attacks cluster in space *and* time above and beyond what would be expected given these assumptions—evidence which would corroborate the expectation that insurgents act purposively to deploy their scarce resources most efficiently: namely, concentrated locally and episodically.

Results of the Knox Analysis

For the six month interval analysed (January-June 2005), there were a total of 3,775 IED attacks across Iraq which resulted in explosions.   For unexploded IEDs the intended timing of the attack or the date on which the device was planted will be unknown; only the date on which the IED was uncovered will be available. For this reason, data for events of this type were excluded from analysis.

For each incident, data were available regarding the spatial location – accurate to a resolution of 100m – and the date of the attack. The results shown in Table 1 are based on 99 iterations of the MC simulation. In addition to showing the knox ratios, to ease interpretation, each cell of the table is shaded in grayscale proportionate to the value of knox ratio (e.g. a Knox ratio of 1.5 (1.1) would be shaded 50% (10%) grayscale). The findings confirm that IED attacks cluster in space *and* time. That is, while there may exist "hotspots" of activity, the patterns are also dynamic. When an IED attack occurs at one location there appears to be elevation in risk at locations within 2km for a period of around 14-21 days. The pattern generally conforms to one of spatio-temporal decay; decreasing as a function of time and space. It also appears that previously targeted locations are at an elevated risk between 28-35 days after a previous attack. This is not unlike the pattern observed by Berrebi & Lakdawalla (2007) for terrorist attacks in regional and national capital cities in Israel.

In line with the strategies discussed in the introduction, one interpretation of the patterns is that insurgents move and do so with an observable regularity but - in the short term at least - return to the locations of previous attacks when local defences once again permit. Without the addition of counterinsurgency data it is, of course, impossible to show that the patterns are generated by insurgents adopting such strategies, but the patterns are certainly consistent with this suggestion.

INSERT TABLE 1 ABOUT HERE

Table 2 shows the same analysis for the range of non-IED attacks. Again, it is evident that events cluster in space and time, but in this case the pattern is more diffused, with the risk of attack appearing to endure for longer and extending over longer distances. In other words, when a non-IED attack occurs at one location there is an elevated risk at proximate locations (interestingly, more distant locations than for IED attacks—up to 5km in this instance) for a period of 28-35 days. Though more diffuse than the pattern for IED attacks, non-IED attacks then also subsequently also conform to a pattern of spatio-temporal decay. Table 2 also demonstrates that at proximate locations, the risk of attack is lower than expected after seven weeks or so have elapsed.

INSERT TABLE 2 ABOUT HERE

The Duration of Risk Elevation

The general pattern observed – that events (of each type) which occur close to each other in space are more likely to also occur close to each other in time – could be generated by (at least) one of two processes. First, as the analysis so far presented examines only the space-time clustering of pairs of events, it is possible that the observed patterns could be generated by there being many more pairs of events occurring close to each other in space and time, but with there being very few instances where three or more events occur close to each other in space and time (Johnson and Bowers, 2004). Second, it is possible that the results are generated by three or more events clustering in space and time. The two possibilities are shown in Figure 1. The operational implications of the findings for counter-insurgency practices vary according to what type of process generates the findings. If the latter, this means that once an attack occurs at a location a series of attacks are likely to occur swiftly nearby and hence that the allocation of resources to recent attack sites would be wise. If the former, such an allocation of resources would likely prove sub-optimal, making a different response strategy more appropriate.

INSERT FIGURE 1 ABOUT HERE

An alternative approach to analysis involves the examination of poly-order chains of events that occur close in both space *and* time (Johnson et al., 2007; Townsley, 2007). This would provide an indication of the duration of localized increases in the likelihood of insurgent activity and answer the question “after how many attacks are insurgents likely to target new locations?”. For example, if the longest clusters that could be identified generally consisted of only two events, this would suggest that rarely do insurgents sustain their targeting in the same locale for any period of time. To examine this issue, an algorithm was developed to identify series of events that occurred close in both space *and* time, ranging from two events (pairs) onwards.

The approach allowed the frequency of different poly-order chains (e.g. pairs, triples, quads and so on) to be enumerated and compared with chance expectation, assuming that the timing and location of events are independent.

The identification and summary of series of events can be done in a variety of ways. Here, for every (reference) event of a given type (again, IED or non-IED attacks), any antecedent event (of the same type) that occurred within a critical distance and time of it was identified and added to the series. Additionally, any events that occurred within the critical distance and time of one or more events already identified as part of that series were added to the chain. Thus, for every event, the aim of the analysis was to determine how many others had occurred nearby in the recent past[9].

It is important to note that using this method it is possible that any chain identified could be part of a longer chain identified when considering (reference) events that occur later in the data. For example, if event E occurs on day 100 and four events (A,B,C and D) are identified that recently occurred near to it, this would be recorded as a chain of 5 events. If, on day 101, event G occurs near (in space and time) to events A-E, a chain of 6 events will be identified. For the two chains, there will be considerable overlap (five of the six events) in the members of the two sets. Other approaches to analysis exist, but this method allows us to answer the simple question "for how many events did *N* events previously occur nearby in space and time?", which is a question that is likely to have tactical implications. The fact that chain membership is likely to overlap is not a problem for interpretation of the

[9] The number of longer chains will be somewhat underestimated as the data are only available for a six month window of time. This creates a temporal edge effect. In some respects this is not problematic as the observed patterns are compared to those expected, given that there is an edge effect.

analysis as the use of a permutation test allows us to compare the observed values with those expected, assuming the timing and location of events independent[10].

In what follows the critical thresholds for inclusion in a chain were 500m and one-week, respectively. Other thresholds could, of course, be used and the length of the chains identified will be positively related to the thresholds selected. The selection of the thresholds should be informed by the purpose for which the analysis is undertaken. In an operational context, it may be more useful to employ a longer interval (say 1km). However, the aim of the analyses presented here was to illustrate the method and discuss the possible implications of the results.

For IED attacks, the longest series identified consisted of 10 attacks. Before discussing the differences between what was observed and what would be expected, it is important to note the implication of this finding, which is that it clearly illustrates the flux of attacks. If IED events occurred in the same places all the time, considerably longer series would have been identified. This suggests a need for a dynamic capability in the (re)deployment of resources. Simply defending the same areas over time is unlikely to direct resources to the right places at the right times.

INSERT FIGURE 2 ABOUT HERE

Considering what would be expected if the timing and locations of events were independent, essentially the same approach as described in the previous section was used. That is, a permutation test was used such that across iterations of a Monte Carlo simulation, the timing and locations of events were shuffled. To

[10] As a permutation test is used, the assumption of independence – a requirement of traditional statistical tests – is not a requirement.

establish p-values, for every iteration the results of the permutation were compared to the observed data. Figure 2 shows the mean frequencies for chains of each order (2, 3, 4 and so on) that would be expected assuming that there is no dependency regarding where *and* when IED attacks occur. There were significantly more chains of 2-4 events than would be expected if the timing and locations of attacks were independent (all $ps<0.01$). There were few chains of 5 or more events and the numbers observed did not exceed what would be expected on a chance basis, given (for example) the spatial distribution of IED attacks. More generally, the difference between the observed and expected frequencies decreases as a function of the order of chain considered. In a further analysis, a spatial threshold of 1km was used to identify chains. In this case, the longest chain identified was obviously longer (25 events), but the same general pattern – of the observed and expected frequencies converging at longer chain orders - was observed.

For attacks, the longest chain was 32 events. For the purposes of illustration, Figure 3 shows the observed and expected frequencies for chains up to 20 events or more long. The differences between the expected and observed frequencies were statistically significant for all chain lengths and it is evident that, in contrast to the pattern for IED attacks, the difference between the observed and expected frequencies actually increases for higher chain orders[11].

Thus, the profile for attacks is very different to that for IED attacks. Simply put, non-IED attacks—including small arms fire and RPG and mortar attacks appear to be sustained around the same location for longer intervals than do IED attacks. This difference clearly warrants additional investigation. We would suggest that perhaps this can be explained by variance in choices made by insurgents acting

[11] Additional analyses that used a 1km threshold generated the same general patterns. That is, the observed frequencies were always larger than those expected and the ratio of the two increased with chain order. The longest chain identified in this case was 89 events.

strategically to overcome counterinsurgency practices. For instance, IED attacks—having consistently been identified as the greatest threat to coalition troops—attract greater counterinsurgency resources. Accordingly, rational insurgents looking to optimise their application of scarce resources may be more likely to employ a roving strategy in order to circumvent counterinsurgency forces.

Discussion

Patterns of insurgent activity will be a function of many things. In this chapter we have focused on how recent activity might inform the timing and location of future attacks. It appears that for both types of attack (IED and non-IED), the recent locations of events provide useful markers for where future ones will next occur (see also, Townsley et al., 2007). However, the period of time over which historic events offer predictive value appears to vary across attack types. Of the two types considered, the space-time patterns of IEDs seem to be more abrupt, possibly suggesting (as already argued) a more deliberate strategy on the part of insurgents. It also appears to be the case that for IED attacks, the risk of further incidents within a previously targeted locality quickly subsides but then increases again around one month later. This chimes with the findings of Berrebi & Lakdawalla (2007) who – using a different methodology - found a similar pattern for terrorist attacks in politically sensitive cities of Israel (but not in other areas). Further investigation of the reliability of this finding is warranted. So too is the investigation of any factors that might indicate when further (delayed) attacks are likely and when they are not.

In the research reported we presented analyses of the patterns for the two types of attack independently. Had we not done so, we would have failed to uncover the differences in the patterns for the two types of attack and the consequent implications they might have for counterinsurgent forces. Separating the types of attack in this way follows the tradition of those who study situational facilitators of crime opportunities. Such researchers (e.g. Clarke, 1997) have long since suggested that where analyses are conducted to uncover preventive solutions to a given crime *problem* (such as burglary) it will be necessary to separate the crime events into more specific sub-types, where possible. For instance, for burglaries where entry is gained via the rear of a property (which amongst other things affords the offender stealth), the preventive solution is likely to be quite different than where it is gained via the front. In the same way it is important to distinguish different types of insurgent attack; after all, the resources required, the organization necessary and the availability of suitable targets, is likely to vary by attack type.

In addition to studying attack types separately, further analyses might be conducted to see if the space-time patterns for one type of attack are independent of those of the others, or if there exist associations between when and where different types of attack occur. Put another way, following a non-IED insurgent attack at a given location, is it the case that the risk of an IED (or other type of) attack is elevated at proximate locations in the near future? An approach to analysis - which has been applied to the analysis of crime data - has been articulated elsewhere (Johnson et al., 2008) so we will not discuss the method further here. However, it is worth saying that this type of analysis might inform approaches to next event prediction. The general finding that insurgent attacks cluster in space and time has predictive value, and the analyses of poly-order chains offer additional insights by showing how many attacks of a given type are likely to occur within a particular space-time interval of previous events. However, it is possible that still further insight may be provided by the analysis of inter-attack type patterns of insurgent activity.

These findings may (for example) be used to refine existing methods of next event predictions, such as *prospective mapping* (Bowers et al., 2004; Johnson et al., 2007; Johnson et al., 2008). Briefly, this approach to hotspot derivation departs from traditional methods by considering the timing of events as well as their location, along with features of the urban backcloth that might affect crime placement. In analyses so far conducted (Bowers et al., 2004; Johnson et al., 2007; Johnson et al., 2008), the approach has been shown to be more accurate than contending alternatives. An obvious next step would be to see how accurate this type of approach is in the forecasting of when and where insurgent attacks are most likely, and how efficient any search strategies based upon such predictions might be.

More generally, further investigation of spatial variation in risk will be useful. As a starting point, enumerating those locations most (least) at risk will be helpful. Clarke and Newman (2006; Newman and Clarke, 2008) have developed the EVIL DONE acronym to describe those types of location that terrorists are most likely to favor in the USA; these being those that are Exposed, Vital, Iconic, Legitimate, Destructible, Occupied, Near, and Easy. Boba (this volume) provides an illustration of how this type of analysis may be implemented using spatially referenced data and a Geographical Information System. In further work we aim to collate data on features of the urban environment for the Iraq region so that correlates of insurgent activity might be identified. This type of work will require the use of spatial models sensitive to the effects of unmeasured variables (e.g. see Anselin and Kelejian, 1997) so that any patterns so identified do not result from spurious associations.

Counterinsurgent tactics will also be a salient influence on space-time patterns of insurgent activity, either attracting or deflecting it. We are currently in the process of exploring the possibility of modeling the influence of insurgent-counterinsurgent interactions using both real world data and computer simulations (for an example of the application of agent based modeling in the investigation of insurgent activity, see also N.F. Johnson, 2006).

The approach to analysis discussed here is relatively simple but we believe it provides insight that might otherwise go un-noticed or would be unconfirmed. The findings suggest different strategies are likely to be warranted for different types of attack and that attacks occur with a regularity which is likely to make them predictable.

In closing we speculate on how the results suggest counter insurgency resources might be allocated. First, it appears, for instance, that rapid and localised allocations may help to protect locales from the spectre of IED attacks, but a more sustained presence at IED hotspots (potentially covert) may prove beneficial, particularly if research identifies those types of location at which the risk of attack is likely to initially decrease only to subsequently rise again.

Second, one interpretation of the above findings – which resemble a slow pattern of spatial diffusion - is that non-IED attacks are not targeted against iconic locations but, rather, against coalition forces that are locally present. If this is the case, then it may be wise to allocate defences more uniformly so as to minimize the density of targets (in this case clusters of coalition forces) that might attract insurgent attention. Additional effort focused on proactively stemming the flow of arms and munitions might be more effective than simply reacting to new attacks. Again, each of these hypotheses warrants investigation with more detailed data.

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Table 1 Space-time clustering of IED attacks (statistically significant ratios in bold, p<0.025)

Distance between events	Days between events: <7	7-14	14-21	21-28	28-35	35-42	42-49	49-56	56-63
≤500m	**1.49**	1.09	0.99	0.97	**1.13**	0.95	1.08	1.10	0.93
500m-1km	**1.14**	**1.15**	**1.12**	1.04	1.00	0.99	0.99	1.08	**1.17**
1-1.5km	**1.13**	**1.08**	1.04	1.03	1.05	1.07	1.10	1.06	0.99
1.5-2km	**1.06**	0.97	1.07	1.04	0.99	1.04	1.03	1.03	1.05
2-2.5km	1.04	1.01	0.98	0.96	1.02	0.98	1.05	**1.10**	**1.11**
2.5-3km	**1.13**	1.01	1.00	1.07	0.97	0.99	1.05	**1.15**	1.05
3-3.5km	1.03	0.98	1.01	0.98	1.03	1.06	1.05	1.04	1.05
3.5-4km	1.05	1.01	1.02	0.99	0.95	0.99	1.06	1.00	0.99
4-4.5km	1.02	1.03	1.00	1.03	1.00	1.00	1.00	1.00	1.02
4.5-5km	1.04	0.99	0.95	0.99	1.03	0.96	1.03	1.01	1.02

Note: The data were accurate to a resolution of 100m and so an examination of attacks at the exact same location was not possible

Table 2 Space-time clustering of Attacks (statistically significant ratios in bold, p<0.025)

Distance between events	Days between events: <7	7-14	14-21	21-28	28-35	35-42	42-49	49-56	56-63
≤500m	**1.73**	**1.31**	**1.16**	**1.11**	**1.14**	1.01	0.93	0.80	0.95
500-1km	**1.34**	**1.24**	**1.20**	**1.14**	**1.12**	1.02	0.92	0.86	0.97
1-1.5km	**1.28**	**1.22**	**1.14**	**1.12**	**1.06**	1.01	0.97	0.98	0.91
1.5-2km	**1.19**	**1.14**	**1.13**	**1.10**	**1.05**	1.01	1.02	0.98	0.97
2-2.5km	**1.20**	**1.13**	**1.11**	**1.09**	**1.11**	1.02	1.02	0.99	0.95
2.5-3km	**1.17**	**1.09**	**1.07**	**1.07**	**1.09**	1.02	**1.06**	**1.04**	1.01
3-3.5km	**1.13**	**1.08**	**1.07**	**1.10**	**1.04**	1.04	1.02	1.02	1.00
3.5-4km	**1.13**	**1.10**	**1.10**	**1.08**	1.03	1.03	1.00	0.99	1.00
4-4.5km	**1.10**	**1.06**	**1.08**	**1.05**	**1.06**	1.01	**1.06**	**1.07**	**1.06**
4.5-5km	**1.08**	**1.08**	**1.09**	1.01	**1.05**	1.03	**1.07**	**1.05**	**1.06**

Note: The data were accurate to a resolution of 100m and so an examination of attacks at the exact same location was not possible

Figure 1 Illustrations of different distributions that would generate the same patterns of space-time clustering in the analysis of pairs of events

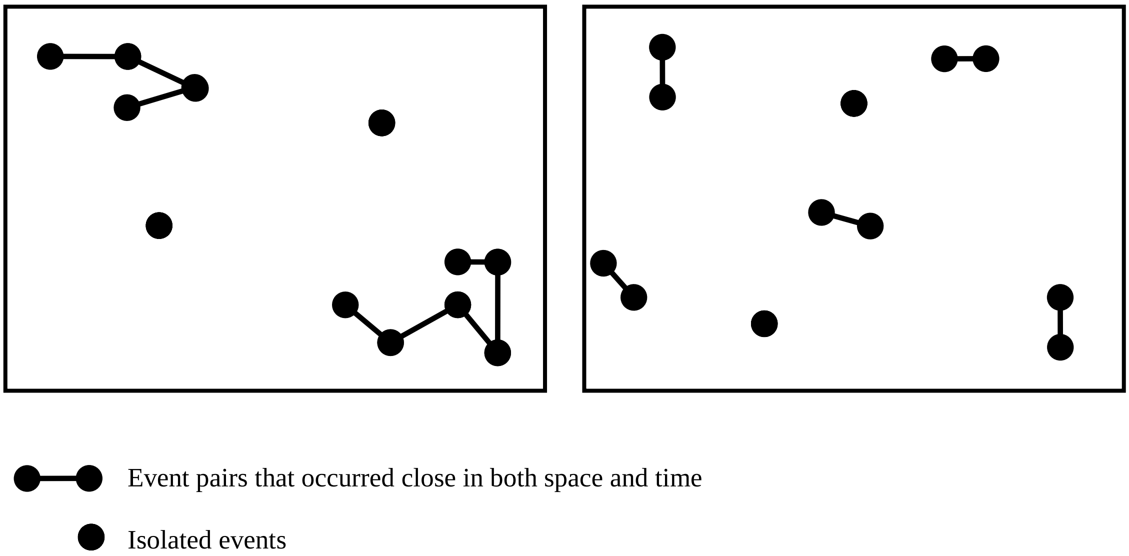

Figure 2 Analysis of poly-order chains for IED attacks (NOTE: y-axis is on a log scale)

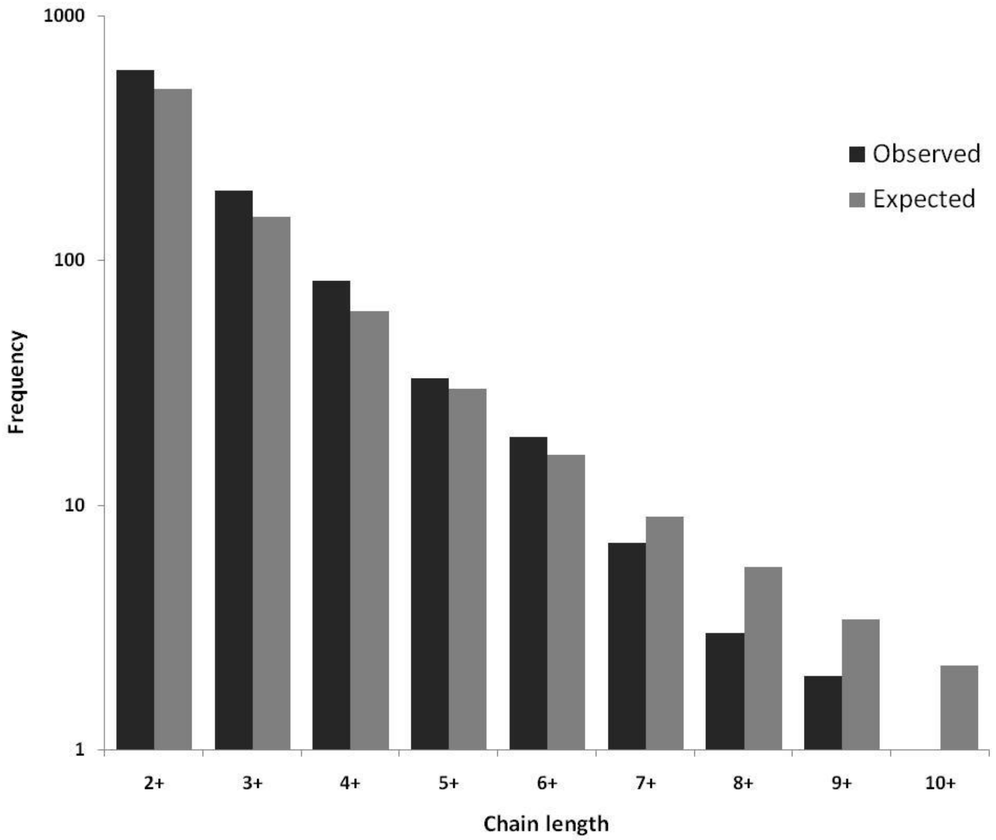

Figure 3 Analysis of poly-order chains for non-IED attacks (NOTE: y-axis is on a log scale)