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Patterns of war

The rules of military engagement need a rethink to cope with modern conflicts, says **Kate Ravilious**

IN 2003, US soldiers in Iraq were given a pack of playing cards showing Iraq's "most-wanted". In the top position – the ace of spades – was Saddam Hussein. His sons Qusay and Uday were the ace of clubs and the ace of hearts. The message was simple: capture the entire pack, and regime change would be achieved and the war in Iraq won.

It hasn't worked out to be that easy. Part of the reason is that in this age of terrorist attacks, insurgencies and "asymmetric" wars between parties of vastly differing firepower, the dynamics of conflicts have shifted irrevocably. Now mathematicians are starting to build models of how such present-day warfare plays out. As they do so, they are coming to the conclusion that it is time to rewrite the military rule book.

Mathematics can never hope to fully encapsulate the complex business of war. It has long been used, however, to suggest tactical approaches. During the first world war, for example, the English polymath Frederick Lanchester devised a series of equations to calculate the power balance between opposing forces in a classic symmetric war, in which two hierarchically organised armies fight until one keels over.

Lanchester showed that long-range weapons had changed such conflicts. In old-style one-on-one combat, an army's strength was proportional to the number of men or guns at its disposal. Weapons that allowed many targets to be attacked simultaneously increased that potential, upping an army's strength so that it was proportional to the square of its firepower. Concentrating your army's firepower, dividing enemy forces, and removing opposition leaders to disable the units under their control were key tactics that followed (see "Lanchester in action", page 37).

Other statistical approaches have been used to make comparisons between wars. In 1948, Lewis Fry Richardson, a British physicist and pacifist who was an ambulance driver during the first world war, studied the fatalities of all wars between 1815 and 1945. When he split conflicts according to the number of fatalities he found a clear trend. Little skirmishes with few casualties were common, big wars with many casualties were rare, and between the two extremes a smooth curve connected the size and frequency of battles.

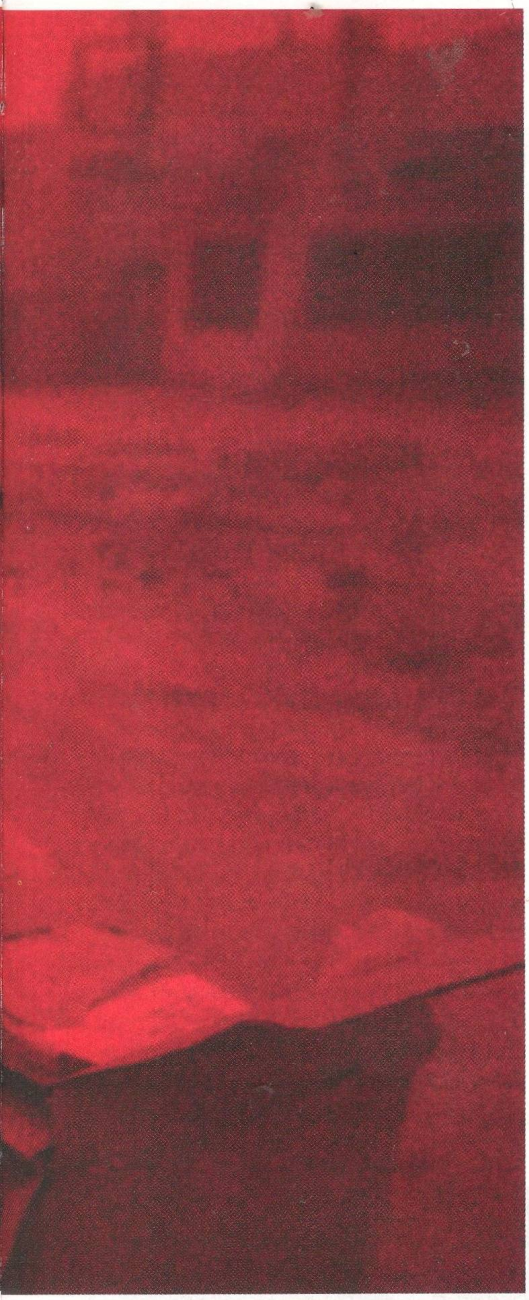
Such "power-law" behaviour contrasts with the "normal" or bell-curve distribution, in which average-sized events are the most common, with extremely large and extremely small events significantly less likely. Similar power laws are seen in other complex systems with many moving parts: small earthquakes occur more often than medium-size earthquakes, which occur more often than large earthquakes; small stock market fluctuations far outnumber crashes.

Something similar is true of modern asymmetric conflicts, too. Analysing fatality statistics from acts of terrorism since 1968, Aaron Clauset of the Santa Fe Institute in New Mexico and colleagues have shown that terrorism produces an even closer fit to a power law than conventional warfare does. What's more, the precise shape of the power-law curve varies according to location. Terrorist attacks within industrialised nations have a shallower power-law gradient than those in developing nations, indicating that they tend to be fewer in number, but bigger when they do occur (*Journal of Conflict Resolution*, vol 51, p 58). "Possibly it is easier to get hold of weapons in the developing world, or perhaps the infrastructure of the industrialised world lends itself to larger-scale attacks," says Clauset.

"Mathematics will never capture the full complexity of war. But it can suggest tactical approaches"

Similarly, Neil Johnson and his colleagues at the University of Miami in Florida have compared the fatality statistics of individual battles within symmetric conflicts, such as the world wars, and insurgent conflicts in which a regular army takes on bands of rebels or freedom fighters. For insurgent conflicts the power-law fit was particularly striking: each individual war had a power law with a gradient close to 2.5. That means an attack killing 10 people is 316 times as likely as an attack killing 100 people, as 100/10 raised to the power 2.5 is 316.

That might seem to suggest that the focus should be on reducing small-scale conflicts between warring groups, but don't be fooled. Extremely large events are still more likely under a power law than they would be with a normal distribution, and can potentially entail more casualties than many small events. So in Afghanistan, for example, resources should not just be channelled into countering small-scale insurgent attacks, says Brian Tivnan of the MITRE Corporation in McLean, Virginia, which carries out research and development for the US Department of Defense, among other agencies. "It changes the risk profile ›



Insurgent wars such as in Afghanistan and Iraq require radical new tactics

War with drugs

With researchers from Harvard Medical School and the University of Miami's Sylvester Comprehensive Cancer Center, Neil Johnson of the University of Miami is looking at how his insurgent conflict model might shape tactics in another fight – the battle between infections and the drugs used to combat them.

In some people, cancer spreads further and faster than in others. To find out why, Johnson replaced the insurgent groups in his model with tumours. Preliminary results, which he presented at the Targeting Cancer Invasion and Metastasis symposium in Miami in February, suggest that the rate of spread is linked to how efficiently the immune system is organised. "Like troops that fragment into smaller groups, a system that monitors lots of sites appears to be more successful in curbing the spread of cancer," he says.

Meanwhile, when it comes to using drugs to combat disease, the way doses are administered could be vital: one big dose does more than many small ones. "If you consider the disease itself to be like the insurgents, then the drugs are like peacekeepers," says Johnson. "In order to be effective peacekeepers, they must be bigger than the warring groups they are trying to divide."

and tells us that large events have a non-zero probability. If we only respond to averages we can be severely misled," he says.

A conflict's progress can also be determined by the way power-law gradients change over time, says Johnson. In the guerrilla war between the Colombian government and the revolutionary group FARC, for example, there was a steady decrease in the power-law slope from around 3 in 1989 to 2.5 in 2004 (see graph, opposite). That reflects an escalation from a war characterised by frequent small skirmishes to one with bigger clashes, as the rebel group increased in size and organisation. In contrast, the conflict in Iraq started off in 2003 with a gradient of 2, but this soon increased – probably reflecting a change in the nature of the enemy from rigid units of the regular Iraqi army to smaller insurgent groups, Johnson says (arxiv.org/abs/physics/0605035).

Can these insights determine tactics for modern warfare? Possibly, but first we need an additional piece of the puzzle: why does the power-law relationship exist in the first place? To investigate, Johnson and his colleagues modelled insurgent groups to see if they could reproduce the observed behaviour.

This is where things begin to diverge from conventional conflict models such as Lanchester's. These treat warring parties like chemicals reacting in a test tube. "Everything is mixed with everything and the rate of casualties is proportional to the concentrations," says Johnson. "This kind of model works perfectly in a 'Hollywood' war, where the armies are lined up opposite each other at dawn and bash each other all day, but it doesn't work for insurgency."

Instead, Johnson's team allowed their model insurgent groups to act dynamically, developing and breaking up over time like a poorly mixed chemical reaction. They applied two rules to create this behaviour: if different groups made contact they would join to make a larger group, but if any group sensed danger it would fragment completely.

In contrast to the traditional armies, these insurgent groups have no permanent network of leaders. "It is similar to the behaviour you see amongst prides of lions," says Johnson, with one crucial difference: the groups can communicate over long distances. "Long-range communications – cellphones, the internet and radio, for example – can act as an invisible hand in terms of coordination," says Johnson. Adding this to the model turned out to be the crucial tweak that allowed it to reproduce the power law seen in real insurgent wars (*Nature*, vol 462, p 912).

Johnson presented his findings most recently in June at a conference on "operational adaptation" sponsored by the US Office of Naval Research Global, a division of the US Department of the Navy, and held at the University of Edinburgh, UK. Initial reactions have been cautiously positive. "I think the model captures two very prominent features of terrorist groups – their dynamic fusion and fission, and the reliance on long-range communication, particularly the way mass media is used to appeal to an audience," says Lars-Erik Cederman of the Centre for International Conflict Research at the Swiss Federal Institute of Technology in Zurich. But he cautions against oversimplification. As with other highly complex systems such as the weather, the reality of war is often messy, placing a limit on what can be predicted or explained.

Clauset agrees. "It is very difficult to nail down precisely what causes an observed behavioural pattern," he says. "I think there are still a number of possible explanations, of which this model is just one."

Informed strategy

Others, such as Chris Danforth, a mathematician at the University of Vermont in Burlington, think the model supplies valuable information for ongoing wars. "It could provide military strategists with statistical measures of similarity between insurgent campaigns, and potentially suggest when one temporal or spatial pattern of behaviour may be giving way to another," he says. London's Metropolitan Police Service appears to agree: it recently approached Johnson to see if he can help detect potential terrorist activity in the build-up to the 2012 Olympic Games.

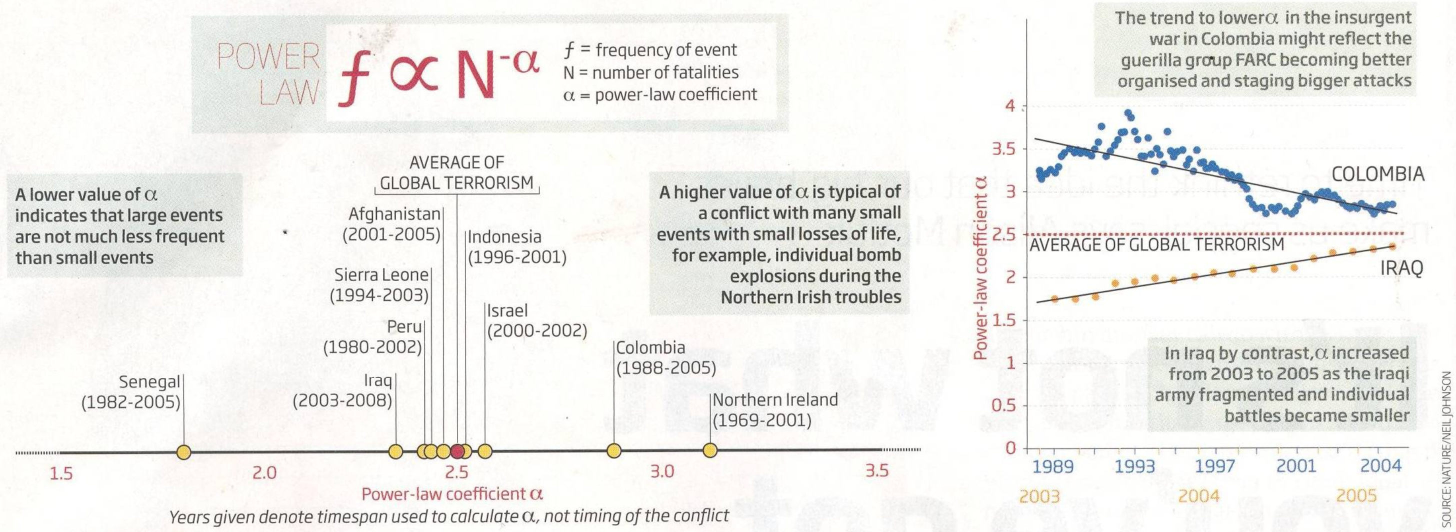
Johnson is confident his model can inform tactics in real conflict situations – wherever they might occur (see "War with drugs", above). Its suggestions for dealing with the enemy are very different to Lanchester's.

In insurgent battles, it is not always obvious who the enemy is

LAURA RAUCH/AP/PA

Power wars

The size of individual battles during a conflict has a smooth "power law" behaviour: small events with few fatalities occur more often than big events with many fatalities. Assessing how much more often can tell us something about the nature and progress of a war



When faced with insurgent warfare, "it is better to split your troops into smaller groups and send them out to do multiple small-scale attacks", he says. When he began working on his model several years ago, Johnson says he was invited to meet US top brass. Perhaps as a consequence, in recent years troops in Iraq have been split into smaller groups.

The fluidity of insurgent groups also suggests that taking out the top dogs is unlikely to disable an enemy for long. "An insurgency behaves like a 'soup-of-groups', with no permanent network or leaders. So, as we have seen in Iraq and Afghanistan, knocking out the people we perceive to be in command has little effect," says Johnson.

Both Johnson's and Clauset's findings suggest a different strategy: cutting insurgency at source. "I call this the 'starve the beast' approach," says Clauset. "If an insurgent grouping is unable to replace the members it loses or acquire new resources, it must eventually collapse – just like a regular business whose product no one wants to buy."

This philosophy is already being put into practice. "Rather than engaging with the enemy we have started to engage with the local community in Iraq, listening to their concerns and helping them regain control from the insurgent groups," says Tivnan.

Focusing on long-range communication is another approach to overcoming insurgent groups. "Media attention drives the recruitment cycle and we need to understand that," says Tivnan. With Johnson, Danforth and others, he is analysing news articles and status updates from social networking sites such as Twitter, noting the frequency of particular words. The team hope this will allow them to judge the "mood" of a country, region or particular group of people (*Journal of Happiness Studies*, DOI: 10.1007/s10902-009-9150-9). "We are looking into the potential for identifying coupled signals between media reports and terrorist events, to see if there is some way to foretell an increased likelihood of attack," he says. An increase in the use of words relating to organising and planning might hint at an imminent attack, for instance, or a surge in positive words following media reports on a terrorist strike could suggest an increase in potential recruits for an insurgent group.

Tivnan is also bringing Johnson's and Clauset's models to the attention of a US Department of Defense body he is part of, the Joint Improvised Explosive Device Defeat Organization or JIEDDO, which focuses on roadside bombs. "We are using these models to understand how these organisations work, where their raw materials come from and where their key supply points are," he says. "We are also working out how best to focus our limited resources to gather intelligence."

This is an ongoing process. One consequence of the dynamics of the new models is that, like the natural systems they mirror, terrorists and insurgents will rapidly evolve new strategies in response to changes in their environment and the tactics of their opponents. Unless mathematicians can predict these "mutations", staying ahead of the game will be a tough task. The rules of war are being rewritten – but they could prove as fluid as the insurgent groups they are designed to beat. ■

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Lanchester in action

The tactician Frederick Lanchester's ideas almost certainly influenced military thinking in the first and second world wars - in battles that took place, and some that didn't.

"The Battle of Jutland was the great Lanchestrian battle that never quite happened," says Niall MacKay, a mathematician at the University of York, UK, who has studied patterns in historic battles. On 31 May 1916, shortly after Lanchester had published his ideas on military superiority in an era of long-range weapons, German and British battleships lined up to fight in the North Sea near Jutland, Denmark. After initial heavy clashes the German fleet headed back to port, realising they were outgunned. After the battle, John Jellicoe, commander of the British forces, wrote to Lanchester, "your *N*-square law has become quite famous".

With aerial combat, Lanchester's laws seem less successful. Analysing daily data from the Battle of Britain in 1940, MacKay has shown that the British and their allies suffered heavy losses during its first half, when their favoured strategy was "big wings" - large formations of aircraft that concentrated firepower, as Lanchester recommended. Only later, when the tactic of using smaller "rapid-response" units to meet a raid from many directions was introduced, did the battle turn (*Naval Research Logistics*, DOI: 10.1002/nav.20328).