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Iruba: An Agent-Based Model of the Guerrilla War Process

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Abstract. We suggest that, as an extension to traditional historical analysis, it is potentially insightful and useful to model guerrilla wars in agent-based terms. Accordingly, the Iruba agent-based model of a guerrilla war has been designed and implemented. Some experimental results obtained with the model and conclusions that may be drawn from them are reported, particularly in relation to Guevara and Debray’s theory of “foco” and to a set of sufficient conditions for insurgent success asserted by T. E. Lawrence. Then the limitations of the Iruba and similar models are considered and the need for and possibility of direct analysis of an agent-based computational model discussed.

Keywords: agent-based modelling, guerrilla wars, asymmetric warfare, Iruba model, validation, algorithmic model analysis

INTRODUCTION

Both guerrilla warfare itself and the study of it are at least as old as recorded history (e.g. the writings of Sun Tzu in the fourth century BC). Although the concept of guerrilla warfare is perhaps a little unclear, all agree that it involves asymmetric forces with the weaker force (in conventional terms) deploying mobility and surprise “hit and run” tactics, and using difficult terrain or a sympathetic general population as a safe refuge as required. Typically there is an “insurgency” and “regime forces”. Complementary political action is entwined. “Terror” may be used at an extreme by either side (e.g. Sederberg, 1989) either as a consequence of a failure of discipline or as a deliberate means to victory.

Relatively modern studies of guerrilla warfare, such as those of Mao Tse-Tung and Che Guevara (1962), Tabor (1970), Gann (1971), Arquilla and Ronfeldt (2001), Beckett (2001), offer general insights coupled with practical guidance, from the perspective of both insurgents and counter-insurgents. In what follows we shall consider particularly Che Guevara and Regis Debray’s theory of “foco” (Beckett, 2001, p. 170-1) and the following well-known assertion of T. E. Lawrence:

"Granted mobility, security (in the form of denying targets to the enemy), time and doctrine (the idea to convert every subject to friendliness) victory will rest with the insurgents, for the algebraical factors are in the end decisive, and against them perfections of means and spirit struggle quite in vain”

(Lawrence, 1929, page 953).

There are more than a dozen ongoing guerrilla conflicts worldwide (notably in Chechnya, Columbia, Iraq, Nepal, Spain, Sri Lanka) in various stages of development. Thus there is a pressing need for maximum scientific understanding to be achieved. Agent-based modelling on a computer offers a potential way to find new understandings and to enhance those already documented in the literature.

Previous and relevant agent-based modelling studies are those of Epstein (2002) and Raczynski (2004). Epstein reports an interesting series of experiments with a model that captures a form of “decentralised rebellion” reflecting initial population grievance levels and degree of perceived regime legitimacy. The model is grounded at the level of the individual and targets “recognisable macroscopic revolutionary dynamics” and effective methods of suppression. Raczynski’s study puts the emphasis on the dynamics of terrorist and counter-terrorist organisational structures and on the process of destroying terrorist organization links by the anti-terrorist agents.

Again, agents correspond to individuals. Neither study seeks objectively to model a guerrilla war as a whole.

There is, of course, much ongoing work deploying simulations and "intelligent" agents in mainstream defence contexts (see, for example, Mittu, 2004) but such work is typically concerned to enhance existing military capabilities or to support planned military operations rather than to build scientific understanding.

THE IRUBA MODEL

Standard agent-based social modelling procedure (Doran and Gilbert, 1994; Doran, 1997; Gilbert and Troitzsch, 1999) envisages the following stages: initial study of target social "system", formulation of model, validation of model, use of model to gain insights into target system. Key issues are the choice of computational structures to represent agents, the nature of agent interactions, the agents' joint environment, and the specific techniques adopted to validate the model, that is, to ensure its reliability as a source of insight about the target.

The Iruba project at the University of Essex is following this approach to construct and experiment with a holistic generic model of a guerrilla war sufficiently realistic to offer new insights into dynamics or to further develop existing insights. In the model agents correspond to guerrilla bands, regime bases or outposts, and to headquarters on each side. A particular objective is to establish sets of conditions expressed in terms of the model's parameters and structures that guarantee that an insurgency will succeed or, alternatively, will fail.

The Iruba model has been made broadly realistic having regard to the relevant literature. In particular, the model is loosely based on (extensive descriptions of) guerrilla wars that took place in the last century in Ireland (1919-1921) and in Cuba (1956-1959), with some further features drawn from the Arab Revolt against the Turks in the Hejaz (1917-1918) towards the end of the First World War.[1] A reliable source for these conflicts is Beckett (2001) but there are many others. The most important structural and behavioural concepts used in building the Iruba model are drawn from the Irish insurgency: near autonomous regions with only limited central control; mobility notably in the form of "flying columns"; limited weaponry; the importance of terrain; and the importance of ideology and popular support.[2]

Correspondingly, the Iruba model is structured as a network of 32 relatively autonomous regions that vary in terrain and population. The population of a region provides a (finite) recruitment pool for both insurgents and regime forces. Initially the regime forces are relatively numerous, distributed in bases over the island, and relatively static, whilst the insurgents are small in number, localised, mobile and hard to find. As indicated, computational agents represent guerrilla cells/bands and regime bases and insurgent and regime headquarters. Attacks take place within regions following simple rational strategies. For example, a guerrilla band may attack a poorly defended regime base, with the outcome dependent upon terrain, relative numbers and weaponry, and random factors. A successful attack may well lead to capture of weapons. Movement of insurgent or regime forces between neighbouring regions takes place under appropriate conditions. For example, neither the forces that are moved nor those that remain behind are left at significant risk (but see later – hyper-mobility). Recruitment to insurgents and to regime forces (and defection from regime forces) reflects the numbers and attitudes of the so far uncommitted general population of the region in question. This population will partially support the insurgents, and will partially be aware of the insurgency, depending upon the conflict history in that region. These two "attitude" variables and their use are intended to go some way towards capturing the dynamics of population opinion and its impact upon the course of the insurgency.

The core cycle of the model may be expressed in outline pseudo-code as:

Repeat
    Attacks and their impact
    HQ decisions
    Recruitment
    Force movement
Until termination

As indicated above, a degree of central control by "headquarters" agents is possible for both sides. If an insurgency grows, regime forces

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[1] In each of these examples, the insurgents proved (more or less) successful. However, the structure of the Iruba model also allows regime success as will become apparent.

[2] The reader should note that there is often much in the published descriptions of insurgencies that is inaccurate and biased to one side or the other. This is certainly true of aspects of the Irish insurgency as has been amply demonstrated by Hart (2003).

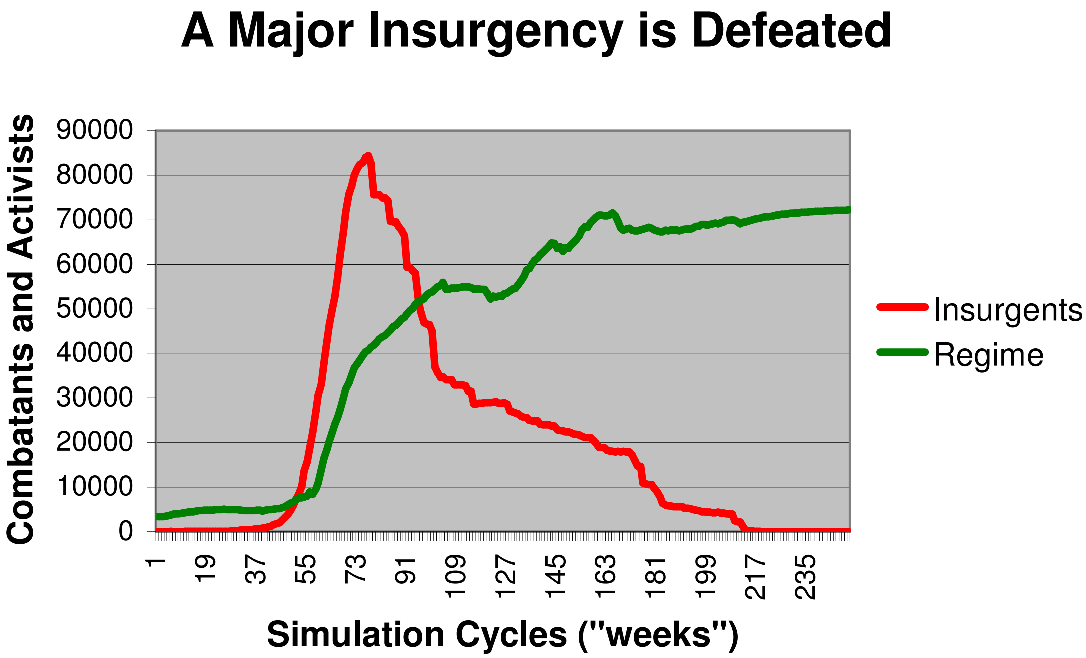

Figure 1. A simulated insurgency "takes off" but is then defeated by regime counter-action. See text for further commentary.

may be concentrated into regions where the insurgency is at its strongest. Furthermore, faced with a dangerous insurgency the regime may take "all out" measures (comparable with, for example, the so called "Salvador option").[3] On the other side, in appropriate circumstances the insurgents may be switched into "hyper-mobile" mode (comparable with the use of "flying columns" by the IRA in Ireland) and/or an "all out" attack across a range of regions or even the entire island, may be triggered (compare the Tet Offensive in the Vietnam war).

Victory in this model is a matter either of insurgent annihilation, or of the insurgents achieving numerical superiority and hence, by assumption, political power. At several points the model invokes chance factors (using a pseudo-random number generator) so that the success or failure of an insurgency may vary with the pseudo-random number stream seed even if all other model setting are the same.

The Iruba model has been implemented in the C programming language.[4] Although some model variables (e.g. population support for insurgents) are updated by simple mathematical relationships, many aspects of the model structure are much more complex. For example, agents (guerrilla bands, regime bases and HQs) are essentially expressed as sets of conditional rules. Thus, even if feasible, formal mathematical or logical specification of the model, independent of the code would achieve nothing (but see later).

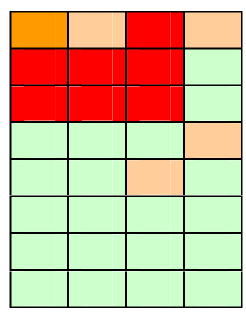

Figure 2. Shows the spatial distribution of the insurgency of Fig 1 on cycle 84 (just after its maximum). The insurgents (red) are still concentrated around their start point in the (mountainous) "north-west" of the Iruba "island". Most of the island remains under regime (green) control and the regime is beginning to regain control of the core region of the insurgency

EXPERIMENTAL RESULTS AND INTERPRETATIONS

A typical insurgency within the Iruba model is shown in Figure 1. This particular insurgency fails after making good initial progress. The regime goes into a sustained "all-out" mode when the insurgency reaches a certain size (in this case, 15000 personnel in total see Table 5). The immediate effect of this spatially to

[3]For a discussion of the "Salvador option" see Michael Hirsh and John Barry, NEWSWEEK, Jan 10th, 2005.

[4] Guidance on downloading and running the Iruba code is available by email from the author.

contain the insurgency and it is ultimately decisive, in spite of further insurgent successes, when the recruitment pool within the insurgency area is exhausted. It is important to know that the number of weapons available to the insurgents is restricted by their ability to capture weapons from the regime forces. This means that for much of the time the insurgency in Figure 1 is much less powerful than its numbers suggest. Figure 2 is a snapshot of the spatial development of this insurgency at its maximum showing how it has spread out from its region of origin in the mountainous "north-west" of the "island".

Experimental trials[5] with the Iruba model show, as expected, that victory for the insurgents or for the regime in the model depends crucially upon parameter settings. Initial experiments have focused on the impact of the initial size of the insurgent group, and of a limited form of central decision making by both insurgents and regime forces. Part of the motivation for the experiments was to test *foco* theory as propounded by Guevara and Debray (Beckett, 2001, p 170-1) following Castro's success. This holds that even a very small dedicated group of insurgents will succeed provided that they have a political as well as military strategy, and provided that there is a significant level of initial support in the population at large.

Initial guerrilla band size	**30**	**35**	**40**	**45**	**50**	**55**
Insurgent success (%)	**5**	**28**	**58**	**79**	**86**	**90**
Insurgent success (%) if regime force concentration	**3**	**23**	**45**	**77**	**83**	**80**

Table 1 Impact of initial guerrilla band size on insurgent success rate. Success is taken to mean that the total insurgent force has grown to more than 100,000. Results were compiled from 100 trials (ie 100 simulated guerrilla wars) for each band size, each with a timespan of 150 cycles (notionally weeks). For other parameters settings see text.

Iruba results (Table 1) suggest that, with this particular calibration of the model, an initial band size of about 40 is needed to give a 50% chance of insurgent success. The insurgent success rate is significantly reduced if there is an element of centralised force concentration on the regime side. In this (and the following) experiments the population in each region was initially set at 10,000 and was fully "passive" with only 10% insurgent support. Other parameters in the Iruba model were set at plausible values.

For comparison, at the outset of his Cuban insurgency Castro initially had 81 followers, who were almost immediately reduced to about 20 in an attack by regime forces. The results of Table 1 indicate the unreliability of *foco* theory as propounded by Guevara and Debray. In fact, most insurgencies inspired by *foco* theory do seem to have failed (Beckett, 2001, p. 171).

Insurgent mobility	**0**	**0.01**	**0.02**	**0.03**	**0.04**
Insurgent success (%)	**0**	**78**	**84**	**84**	**86**

Table 2 Shows variation of insurgent success with mobility. "Insurgent mobility" is a measure of the probability of movement of insurgent forces on any specific occasion. As in Table 1 success rates shown are based on 100 trials, each of length 150 cycles, with an insurgent success criterion of 100,000. Initial insurgent band size is 50.

For the insurgency to spread beyond its region of origin insurgent forces must obviously be mobile. The results shown in Table 2 indicate that even minimal mobility is sufficient. By contrast Table 3 presents results obtained when the insurgents react to regime force concentration by *hyper-mobility*, that is, by continually and relatively incautiously moving forces from region to region ("flying columns"). Perhaps predictably, this strategy proves disastrous for the insurgents.

Initial Guerrilla Band Size	**100**	**300**	**500**
Insurgent success rate (%) with rfc	**96**	**100**	**100**
Insurgent success rate (%) with rfc if insurgents react with hyper-mobility	**0**	**3**	**16**

Table 3 Impact of initial guerrilla band size on insurgent success rate when insurgents react to regime force concentration (rfc) with hyper-mobility. Hyper-mobility typically makes the insurgents much *less* successful. Success is here defined to mean merely that the total insurgent force exceeds 10,000 implying that a minimal amount of spatial spread has been achieved.

[5] Using Iruba version 5.9 throughout.

Table 4 shows what happens when the insurgents are made more effective in attack, and when their efficiency at recruitment (in real life partly a matter of communication) increases. Interestingly, the results suggest that within the Iruba model effective recruitment is more important than military skills.

	1.0	1.5	2.0
1.0	**58**	**68**	**68**
1.5	**73**	**86**	**90**
2.0	**94**	**95**	**97**

Table 4 Impact of insurgent attack effectiveness and insurgent recruitment efficiency. The former increases with column, the latter with row. Table entries are insurgent success rates (again calculated over 100 trials), with a success criterion of 100,000. Initial insurgent band size is 50.

Taken together these results suggest that sufficient preconditions for insurgent success in the Iruba model as calibrated are: a sufficiently large initial band, at least minimal mobility, attack efficiency, some initial population support, and communication processes by which insurgent successes impact the population at large and increase awareness and support for the insurgents. These preconditions partly agree and partly contrast with those put forward by Lawrence: mobility, security and political/social persuasiveness. The results presented in Table 3 also qualify (in a rather obvious way) the mobility called for in Lawrence's set of insurgent success preconditions. Movement must be considered and appropriately directed.

In all these results a potential positive feedback loop is apparent: *increasing insurgent numbers make insurgent success more likely which increases population support for the insurgents and hence recruitment to and the numbers of the insurgents.* All the forgoing results suggest that if this loop is reliably established, and if spatial spread is achieved, then the insurgents succeed. If not, then they partially or completely fail. However it is possible, within the model, for the loop to be disrupted even when it has been established. In Table 5 is shown the average impact of an "all out" regime counter attack on the insurgents when triggered by the insurgency reaching a threshold total size.

An "all-out" regime counter attack comprises a set of regime changes including better attack efficiency, more effective recruitment, more focussed force concentration, and more effective insurgent group detection techniques, all implemented by appropriate parameter adjustments within the model. Once these changes are triggered in a particular trial, they remain in place until the end of it.

Regime counter-attack threshold	**5000**	**10000**	**30,000**	**50,000**
Insurgent success rate %	**0**	**4**	**27**	**52**

Table 5 Insurgent success rates when, in addition to rfc, an "all out" regime counter attack is triggered at the stated insurgency size. Success criterion for insurgents is 100,000, and table entries are again based on 100 trials each here of length 300 cycles. Recall that a total insurgency size of more than 10,000 implies that the insurgency has spread beyond its initial region.

Table 5 indicates that an "all out" response by the regime is highly effective, especially if deployed early. For comparison, with no "all-out" counter-attack at all the insurgent success rate is 88.

LIMITATIONS OF THE MODEL

Complex as it is, a very great deal of relevance is missing from the Iruba model. The omissions include matters of relative detail (for example, different types of attack including explicit "terror" attacks and assassinations, the distinction between death, injury, and imprisonment, and intelligence gathering) and such major matters as population movement, external third party involvement, and the political and administrative structures that insurgents often create as part of their struggle.

A particularly thought provoking challenge for model builders is the demonstrated importance of able and charismatic insurgent leaders such as T.E. Lawrence, Michael Collins, and Fidel Castro, or, on the counter-insurgency side, Sir Gerald Templer (who carried through a successful "hearts and minds" counter-insurgency policy for the British in Malaysia in 1952-4). How can such leadership be built into a computational model? Whilst leadership and charisma can to some degree be expressed by choice of values for parameters that characterize individual agents (e.g. willingness to fight and take risks, willingness to spread propaganda) and that characterize the general population (recall that the Iruba model contains two variables that express the levels of awareness and of support for the insurgents that exists within the general population), this seems inadequate. For example, a key aspect of effective leadership is surely the ability to assess complex situations and decide what should be done. But we do not really know how to incorporate such abilities into a model. And the emotional appeal of the charismatic personality seems quite beyond us to model.

Similar considerations concern ideologies (including religious and nationalist ideologies) that either or both of insurgents and regime may hold to. Ideological belief systems are typical components of guerrilla warfare. At an extreme, consider the likely beliefs and motivation of a "suicide bomber". Although the typical dynamics of belief systems may be studied abstractly and independently of any individual believer, belief systems are expressed in the thinking and actions of individuals, and shaped by events, and it is far from clear how these processes can be captured within computational agents and their inter-relationships in models of the Iruba type. This matters because ideology may well be a key factor in determining response to events.

METHODOLOGICAL PROBLEMS

It soon becomes clear that guerrilla warfare presents agent-based modellers with particular and major *methodological* difficulties.

The most apparent of these difficulties is that a realistic model of the guerrilla war process as a whole, as it extends in space and time, quickly becomes very complex and correspondingly difficult to work with and validate. To the extent that agent cognition and inter-agent communication is included in the model, its complexity much increases.

Experience with the Iruba model has already indicated that such models contain a wide range of adjustable parameters and also many model components that can be structured in alternative ways. The previously discussed studies of Epstein and of Raczynski confirm this. Which parameter values and which structural alternatives should be used are impossible to determine with any confidence even for a specific ongoing conflict. Even where numerical measures are available in the literature (e.g. kill rates in engagements, availability of weapons – see Hart, 2003) these are typically approximate, not fully reliable and refer only to a specific conflict. Any idea of surveying insurgents, say, to establish empirically the risks they are prepared to take is clearly a non-starter. Yet seemingly quite minor matters (e.g. what happens to the weapons carried by an insurgent when he or she is eliminated?) can have far reaching consequences All this means that such models are hard to validate and experimental conclusions drawn from them are difficult to take seriously.

There seem to be two possible ways out of these difficulties. The first is to work with a more highly abstract and simplified model, concentrating, perhaps, on the feedback loop described earlier. The problem with this approach is that the structure of the model is then necessarily based on macro-assumptions derived largely from the preconceptions and inferences of its designer(s). But to discover what high-level properties *emerge* from the low level detail is a large part of the *raison d'etre* of a modelling study such as this. We wish to minimise reliance on subjective assumptions or beliefs. Can simplifying abstractions such as feedback loops be discovered algorithmically? We return to this question shortly.

An interesting second option is to work with a generic, relatively detailed and broad based, "all possibilities included" model, with a correspondingly very large parameter and alternative component space and to search for generalisations that hold over significant regions of this space. The literature of guerrilla warfare suggests, perhaps surprisingly, that such generalisations do exist – for example, the Lawrence assertion considered earlier. But how can such generalisations be found from a computational model? For complex models comprehensive trials are impossibly laborious. Fortunately, it may be possible to derive simple but potentially important generalisations analytically by working from the properties of the model itself, *provided that the model is expressed in tractable terms rather than by using the full expressiveness of a general purpose programming language.*

PRODUCTION SYSTEM MODELS AND THEIR ANALYSIS

In the previous section we suggested that it might be possible to analyse an agent based model directly, provided that it was expressed in tractable terms. One possible way of rendering a model analytically tractable is by formulating it as a *production system*.

The computer science concept of a production system is well established (Wulf et al., 1981, p. 550-555).[6] It comprises a combination of (i) a set of rules in a defined rule specification language, (ii) a memory that the rules can read and write to, and (iii) a control process for rule activation. Contrary to first impression, the use of rules to construct a model is not inherently limiting since fully

[6] Programming languages such as CLIPS are based on the concept of a production system.

complex behaviour, including "intelligent" agents, learning, and multiple feedback loops, can be designed into a production system. [7]

Production system models may usefully be compared and contrasted with models that comprise systems of differential equations. In each we can look for stable states, that is, states (of the memory in the production system case) that once reached are never left. Furthermore, given a production system model we can devise algorithms that identify those memory states that lead to an outcome of particular significance, for example, the defeat (victory) of the insurgents. In effect, such algorithms can discover the preconditions of insurgent success, as was our original objective.

In outline pseudo-code, a simple algorithm for finding preconditions for a particular target outcome is:

Form immediate precursor set for target outcome

Repeat

> *Select an unexamined element of the precursor set and add its immediate precursors to the set*

Until termination

Detailed elaboration of this algorithm into actual code encounters significant difficulties, notably how best to handle the so-called "Frame Problem" (see Russell and Norvig, 1995, page 207), which concerns the persistence of variable/value combinations in the system memory when they are *not* involved in the rule firings of a particular cycle. Nevertheless, a version of it has been implemented in C as the PS-ANALYSIS program.

As an illustration of the application of PS-ANALYSIS, consider the following somewhat trivial formulation of the Lawrence scenario. The formulation assumes that there exist N distinct locations of relevance, interprets Lawrence's "mobility" as implying directed movement, his "security" as implying no regime attacks, his "doctrine" and "friendliness" as implying that control once achieved is never lost, and finally makes the basic assumption of insurgent military effectiveness. There are three condition-update rules, as follows:

RULE 1:
L(I)_control/regime & L(J)_insurgents/total & L(J)_control/insurgents =>
L(I)_insurgents/total & L(J)_insurgents/0

RULE 2:
L(I)_insurgents > L(I)_regime =>
L(I)_control/insurgents

RULE 3:
L(1)_control/insurgents & ….. & L(N)_control/insurgents =>
victory/insurgents

In the foregoing A/Q has the meaning that variable A has value Q. J and I are intra-rule variables that range over the set of locations. To cast these rules into a form suitable for the application of the PS-ANALYSIS algorithm, some pre-processing is needed. The inequality must be reformulated in finite extension, and the intra-rule variables must be replaced by an extended rule set and value set.

For simplicity the number of locations was reduced to just two: Location1 and Location2. PS-ANALYSIS then determined that a sufficient set of conditions for insurgent success is for the insurgents to have their total force at Location2, provided that that total insurgent force exceeds in number the regime forces at each of the locations. As part of its determination of sufficient conditions PS-ANALYSIS also identified the stable states of the PS. For this particular example these stable states are of no special interest.

Can feedback loops be discovered algorithmically in a production system? It seems that, in principle, they can although nothing has yet been implemented. For example, consider the following. Suppose V takes ranked values. To increase V's value from its minimum to its maximum, say, then a particular sequence (perhaps one of many possible sequences) of rule firings will be required.[8] We can search algorithmically for such sequences, concentrating on those for which the rules invoked are in principle capable of compression by the insertion of intra-rule variables and for which few external preconditions are required.

For more details of the PS-ANALYSIS program and the ideas and objectives that underlie it, and the connection to diagnostic expert systems, see Doran (forthcoming).

[7] Compare the capabilities of Turing Machines

[8] Recall that in our formulation rules are without intra-rule variables.

CONCLUSIONS

In conclusion, it is quite possible to create an agent-based model of a typical guerrilla war that has a degree of realism. The Iruba model is an example. Furthermore suggestive insights have been obtained with this model, notably concerning the unreliability of the "theory of foco", qualifications to Lawrence's sufficient conditions for insurgent success, and the impact of such counter-insurgency strategies as the "Salvador option". However, it seems that to go further and to obtain genuinely reliable scientific insights to complement those already existing in the technical literature of guerrilla warfare requires that models be further developed and that we address difficult issues of model analysis. Although we have shown that production system models in particular can be analysed algorithmically to find sufficient conditions for particular outcomes, and perhaps to identify significant feedback loops, the work has thus far been small scale and falls well short of the complexity of the Iruba model itself.

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