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Abstract:

A generic peacekeeping combat model is described within the framework of the ISAAC cellular automaton model. The aim was to explore the role of personalities and how changing the attitude of opportunistic groups of militia/pirates to peacekeepers affects the risk they face. The results suggest that the militia need not be particularly well armed to cause significant problems for peacekeepers, showing how easily a peacekeeping situation can become dangerous. The results also emphasize the value of intelligence, in particular, an ability to exploit and dominate the electromagnetic spectrum, and to monitor distributions of foes. Constant monitoring of potential foes was found to be vital to determining if an originally benign situation could degenerate into something much worse. A crucial factor in reducing risks to peacekeepers was to maintain a perception with the foe that they were sufficiently dangerous that it was not worth challenging them outside of opportune circumstances. However, if this unit "mana" diminishes due to the militia discovering that their enemy was not as tough as first thought, the risk faced becomes much more significant. The same would also be true if certain events lead to a deep hatred of the peacekeeping force, such that the militia attack it fanatically. The results suggest that well trained and equipped peacekeepers are both likely to minimize the threat level to the operation, as well as being the most capable of dealing with the situation should it turn bad. The report also describes a possible system to describe degree of risk of a given scenario in terms of a logarithmic index. Its logarithmic nature is necessary due to the dramatic rate at which risk levels rise as the result of changes in behaviour.

Defence Operational Technology Support Establishment
Auckland, New Zealand

EXECUTIVE SUMMARY

Background

Increasingly, the New Zealand Army is having to adapt to the demands of performing peacekeeping operations. In support of this requirement, it may be useful for DOTSE to conduct Operational Analysis (OA) to explore issues relevant to this kind of operation. Indeed, when British forces were deployed to Bosnia and Kosovo, OA teams were employed in a support role.

However, there are difficulties applying OA to peacekeeping operations, particularly in terms of combat modelling. In real life, restrictive rules of engagement mean that the personalities of the participants are often far more important than the kinds of weapons employed. Yet, traditional combat models are equipment centric, designed to explore such things as small differences in the performance of different manufacturer's guns, to aid in the procurement process.

For the British forces in Bosnia, a much more useful OA tool was an index of "stability" provided to the commander in order to assist with monitoring the situation and all its components, across a spectrum of military and political factors. The aim with this model is to do a similar thing, by attempting to identify the processes that lead to heightened risk.

Sponsor

New Zealand Army under Project 9703, Army Operational Effectiveness Studies.

Aim

The purpose of this report is to explore how risk to peacekeepers varies as the behaviours of the "locals" change, with a view to producing a "risk index" similar to that used by the UK.

This is done with the ISAAC model, acquired by DOTSE from the US Center for Naval Analyses' Website. DOTSE's expertise in using this model has been helped by its involvement with the US Marine Corps' Project Albert. The Marine Corps is one of a number of organisations who have recognised that traditional combat models fail to explain how an apparently superior force can face disaster at the hands of a poorly equipped foe.

While ISAAC is still somewhat limited as a tool, DOTSE has recently developed a version of this kind of model which allows much more sophisticated behaviour to be explored. This model, called Maui, will be available for future studies, but is only discussed briefly here.

Results

The modelling confirms the intuitive idea that the main determiners of risk to a peacekeeping patrol in an environment where potential foes outnumber it substantially are the foe's disposition towards the peacekeepers, the disposition of non-combatant parties, and the ability of the foe to mutually support each other in attacks (reflecting "training") and coordinate and concentrate forces (reflecting "communications").

The results suggest that in order to properly characterise the degree of risk to patrols of various sizes, there needs to be knowledge of the density of potential foes, the nature of the variation of the density within the area of operations (by determining the

fractal dimension of the distribution), knowledge of the foe's level of training and resolve, and knowledge of the foe's communication capabilities.

This emphasizes the value of intelligence, in particular, an ability to monitor and/or dominate the electromagnetic spectrum, and to monitor distributions of foes, preferably via some sort of "God's eye view" capability.

The model shows how dramatic a difference behaviour makes. In fact, the results suggest that an opponent need not be particularly well armed to cause significant problems for peacekeepers operating in such an environment. This shows how dangerous a peacekeeping situation can become even without dramatic changes in the equipment or structure of the potential foes.

Constant monitoring of potential foes is thus vital to determine if an originally benign situation will degenerate into something much worse.

A crucial factor in reducing risks to peacekeepers is to maintain a perception that they are sufficiently dangerous that it is not worth challenging them outside of opportune circumstances. However, if this unit mana[1] diminishes due to militia discovering that their enemy is not as tough as first thought, or alternatively, if certain events lead to a deep hatred of the peacekeeping force such that militia fanatically attack it, then the dangers to the force become very significant. Indeed, it appears the latter situation is a problem that US forces are prone to facing, as the recent example of Mogadishu illustrates. In that case, the danger was even greater due to the active participation of non-combatants in assisting attacks on US forces.

While it is far more preferable to rely on the foe's primeval fear of the peacekeeping force and other avenues such as blocking of militia communication channels to reduce risk, it is also clear that if the situation does degenerate, only concentrated and overwhelming firepower can defend the patrol to any degree. Further, only a well-trained and armed peacekeeping force is likely to maintain an appropriate level of mana with the militia.

[1] A Maori expression meaning the aura of strength and authority belonging to an individual or group of individuals.

CONTENTS

1 INTRODUCTION

1.1 Background

This work examines the behaviour of a generic peace support model using the ISAAC cellular automaton tool. It also briefly discusses the first results obtained using the much-more sophisticated Maui model developed by DOTSE.

The model is intended to be a “distillation” rather than a detailed simulation. This means that the model does not use a high level of detail. For example, terrain features are simply modelled as block obstacles that are impassable. Hence they serve to slow down groups of entities moving through the area, and force their formations to condense, but that is all. Likewise, weapons are modelled in terms of a range and a kill probability within that range.

The purpose of keeping the level of detail low is to allow the analyst to concentrate on the “behavioural” dynamics of the situation, rather than physics of weapons ballistics etc.

Ideally, the analyst should seek to explore “emergent behaviour”. This is a term that gets heavy usage by complexity theorists, but is one for which there is yet to appear a consistent definition. For the purposes of this report, emergent behaviour shall be defined as a pattern or trend that emerges from the model as it runs. If the analyst notices such a trend, then it becomes possible to explore the behaviour further by manipulating the appropriate parameters.

Such behaviour arises as the result of the large number of interactions between numerous entities with various “personalities”. Mathematically speaking, this behaviour represents an “attractor” for the dynamics of the system, an attractor being a set of end-states which are similar in some sense and to which the model tends to for some portion of the runs. For a given set of parameters (i.e. scenarios with entities having certain personalities), multiple attractors may exist, as discussed in DOTSE Report 169.

The aim of this report is to look for the attractors that emerge from a generic model of a patrol/convoy moving through a built-up area containing a mix of neutral and hostile forces. This includes exploring the role of behavioural attributes which are considered to be “intangible” in the framework of conventional physics-based combat models. These include such things as unit mana[2], level of training and attitude.

While there are examples from lessons learnt databases etc. of the value of mana, it is much harder to convince policymakers as to its role, particularly since it is not something that can be entered on a balance sheet as an asset or consumable.

One of the main purposes of this report is to show just how much of an impact such an “intangible” has once incorporated into a model.

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[2] A Maori expression meaning the aura of strength and authority belonging to an individual or group of individuals.

It must be acknowledged that it is unrealistic to expect any model to be capable of portraying all the likely behaviours of real troops/militia/non-combatants: rather, what is used is a simplified set of behaviours.

The ISAAC model used here has quite a limited range of personality parameters that are difficult (but not impossible) to manipulate to produce realistic behaviour. The model is described in Annex A.

DOTSE and the US Marine Corps' Combat Development Command are currently developing models that will supersede ISAAC, and allow more sophisticated behaviour than is possible with ISAAC. These models may then be used to explore similar scenarios to that modelled here, using the results in this report as a reference point.

1.2 Scenario

The model was set up with a peace support type operation in mind. It describes a patrol of peacekeepers (Blue Force) operating in a built-up area containing a mix of non-combatants and anti-peacekeeping militia/opportunist pirates. This latter group outnumbers the peacekeepers by more than 10-to-1 within this area. Baseline size of the patrol is nine.

The scenario is not designed to represent a peacekeeping force tracking down militia. Rather, it is envisaged that the scenario represents a patrol which is part of a United Nations (UN) force which does not involve itself in factional conflicts, but has created safe havens for refugees, protects humanitarian organisations and infrastructure, and intervenes when opposing forces threaten non-combatants.

The patrol thus represents a group of peacekeepers moving between safe-havens. The safe-haven is, for the purposes of this scenario, considered to be invulnerable. On its way, the patrol is slowed by having to interact with non-combatants.

Since such a force is also likely to have to conduct convoy protection, one might alternatively chose to view the patrol as a convoy (since the model deals with generic capabilities and behaviours, it doesn't really matter what the Blue group is viewed as).

The purpose of the model is to assess the risk to peacekeepers operating in an area where they are substantially outnumbered by potential foe. Thus the "militia" members should be seen as — and can be made to represent — any sort of threat level from resentful individuals who will physically assault peacekeepers given the opportunity, to armed paramilitary ready to engage the peacekeepers. They are thus not obvious military targets for the peacekeepers, and will generally not attack unless in a group. However, they have a tendency to congregate, raising the threat level.

Figure 1 shows a screen shot of the model. Here, Blue dots represent the peacekeepers, Yellow are non-combatants, and Red are hostiles. The gray areas are obstacles that could be natural or man-made features. Their presence causes congestion of automata moving past them, thus slowing passage.

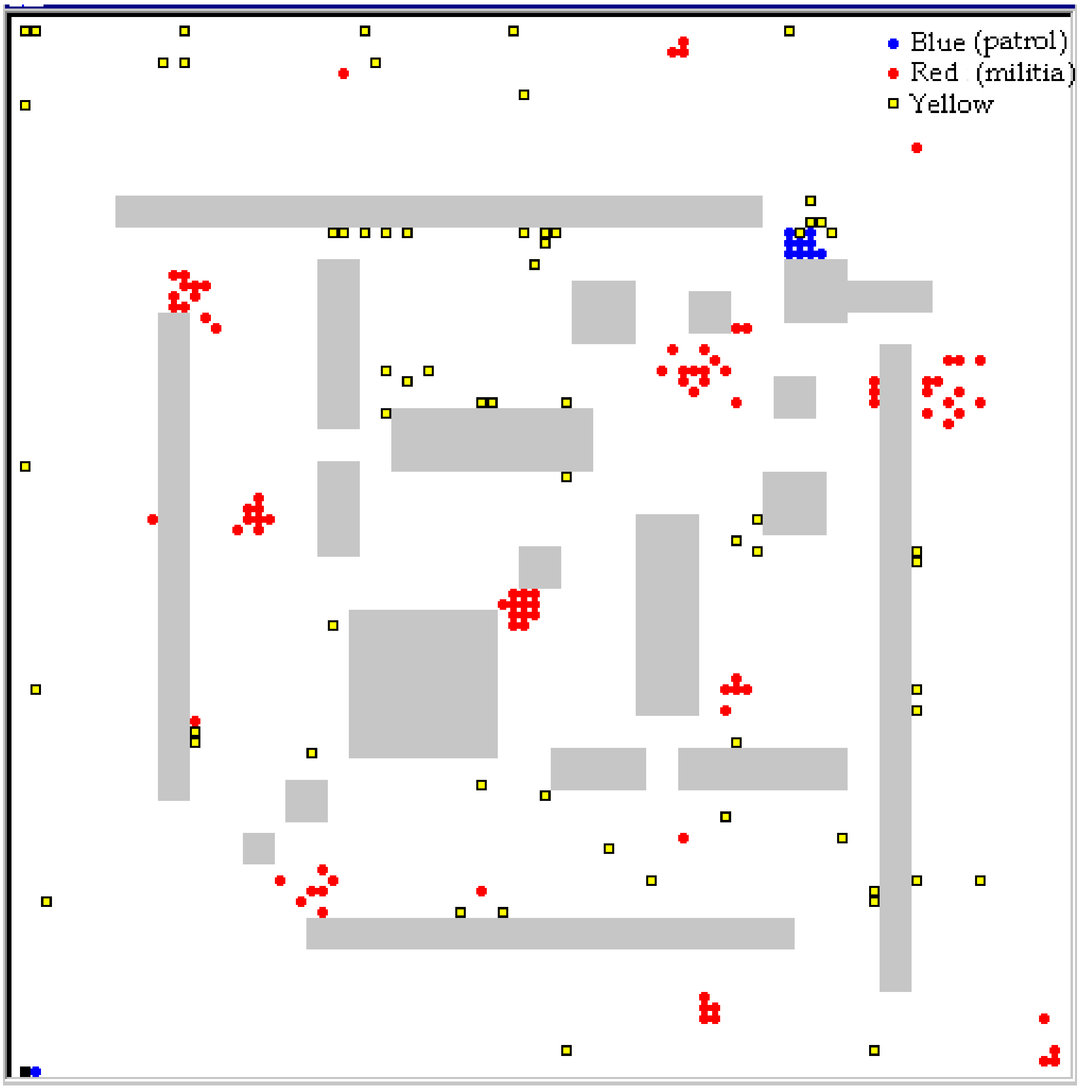

Figure 1: Screen grab of ISAAC model run. The Blue patrol starts at the top right-hand side and must proceed to the bottom left-hand side (grid size is 100x100, units are arbitrary).

1.3 Automata personalities

For the baseline case, the automata were given these personality traits:

Blue automata are motivated to get to their goal (base). They are also strongly motivated to stick together, and try to remain in a single grouping. They have the ability to communicate their positions to each other to assist this. Injured Blue have reduced mobility and firepower. Uninjured Blue try to stay with injured Blue.

Yellow automata are attracted to Blue, provided there are not too many Red around. They become more strongly attracted to Blue when injured. Both Red and Blue can cause injury to Yellow. In Blue's case, this notionally represents a Blue automaton having "dealt" with the Yellow's requirements, and moving on. Hence Blue remove Yellow from the grid, but notionally don't kill them. It takes two "hits" for Blue to do this. Red, on the other hand, notionally attack Yellow, causing them harm and to become more attracted to Blue (this is achieved by making use of the fratricide feature in ISAAC).

Red automata are inclined to cluster together in groups of up to 10. They are attracted by Blue, but will only approach them if they have a local numerical advantage of a given level (i.e. how many more Red they see than Blue). Thus they have a fear of the Blue that can be overcome by mutual support. In the baseline case, Red has no long-range communication capability.

2 PARAMETERS AND INTERPRETATION

A detailed list of the baseline parameters is given in the Annex B. In this section, we discuss the various parameter values and explain the rational for using them and the values chosen. Not every parameter is discussed. Rather, we focus on those most relevant to this scenario, and discuss the rational for their inclusion as variables in this study.

2.1 Combat and threshold parameters

The "combat" parameter determines the numerical advantage that an automaton must have before advancing towards detected enemies. The "threshold" parameter determines how near other automata must be to be included in the count which determines if a numerical advantage exits.

For the baseline case, a threshold range of 5 cells was used, and Red was given a combat parameter value of 2.

The combat parameter is included to allow the exploration of the notion that different units are feared by their opponents by differing degrees, depending on their perception of the unit's mana. Fear of this mana can be overcome if the attacker has enough friends helping in the attack.

Since selecting a large value for the threshold parameter allows the Red to approach the Blue by relying on the support of other Red automata relatively far away, this parameter can be seen as reflecting the degree of training. That is, a trained force is more likely to be able to rely on the mutual support of friends even when separated. By acting as a team, they can consistently overcome the mana of the Blue unit even if separated by a modest distance.

Historical examples of the importance of mana are many and varied. In Northern Ireland, for example, it is well known that when a regiment began its tour the dissidents would immediately spark skirmishes with it to determine its "backbone". If the regiment retaliated sufficiently then the dissidents would back off. It had established mana. If not, then the regiment was in for a very long tour ...

Another example, from the US, concerns riot control. During a particular incident, the National Guard was posted to defend certain positions from an angry crowd. However, the crowd did not perceive the Guards as a threat and overwhelmed them.

The next day the Guards were replace by the 82nd Airborne Regiment. This fixed the problem.

However, the combat parameter does not necessarily need to be seen as some sort of mystical quantity. Another way of viewing it is that the Red force follows doctrine that requires them to leave a peacekeeping patrol alone unless it possesses a certain numerical advantage over it. But since the actual advantage required reflects Red's perception of Blue's capabilities, the one naturally leads to the other.

2.2 Fire range, kill probability and sensor range

Firing and sensor ranges were chosen so as to represent asymmetric rules of engagement. Specifically, Blue do not shoot unless the militia come within a certain range, and Red do not attack Blue unless they see an opportunity they can exploit. In order for ISAAC to produce this behaviour, the detection range for both sides (value of 10) was set to be much higher than the firing range (value of 3). Thus firing range should not be viewed as the maximum range of the Red or Blue weaponry, but rather the range at which combat occurs.

Setting the firing range to match detection range causes both sides to engage whenever contact is made. This situation is much closer to an outright war scenario than a peacekeeping one.

Kill probabilities were set at 0.01 for Blue and 0.005 for Red. In each time step, each Blue or Red automaton could shoot at up to five different targets, representing the effect of dispersed automatic fire. Consequently, the "effective" kill probability per automaton per time step varied depending on the number of enemies faced (i.e. if at least five enemies were faced by Blue, the probability of killing one of them was 0.05. If only one was faced, the probability was 0.01). This reflects the fact that shooting multiple times at a single target does not necessarily kill it if it is hiding, but if multiple targets are present, there is a better chance that a clear shot can be achieved on at least one of them.

2.3 Communications range and weighting

Here, communications range should not literally be seen as representing the maximum range of the communications devices being used. Rather, it represents the range at which friendly units will respond to information available to other units with the ability to communicate with them.

For the baseline case, the militia was not given any communication attributes, representing the fact that they were not coordinating their attacks on the patrol. Rather, the attacks were completely opportunistic. Turning the communication attribute on allows for concentration of the militia on the patrol, and represents that the militia behave in a much more calculated way.

3. RESULTS

While the analysis conducted here with ISAAC was quantitative, it was extremely difficult to present a systematic series of graphs and plots to demonstrate trends without overwhelming the reader. Additionally, for the study to be truly systematic would require an enormous number of runs (the Marine Corp make use of Maui High Performance Computer Center's supercomputer to do this many runs).

However, it is fortunate that the metrics we were interested in changed dramatically past certain critical points (one consequence of being non-linear). Consequently, these points are easy to identify without large numbers of runs, especially given the quantised nature of the model. In the description of the results that follows, typically we identify these critical values rather then display graphs. In section 4, a quantitative index of risk is presented.

3.1 Role of squad size

Running the baseline case showed that the patrol was in little danger, with almost always no casualties/injuries.

Reducing the size of the Blue squad showed a very slight increase in the incidence of casualties. However, when the squad size reached four, the mission became dramatically more dangerous, with the squad suffering casualties the majority of times. Below this size, the squad gets wiped out consistently. Thus squad size is an important determiner of the risk the squad faces.

Note that this result reflects the ISAAC behaviour that prevents the Red force approaching Blue without a certain numerical superiority. However, it was found that the relationship between this parameter and the critical patrol size was non-linear, reflecting the complicated geometry of the situation (i.e. increasing the "bravery" of the militia increased the danger to the patrol by a disproportionate amount. The braver the militia, the more this is so).

Modifying the threshold range parameter (which to some degree represents the ability of Red to cooperate in overcoming Blue's mana, and hence Red's training), has a dramatic effect. If Red requires friendlies to be in the immediate neighbouring cells to overcome Blue's mana, then Red needs a much lower (and hence, braver) combat parameter. That is to say, Red must be prepared to attack Blue with a much smaller numerical advantage (possibly even a disadvantage) than is required when the threshold range is large.

In exploring the relationship between minimum safe size of a patrol group and the number of militia in the area, it should be noted that the distribution of militia is not uniform, due to their propensity to cluster, which in turn depends on the personality parameters. It can be expected that the distribution that Red adopt can be characterised by a fractal dimension (that is to say, a characterisation of how the density of Red varies over the area of operations), as suggested in DOTSE Reports 169 and 172. This suggests it may be possible to infer certain aspects of Red behaviour by determining this fractal dimension.

3.2 Increasing lethality of encounters

It was found that increasing the lethality of the situation (by increasing kill probability and firing range) gradually increased the risk to the patrol, particularly since if the patrol suffers casualties it becomes an increasingly attractive target for an opportunistic militia.

Increasing the kill probability by itself does not necessarily have much effect, as it merely becomes more likely that a casualty will occur if the militia comes within firing range. Generally, this will not happen if Red cannot overcome the effect of Blue's mana.

Increasing the firing range has a marked effect on the patrol's survivability. As discussed above, doing so begins to reflect a situation that resembles outright warfare, rather than a situation with restricted rules of engagement.

When the firing range matches detection range, the patrol suffers attrition at a rate dependent mainly on the kill probability of the opposition's weapons, i.e. enhancing Blue or Red firepower has a proportionate effect on the opposition's survivability.

3.3 Value of unit's mana

As discussed earlier, the patrol's mana reflects the required numerical advantage that Red requires to attack Blue.

Removal of the patrol's mana parameter leads to disaster for the patrol (this is achieved by "turning off" ISAAC's combat parameter), with even a patrol of nine being quickly overwhelmed by militia.

In general, Blue only survives in such a situation when it has significantly higher kill probability (representing more accurate shooting/better weaponry) than Red. However, the Blue patrol still suffers significant casualties. For example, increasing Blue kill probability from the baseline 0.01 to 0.1 (compared to 0.005 for Red), typically allows Blue to reach its objective with 30% to 60% casualties in circumstances where Red had no fear of attacking Blue (of course, making Blue into invincible supermen causes Blue to do pretty well too! What needs to be considered is what is a reasonable kill probability advantage for Blue).

The conclusion from this is that by far the best way to ensure survivability for the patrol is for it to be perceived as a significant enough danger to the militia that they would not attack it except in opportune circumstances. Although the militia could in fact cause significant harm to the patrol if they ignored this danger, the fear of loss of their own lives is a considerable deterrent.

3.4 Role of Red communication

Red automata near to the patrol were given the ability to communicate the patrol's position to other Red by switching on the communication option for Red and giving them a communication range of 25 squares, with a weighting of 0.5.

Once Red had the ability to coordinate via communications, the danger to Blue rose dramatically. Even a Blue patrol of size nine was consistently wiped out.

Once again, by giving Blue significant firepower advantages over Red (increasing Blue kill probability from 0.01 to 0.1), it was able to hold Red off to some degree, and make it to the goal with 30% to 60% casualty levels.

3.5 Role of non-combatants

So far, the non-combatant (Yellow) automata have been considered to be neutral, and hence have done little more than slow the Blue patrol down. This behaviour was altered so that the non-combatants actively tried to undermine the patrol. This meant altering the Yellow personalities so that they flocked to Blue and communicated Blue positions to Red.

This was achieved by setting the Yellow weighting towards Red to zero (so that they no longer ran away from Red). This also allowed Red to use Yellow as a support mechanism for overcoming Blue's mana.

It was found that doing this caused enormous problems for the patrol, with even a patrol size of nine suffering casualties when confronted by a combination of combatants and non-combatants. Patrol sizes smaller than nine tended to be consistently overwhelmed.

Adding the ability for Red and Yellow to communicate made the situation virtually impossible for Blue to cope with.

4. INDEX OF RISK

The results presented in the previous section were mostly in a qualitative form, although the model itself is quantitative. In order to demonstrate how the results might be applied to a quantitative risk scheme, a "Risk Index" was designed based on a logarithmic scale. The use of the logarithmic scale is desirable due to the dramatic way in which risk increases as behaviour changes (thus the index is analogous to the Richter scale used to describe earthquakes).

Risk was measured in terms of how many model time steps might be expected to pass before the entire patrol is wiped out (assuming the patrol path was within an infinite area of operations, with infinite militia forces distributed with the same density as used in the scenario discussed above). The score (index of risk) is the inverse of this value, normalised to the baseline case. Thus it represents a mean attrition rate for each case.

In Table 1, the index has been normalised so that for the baseline risk score is 10 (i.e. 1 on a logarithmic scale). Note that the baseline parameters used for Section 4 have been changed in one regard: the combat parameter has been reduced from 2 to –1. This represents a substantial increase in risk level for the baseline case. This was done in order to increase the attrition rate to a level where it was easy to measure (clearly if the attrition rate is very low, it is difficult to distinguish between the lowest risk cases).

Also note that a score of 0 to 1 on the logarithmic scale represents no or very infrequent casualties; a value between 1 to 2 means casualties occur increasingly regularly; and that 2 is the level at which the patrol will be eliminated before reaching its goal.

Note that the table, running from top to bottom, does not give the risk for a cumulative combination of the listed cases. Rather, each case is simply the baseline case altered in one (or two) particular ways. It should be noted that combining cases has, in general, a non-linear effect on risk index.

Case	**Risk index**	**Logarithmic scale**
Militia require close support (i.e. poorly trained)	3.333	0.3
Baseline (combat = –1)	10	1.0
Increased kill probabilities	20	1.3
Blue mana reduced (combat = –3)	36	1.6
Non-combatants become hostile	36	1.6
Patrol size cut to 6	60	1.8
Militia using communications	120	2.1
Militia using comms, and non-combatants are hostile to patrol	155	2.2

Table 1: Risk index.

5. CONCLUSIONS

The modelling confirms the intuitive idea that the main determiners of risk to a peacekeeping patrol in an environment as described here is Red’s disposition towards it, the disposition of non-combatant parties, the ability of Red to mutually support each other in attacks (reflecting “training”) and the ability of Red to coordinate and concentrate its forces (reflecting “communications”).

The results suggest that in order to properly characterise the degree of risk to patrols of various sizes, there needs to be knowledge of the density of potential foes, the nature of the variation in the density (by determining the fractal dimension of the distribution), knowledge of the foe’s level of training and resolve, and knowledge of the foe’s communication capabilities.

This emphasizes the value of intelligence, in particular, an ability to monitor and/or dominate the electromagnetic spectrum, and to monitor distributions of foes, preferably via some sort of “God’s eye view” capability.

The model shows how dramatic a difference these things make. In fact, the results suggest that the militia need not be particularly well armed to cause significant problems for peacekeepers operating in such an environment. This shows just how dangerous a peacekeeping situation can become.

Constant monitoring of potential foes is thus vital to determine if an originally benign situation will degenerate into something much worse.

A crucial factor in reducing risks to peacekeepers is to maintain a perception with the foe that they are sufficiently dangerous that it is not worth challenging them outside of opportune circumstances. However, if this unit mana diminishes due to militia discovering that their enemy is not as tough as they thought, or alternatively, if certain events lead to a deep hatred of the peacekeeping force such that militia fanatically attack it, then the dangers to the force become very significant. Indeed, it appears the latter situation is a problem that US forces are prone to facing, as the example of Mogadishu (October 3, 1993) illustrates. In that case, the danger was even greater due to the active participation of non-combatants in assisting attacks on US forces.

While it is far more preferable to rely on the foe's primeval fear of the peacekeeping force, or other avenues such as blocking of militia communication channels to protect the force, the results suggest that if the situation does degenerate only concentrated and overwhelming firepower can defend an isolated patrol to any degree. Further, only a well-trained and armed peacekeeping force is likely to maintain a sufficient mana with the militia so as to be left alone.

The results presented here demonstrate some ability to explore the effects of different personality traits, and indeed, levels of training. It may be feasible, for the purposes of future studies, to use this as a basis to explore training requirements for New Zealand forces facing an enemy of varying degrees of sophistication[3]. Clearly, simulating the effects of training appeared possible here by use of the threshold and communications parameter, which allowed differing degrees of mutual support of automata and the ability to coordinate attacks. These things make life much more difficult for the Blue forces.

6. FUTURE WORK: THE MAUI PLATFORM

Though the insights obtained from ISAAC are interesting, the behaviours able to produced were somewhat limited.

DOTSE has been developing a new model based on ISAAC, called Maui. This model incorporates the ability for behaviours to change under a wider range of circumstances than allowed in ISAAC. This facilitates a better ability to model rules of engagement than the method used here with ISAAC.

Maui was applied to a similar scenario as that described here. Our early experimentation with the model bears out the conclusion already discussed, that if Red has the ability to communicate, Blue is in much more danger. Furthermore, the model could be used to demonstrate what happens when Red's personality becomes more aggressive as the result of, say, a shot being fired.

This report does not discuss these results in detail. Rather, Maui is mentioned to alert the reader to the possibilities for future work. It is also intended to distribute Maui with this scenario to interested parties, which will likely include posting the model on

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[3] Such a suggestion has been made by Maj. David Boyd in Personnel Planning.

the Capability, Analysis and Doctrine Branch's DIXS (Internal Defence network) website.

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ANNEX A: THE ISAAC MODEL

ISAAC (Irreducible Semi-Autonomous Adaptive Combat) is a cellular automata model developed by Andy Ilachinski of the Center for Naval Analyses to support the US Marine Corps Combat Development Command's Project Albert. Standard cellular automata models use a coarse grid of cells, in this case representing the "battlefield". A cell may either be empty or contain a single automaton.

ISAAC represents a first attempt to incorporate the behaviour of the participants, rather than concentrate on the physics of the equipment. As such, the model uses generic units (automata) that are described in terms of simple capabilities and personalities, rather than specific pieces of equipment.

Owing to ISAAC's simplicity, it is possible to model a wide range of behaviour quickly and in a systematic way. This ability to map the outcomes for a wide range of differing behaviour allows the model to be used with the intention of exploring the feasible range of solutions to a given problem, rather than producing a single "answer", as often seems to be the goal with conventional methods.

The ISAAC model is relatively simple, and its explanation here will be brief. It is described in detail in Ilachinski (1997), and the executable program may be downloaded from the Web address www.cna.org/ISAAC.

The automata personality parameters break down into three classes: attributes, personalities and meta-personalities.

The first class describes movement rate, weapons range, weapons kill probability, sensor range etc.

The second class are weightings which describe an automaton's propensity to move toward/away from friendly/enemy automata, and toward/away from a goal (flag) point. The model calculates automata moves by summing the number of friendly and enemy automata within a threshold range of each square within movement range, and uses the personality weightings to determine the "penalty" associated with each move in terms of how it positions the automaton relative to the friendly/enemy forces and the goal point. Communications may also be simulated, by including the number of friendly/enemy automata visible to other friendly automata within a set communications range.

The third class modifies the above procedure. Three parameters fit this category: the cluster parameter, which "turns off" an automaton's propensity to move towards friendly automata once a threshold cluster size has been reached; the advance parameter, which requires a threshold number of friendly automata to be surrounding an automaton before it will advance towards its goal; and a combat parameter, which will only allow an automaton to advance towards the enemy once a threshold numerical advantage has been achieved.

The automata themselves can be in one of three states: alive, in which case they use the baseline parameters; injured, where a secondary set of parameters may be used to indicate an automaton has suffered damage; and dead, in which case the automaton is removed from the battlefield.

ANNEX B: BASELINE PARAMETERS