High Level Cellular Automata Model: functional description

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Executive Summary

This document is produced jointly under Applied Research Package ARP2C assignments 011 and 012 and also Strategic Research Package AS02BP22. It describes the functional processes of the High Level Operations Model using Cellular Automata (HiLOCA) which is an extension of an existing model developed under SRP AS02BP22. The work on HiLOCA has already begun with development of a prototype model to test the concepts of Situation Appraisal agents and Command agents and the processes involved in their interaction with the battlefield automata. The prototype HiLOCA model is currently under development and this document summarises the functional specifications for the following extensions to the existing cellular automata model:

- battle group composition changes,
- addition of artillery and air assets,
- addition of sensor automata,
- situation appraisal agents,
- command agents,
- changes to threat map structures.

The existing cellular automata model is essentially a battlefield simulation which uses cellular automata techniques to model the combat agents. The representation of the command function is very limited and the only representation of sensors on the battlefield is in the form of the combat agents' lines of sight to their targets. The cellular automata model has been developed under the Strategic Research package and its merits are that it does not rely on a scripted scenario and it is very fast and flexible. However, an extensive programme of further development is needed to make HiLOCA useful for RISTA (Reconnaissance Intelligence Surveillance and Target Acquisition) effectiveness studies.

The aim is to upgrade and extend the existing models (which are essentially simulations of battlefield movement) to include sensor automata, situation appraisal agents (SAAs) and command agents (CAs). The sensor automata will gather information about the on-going battle, the SAAs will fuse the information to give perceived enemy strengths over the battlefield area and the command agents will use the enemy picture to determine manoeuvre options and to drive the movement of the battlefield units.

Once the modelling concepts have been tested in the prototype model, work will begin on the development of the goal model which will be used to answer questions concerning the impact of RISTA assets on tactical effectiveness. Assessment of RISTA effectiveness requires measurement of the tactical impact of RISTA assets over many different operational settings. Questions such as: What impact on tactical effectiveness does this mix of RISTA assets have?

and also:
Would a variation in the RISTA mix cause a greater range of effects in tactical outcome than would be achieved by changing the chain of command, style of commander, speed of communications, etc.?

The feedback loop from sensors through data fusion, situation appraisal and command decision-making into the production of battlefield orders must be closed before such questions can be satisfactorily answered. HiLOCA will be used to measure operational effectiveness of RISTA assets initially, but such a facility could be used to assess the impact of communications delays, changes in command structure and organisation, and even the effects of commander personality.

This paper firstly explains why a high level RISTA/C2/Combat model is needed within LSC1, and why it should be developed using the cellular automata technique. Sources of input data for the model and other spin-off uses are indicated. It argues that the model should be developed in an evolutionary manner, interleaving incremental developments with use in studies. It gives a comprehensive vision of the form that the goal model should ultimately take, and describes the functional specification for a prototype which is being developed as the first step on the evolutionary path. The paper has two purposes:

- to provide the functional specification for prototype development within ARP2c during 1995,
- to inform a wider audience inside DRA and MoD which might have an interest in exploiting the model.

The HiLOCA model prototype is planned to be completed by October 1995.
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1. Introduction

This section outlines the motivation for investing in a new model which combines RISTA, Command and Control and Combat Operations for the land/air tactical arena. It argues why the cellular automata technique should be used to implement the model, defines the strategy for acquiring the model, and defines its purposes and uses.

1.1 Background

In the run-up to and during a military operation, the RISTA system provides the C2 (Command and Control) function with information about enemy state, behaviour and intention. The RISTA system comprises a set of sensor and information-processing sub-systems and is itself a component of the larger C2-combat system. LSC1 conducts effectiveness studies to support MOD policy-formulation and decision-making on RISTA procurement and associated research. Such studies demand a quantifiable measure of effectiveness (MOE) for RISTA systems under scrutiny, and the means to estimate this MOE. This modelling initiative has its origins in the view that the only useful RISTA MOE is its influence on the outcome of military operations in which it participates, and the fact that there are no known models which relate RISTA to operational outcome, and which are of practical use in RISTA assessment studies.

1.2 Justification for a new high level model

1.2.1 Measurement of the RISTA MOE

The RISTA MOE in terms of operational outcome has by its nature to be measured for specific scenarios. The cost-effectiveness of RISTA assets should be measured in terms of achievement of operational objectives, duration, and level of losses incurred. Operational outcome is of course also influenced by scenario, C2 and combat factors. To make use of such an MOE, it will be necessary to separate RISTA influences from the rest. This will require analysis of a large number of combinations of:

- RISTA system specifications,
- scenario definition (ORBATS, doctrine, environment etc),
- C2 plans, doctrine and "commander's style".

RISTA effectiveness studies therefore have need for a tool which:

- will enable numerate estimates to be made of the manner in which combat outcome in a given scenario varies with specification of the participating RISTA system, and
is capable of handling a large number of combinations of input data defining the other MOE-influencing factors, within practicable study timescales. Such an assessment tool will need to be implemented by a high-level model which represents, equally for Red and Blue, the dynamic interactions between:

- the RISTA system and opposing forces,
- RISTA-derived information and the C2 decision-making,
- C2 decisions and the behaviour of subordinate forces,
- forces in combat, which result in the outcome of the operation (i.e., the MOE).

### 1.2.2 Rejection of existing RISTA/combat models

There are numbers of battle models which deal with the C2/combat system in varying levels of detail, but these all fall short of our requirements in that they

- do not contain adequate representation of the RISTA system,
- are not suitable for rapid amendment, nor are capable of performing large numbers of runs in a short time, to cover the large numbers of combinations of input variables which are needed.

### 1.2.3 The need for a new model

The main reason why a model with the required characteristics (1.2.1 above) does not exist is that no suitable modelling technique has been available for its implementation. The recent advent of the Cellular Automata technique now makes such a model feasible, and thereby provides the opportunity to remedy the assessment of RISTA-effectiveness study problem, which has been accepted up to now as being in the "too difficult" class.

The following description of the fully-developed goal model provides the basis for settling the definition of the prototype. The prototype will necessarily contain only a subset of the fully-developed model’s content and functionality, but should nevertheless form the starting point for smooth and economic progress towards the ultimate version.
2. HiLOCA - the goal model

2.1 Model architecture

2.1.1 Model domains

The model will contain two quite distinct domains:

- Battlefield domain, hosted on a terrain database
- CIS domain

The Battlefield Domain operates in the physical world, in accordance with orders received from the CIS Domain. The CIS Domain operates in a logical world, deriving these orders from given plans, and from situation appraisals based on information supplied from sensors in the Battlefield Domain. From a CIS viewpoint, the Battlefield Domain provides the means for exercising the C2/RISTA-G2 functions, and for measurement of their joint and separate effectiveness.

The model will contain representations of Red and Blue forces, both modelled in a similar manner and to a similar depth of detail. Neutral forces may also be present. Red and Blue forces will interact with each other physically in the Battlefield Domain using cellular automata techniques. Figure 2.1 shows how the Battlefield domain will interact with the CIS domain via SAAs (situation appraisal agents) and CAs (command agents).

2.1.2 The Battlefield Domain

This will contain automata representing the physical behaviour of command posts/HQs, combat units, combat-support and RISTA sensor units, all operating over a terrain data base in accordance with the following types of rules:

- orders from the CIS Domain to implement a battle plan, and defining automata objectives and constraints in terms of
  - manoeuvre plan and geographical objectives vs time
  - response to contact with enemy forces (attack, withdraw)
  - cohesion of combat units.

- rules governing the ability of the automata to follow orders from the CIS Domain and dealing with own force performance degradation as a function of:
  - damage/loss arising from engagement
  - wear and tear related to time/distance from start of run
  - logistic state.
Figure 2.1: Interaction of CIS and Battlefield domains.
rules for triggering of reports to the CIS Domain of
- own state
- intelligence collected.

The battlefield automata will be given initial locations and initial movement/manoeuvre/collection plans in accordance with the study scenario. Their behaviour thereafter will be determined by the interaction between Red and Blue Battlefield automata, in turn determined by their rules, and the responses of the CIS Domain which are driving them. Other explicit rules will be written for the use of attack helicopters and artillery which will simply be different types of battlefield automata.

2.1.3 The CIS Domain

This will contain a hierarchy of Command Agents (CAs). Their function is to generate orders for action by subordinate CAs or by subordinate Battlefield automata. These orders will be derived via rules and constraints which seek to achieve the goals of a given battle-plan, taking account of the current perception of the situation in the Battlefield Domain. To allow for the time required by real-world CAs and SAAs to operate, the model will need to build in delays in their response to stimulus from each other and from the Battlefield Domain.

The perception of the battlefield situation will be generated by Situation Assessment Agents (SAAs). These will use further rules which operate on information supplied by:

- the RISTA sensor automata and the combat units in the Battlefield Domain,
- in-feed of intelligence from Strategic sources which may be
  - part of the scenario input data, or
  - derived directly from the Battlefield Domain via further rules or by additional RISTA-type automata.

Each CA will normally be linked directly to a SAA to represent a HQ, at various levels in the C2I (Command, Control and Intelligence) hierarchy. The product of the SAA at Divisional/Corps level will approximate to the existing concept of the real-world Tactical Ground Picture. The information flows between Command Posts will directly reflect the real-world C2I hierarchy being modelled.

In the early prototype model, the CAs and SAAs will be implemented by automata with appropriate generic (but simple) rule sets. For later versions of the goal model, it is hoped that more complex rules can be derived from the Expert System work done by DRA Fort Halstead in the GeKnoFlexE and IMSA projects respectively.
The SAA rule-sets will provide for:

- interpretation of single-sensor and fused data into low-level components of the tactical picture, mainly current activity and state of opposing forces,
- tracking of own force state and activity,
- interpretation of these components, and others supplied externally (strategic and flanking formation sources) into the tactical picture, comprising a statement of
  - history and current activity and state of own and opposing forces
  - probability-weighted options for the interpretation of opposing force activity in terms of physical and battle objectives.

The CA rule-sets will then provide for:

- the making of command decisions (in G2, G3 and other functions) based on
  - current orders from higher CAs
  - the battle plan (with supporting contingency plans)
  - the current tactical picture from the SAA.
- the conversion of these decisions into orders to subordinate CAs.

The real-world SAA process will provide for consideration of probability-weighted alternatives to the various intelligence products, and for the ultimate product which is the tactical ground picture. If the modelled RISTA system performs well, this should lead over time, to reduction of the numbers of alternatives and convergence towards a single, high-probability tactical ground picture. The modelled CA decision processes should be capable of taking this behaviour into account. The CA could be given different risk-taking styles, which will make the trade between elapsed time and confidence in the tactical picture. The two main factors associated with the output of the SAA process are confidence level and timeliness. The confidence level will have a direct impact on the hesitation or delay in changing the command orders (which could be represented by a negative exponential function). The timeliness will also have a direct impact on the command decision process (for example, a potential reduction in expected casualties due to the surprise factor if the force is attacking).

The command agent's decision should be considered as a stochastic dynamic process. There are mathematical methods for implementing dynamic decision-making models which can even incorporate stress and uncertainty but these will not be implemented in early versions of the model. So the command process will be subject to internal stress (fatigue, anxiety, inability to reach decisions because of uncertainty, lack of orders from above or lack of relevance of given tactical doctrine etc). To allow for these effects, some form of non-linear and possibly irrational CA behaviour may be needed. (This might be governed by use of catastrophe theory to intervene in the CA rules of behaviour.)
Whilst the prototype will use automata with simple local rules to implement the CIS domain, the migration process towards the goal model has the option to use combinations of the following modelling approaches:

- manual supervision of the CAs and SAAs during run-time, with opportunities for manual intervention to amend rules and triggers to achieve more realistic behaviour,

- man-in-loop quasi-gaming, to permit manual participation in some or all CAs and SAAs, some or all of the time,

- construction of more detailed representations of the Command Post organization by use of multiple automata and rule sets, with each automaton representing real-world G2 and G3 processes, or alternatively, use of object-oriented C2I simulations, based on existing codes such as STARDIS for the same purpose.

The last approach is attractive in that it provides a structured but flexible framework for representing the C2I hierarchy in terms of real-world G2/G3/other elements, and opportunities for the use of man-in-the-loop experiments, other codes for specific CA/SAA functions, and mathematical representations of C2I behaviour generated by the SRP programme.

There will also be opportunities to:

- introduce catastrophe models into both CIS and Battlefield Domains, in order to generate the real-world type of non-linear response which can be induced by a build up of "stress" in the broadest sense of the word, and

- investigate, through the model, means for inducing such stress by counter-C3I measures.

2.1.4 Representation of information-exchange and associated telecommunications

Information-exchange links will be provided within and between the two domains. These links will represent real-world information flows. The resultant mesh will thus mimic real-world organization and hierarchy on the Red and Blue sides. In the prototype model, the links will be represented by direct information flows, assuming a communication service characterised only by delay times. This will prevent the model from ignoring the communication problem, but will provide only limited opportunities to use the model to study the effectiveness of telecommunications support to RISTA and C2, and equally of counter-C3I activity targeted specifically at communications.
To improve the opportunities for study of these issues, the model will need to be capable of incorporating an improved representation of telecommunication services. This could be implemented in the form of

- more detailed communications rules within the CIS/battlefield automata, or
- communications automata located within the CIS/battlefield domains, with links to all subscribers, or
- a communications "layer" between the CIS/battlefield domains, through which links have to pass, and which could be implemented by communications automata providing standardised rule-sets for the representation of bearer networks and the circuit-, packet- and message-switched services which they carry.
2.2 Model input and output

2.2.1 Input

The following types of input will be needed to configure HiLOCA for a specific study:

- scenario-independent data
  - performance parameters for sensors,
  - combat unit strength scores,
  - manoeuvre and movement matrices.

- scenario-dependent data for
  - Battlefield Domain
    - terrain data
    - Red and Blue ORBATs, start states and initial deployment
    - met/environmental data affecting automata behaviour
  - CIS Domain
    - Red and Blue objectives and plans
    - Red and Blue tactical doctrine rules (manoeuvre, combat, combat support, RISTA collection)
    - CA trigger values
    - SAA algorithms.

2.2.2 Output

RISTA effectiveness and performance metrics will be the basis for the analytical use of the models (see below). These metrics are expected to take the following forms:

- Extent to which goals of the Blue battle plan are achieved, for example:
  - taking or holding of geographical points or areas, or denying these to the enemy,
  - causing loss to the enemy.

- Costs of achieving these goals, for example:
  - time expended
  - own losses
  - collateral damage (if desired to minimise for political reasons)
  - expenditure of own logistic materiel.

Data needed for comparison of runs with each other or with results of other simulations/studies/games will probably include:
movement of Red/Blue units (inc sensors) vs time
- occurrence of other events vs time
- outcome of sensing or combat events.

Diagnostic data will be obtained from any part of the simulation, with a probable focus initially on CA triggering and consequences in the battlefield and CIS domains.

2.3 Use of HiLOCA

The model will primarily be used in RISTA-assessment studies which will provide advice to the MOD customer on desirable RISTA capability, and on how this capability should be provided by RISTA systems. A contributory aim is to assist decisions on what RISTA research projects should be undertaken to support the capability and procurement planning. The model will achieve the primary purpose by providing an improved and confidence-inspiring service to the customer in terms of

- deeper insights into the RISTA process and its interactions with its parent C2 system its operational environment
- numerate and defendable assessments of RISTA capability-requirements and actual RISTA system effectiveness, especially in the COEIA process for new RISTA systems

Potential spin-offs of the model include

- direct application in C3I and counter-C3I research and effectiveness studies
- direct application as a 'what-if' planning tool for operational HQs (following the initiative of DSc(Land))
- direct applications in gaming for C2 and Collection-Management education
- as an element of command and staff trainers.

The running of the model should be capable of being supervised manually, in order to

- gain insights into the processes modelled,
- diagnose the causes of unexpected or erroneous behaviour,
- gain confidence in the realism of the agents' behaviours.
The supervision is expected to be implemented by using a windows approach to look at specific:

- geographical areas in the battlefield domain,
- automata behaviour,
- CA and SAA behaviour.

2.4 The modelling tool-set

The tool set will ultimately contain the following components:

- A library of automata (with their built-in rule sets) as building bricks for specific study models, possibly augmented by object libraries for the more detailed representation of the CAs and SAs,
- A simulation infrastructure which drives the automata in accordance with their local rules to interact with each other, and interfaces with other simulations, codes, and humans implementing part or all of some or all CAs and SAs,
- Tools for the following:
  - selecting appropriate automata and editing their local rules to set up a specific study model and scenario
  - setting up batch-runs for sensitivity analysis purposes
  - performing any pre-processing needed prior to model running (eg for calculation of intervisibility masks)
  - manual supervision of the simulation during run-time
  - fast-forward/reverse of a run
  - collecting metrics and other data from each model run
  - post-processing of metrics and other data for post-run analysis
  - comparison of model behaviour and output with that of other simulations, exercises etc.

The tool-set will be implemented in C (probably in an object-oriented manner) in a UNIX environment on one or more work stations. Any particular study model will be capable of being flexibly partitioned over more than one work-station. This will facilitate gaming applications and use of the supervisory tool. It will also provide opportunities for holding run-times down to levels acceptable for study purposes.

A model run should be repeatable, with the ability to re-run all or defined parts of the run. The desired part would probably be selected by reference to user specified events or by reference to the simulation clock. The critical-event nature of the models should make it
possible to adapt the run speed to suit the supervisory function and the participation of humans in the CAs and SAAs.

The tool-set will provide for simple switching between two modes, deterministic and quasi-stochastic. The deterministic mode will provide a simple means of establishing the behaviour of specific characterizations of the overall Red/Blue RISTA/C2/combat systems, and lower level components thereof. The quasi-stochastic mode will allow the use of monte-carlo techniques to explore the effects of modelled processes which are particularly difficult to characterise deterministically. This mode could also be used to help settle how to represent such processes deterministically. Such "difficult to characterise" processes may include:

- sensor-target intervisibility where it is desired not to tolerate lengthening of run-times by the use of full intervisibility computation
- combat interactions
- RISTA sensor performance in terms of target detection, geolocation and classification
- operation of the CAs and SAAs.
3. Existing models

3.1 DRA Malvern Cellular Automata model

The existing Cellular Automata model is fully described in Reference 1. It moves battlefield forces according to global rules which use a cost function determined by the terrain and an objective specified in terms of a direction to reach \((x,y)\). There are also local rules derived from a global eight-sector threat map. This battlefield cellular automata model will form the basis for the prototype.

3.1.1 Existing battlefield domain

Existing terrain effects on routes and movements will remain as absolute. Existing rules for battlefield attrition will remain also. Each grid square on the battlefield area is currently defined by the latitude and longitude lines which are 3.5 and 7 degrees respectively. This gives a total area of 400 km square. There is a 500x500 cell upper limit and so each grid square is an 800 metre cell. Currently the cellular automata are fighting units, with a simple representation of command in terms of a movement objective. The automata movements are determined by threat maps which represent the enemy force strengths in eight compass-based sectors. The assessment of enemy strength is currently taken from the ground truth. The automata have simple cohesion rules for the maintenance of contact with other units. The areas of influence of the various units are determined by the ranges of the equipments.

3.2 Synectics Cellular Automata model

MAC31 is a cellular automata demonstration model written by Synectics Corporation. It has been developed in parallel with the DRA battlefield cellular automata model and has been used mainly to try out various conceptual ideas. MAC31 has also given insights into the use of sensor automata on the battlefield. The work by Synectics will continue in the validation and experimental phases of the work plan.
4. The Prototype model

4.1 Purpose of the prototype

The aim is to upgrade and extend the existing battlefield cellular automata model to include sensor automata, situation appraisal agents and command agents. The sensor automata will gather data about the on-going battle, the SAAs will fuse the data to give perceived enemy strengths over the battlefield area and the command agents will use the threat maps from the SAA to determine manoeuvre options and hence to drive the movement of the battle groups. The prototype model will be used to examine simple questions concerning the impact of RISTA assets on tactical effectiveness. For example, if the question was:

What is the impact of using limited RISTA assets on the chance of winning?

The experimental programme aims to produce curves such as in Figure 4-1:

![Figure 4-1: Typical experimental results.](image)
be compared. The choice of the tactical effectiveness measure is yet to be decided. "Chance of winning" is not ideal because it may be difficult to assess when one force has won. Optional measures would be:

- the overall congruence to the plan,
- achievement of the global objective,
- extent of total casualties,
- territory gained,
- loss exchange ratios,
- degree of suppression achieved,
- time taken to achieve objective.

The Prototype Model is intended to be a simple demonstrator which will justify customer investment in further development. A contributory aim is to use the prototype to support an effectiveness study of the airborne MTI/SAR sensor known as ASTOR. This will overlap the planned prototype development work, and will also provide much of the scenario input data needed for the acceptance testing of the Prototype Model. It is not intended to make the ASTOR study depend on the delivery of the prototype.

4.2 Changes to the DRA Cellular Automata model

The existing Cellular Automata model is fully described in Reference 1 and described briefly in Section 3. The battlefield forces will be moved according to movement rules governed by manoeuvre options and impending threat from the enemy. Own force strength will be taken from the ground truth. There will be an overall objective specified at the highest level of command and an associated cost function determined by the terrain. There will be additional attack helicopter and artillery support units in the goal model but in the prototype model each battle group will consist simply of an indirect fire unit, a direct fire unit and a Headquarters.

4.3 Operational setting

The proposed operational setting for the prototype model is given in Figure 4-3. It is an unrealistically small force level but one which is manageable in the first instance, and which can be easily extended to include artillery, air assets and two further Brigades on each side. It will be adequate for proof of concept of the command agents, the sensor automata and the situation appraisal agents.

The Blue Brigade is advancing to contact with the Red Brigade who are in a prepared defensive position. The Blue Brigade commander needs to issue orders for manoeuvre to the Battle Group (BG) commanders. Each of the Blue BG commanders will take their orders in the form of an ordered pair (ie a manoeuvre option with an optional (x,y) objective: for example, deliberate attack; take ground at grid(x,y)). They will continue to operate within the bounds of this order (provided that their "get out" triggers are not activated) and they will move according to the movement matrices and a six-sector enemy threat map. The Red Brigade commander will issue orders to defend the ground and his BG commanders will
Figure 4-3: Operational setting for initial prototype.
continue to operate within that directive until their "get out" triggers are activated (for example, to mount a withdrawal or to counter-attack). There are obvious problems in coordinating the triggers across the various levels of command. A "get out" trigger activation at the Battle Group level, for example, will trigger the Brigade commander to reassess the situation. The "get out" triggers will be based on force ratios and the check for a "get out" trigger activation at the Battle Group level will be carried out at regular intervals of battle time. (See section 4.6 for more detail on command agents.)

4.4 Field Orders

The primary land Operations of War are Offence and Defence. In line with current NATO doctrine, a third operation is also recognised at the tactical level, Delay. To ensure the continuity of operations, the Operations of War are linked by transitional phases. The full array of operations and phases is as follows:

Offence
- Deliberate attack; hasty attack; pursuit;
- recce in force; feint and demonstration;
- counter-attack; raid.

Defence
- Mobile defence; area defence; hasty; prepared.

Transitional
- Advance to contact; meeting engagement; withdrawal;
- relief of troops in combat; link-up operations.

Delay

The current Army field manuals state that there are four phases of battle (Advance, Attack, Defence and Withdrawal) and within those main phases there are different forms which depend on battle conditions:

Advance - to contact, in contact, pursuit, (by-pass)
Attack - quick, deliberate
Defence - deliberate, hasty
Withdrawal.

Bypassing in the advance phase is carried out only if there is accurate recce and high confidence in the intelligence of the exact enemy position.

To stay in line with the Operations of War and the existing Army Field Manuals it is proposed to adopt the following definitions of eight mutually-exclusive tactical manoeuvre options:

Offence
- deliberate attack; hasty attack; pursuit; counter-attack.

Defence
- prepared; hasty.

Transitional
- advance to contact; withdrawal.
The initial operational setting describes a deliberate attack for Blue with a prepared defence by the static Red Brigade. The ensuing outputs for the Blue Brigade command agents could be to maintain deliberate attack, mount a hasty defence or even a withdrawal. The ensuing outputs from the Red Brigade command agents could be to maintain the static defence, mount a counter-attack or a withdrawal.

4.5 The threat maps

4.5.1 The battle group movement threat map

Every Battle Group (BG) must move according to manoeuvre orders from the Brigade commander and yet be able to react to its own current threat situation. Each BG has a six-sector threat map which is aligned according to the direction of movement of the BG; so the threat map sectors represent the perceived level of threat in the front, deep, left flank, right flank, back and rear with the centre of the threat map positioned on the BG HQ. The perceived threat levels will be derived from the sensor automata and the BG level SAs. No specific degradation factors (e.g., meteorological conditions) will be applied initially. The radius of the BG movement threat map is 10km with the inner close sectors at 5km range.

4.5.2 The manoeuvre options threat maps

The manoeuvre options threat map covers exactly the same areas as the BG movement threat map but the sectors represent force ratios rather than simple enemy strengths. The Brigade commander's threat map will have an inner radius of 10km and an outer radius of 20km. Each sector will contain a force ratio (enemy:own) calculated from aggregated force strength scores or perceived combat power scores (PCPs). The force ratios will be called perceived combat power ratios (PCPRs). Weighting factors may be applied to represent the relative strengths of own forces in the various sectors. The PCP threat maps are the final output of the SAA and form the basis of the command decision for manoeuvre. The aim is to transform the PCPRs into binary values so that they can be directly input into the CA decision matrices. For example, a PCPR less than 1/3 would give a zero value (indicating low enemy strengths in that sector) and a PCPR greater than 1/3 would give a value of one (indicating a high level of enemy threat for that sector).

An alternative for the binary coding is via a transformation of PCPRs into casualty figures and the operation of a command decision trigger value (for example, a maximum acceptable casualty level of 5%). Whether the binary coding is done using PCPRs or expected casualties, the result is a binary valued threat map as in Figure 4.5, which depicts a high level of enemy threat in front, left and back sectors with low threat on the right flank, deep and rear sectors. These binary patterns are then converted into an acceptable manoeuvre option within the Command Agent process using a CA rule-matrix which takes the 6-element binary vector as input and gives one manoeuvre option as output.
The six sector threat map is represented as a vector 110100

Figure 4-5: An example of a binary threat map.
Figure 4-6: Schematic CA flowchart.
4.6. Command Agents

There are to be two effective levels of CA:

High = Brigade
Low = Battle Group.

The high level CA is driven by the strategic objective and the intelligence about own force and enemy force dispositions. The output of the High-level CA is the tactical manoeuvre option using the binary threat map and the manoeuvre transition matrix. The low level CA takes the manoeuvre option and selects the appropriate movement decision matrix which is then combined with the BG movement threat map (enemy strengths only) to give the direction of movement for the Battle Group. An initial set of the potential manoeuvre options is given in Section 4.4.

4.6.1 Command Options and triggers
The emphasis in the CA modelling is on defining "Options and Triggers". The BG command agents will have local movement options consistent with their current orders which depend on the perceived enemy threat. These options will determine the next step for directed movement of the subordinate forces and will be driven by the low-level enemy threat map. The Brigade command agents will need to reassess the battlefield situation, say, every two hours. Their options for change will be determined using the binary threat map and the manoeuvre rule matrix. The CAs will also have "get out" triggers which could cause them to change to another tactical option. These get-out triggers could either be to get out of trouble if things are going badly locally or to exploit the situation if things are going well locally. The matrix for change in manoeuvre options in order to exploit an advantageous situation is a simple binary 8x8 transition matrix. The command trigger flowchart is given in Figure 4.6. All CAs, at whatever level, will operate using this generic flowchart to trigger a change. The Red commander can obviously have different trigger values to those of the Blue commander.

4.6.2 Battle Group movement

There is a set of movement directives for the BGs in the form of movement matrices. At regular intervals of simulated battle time each Brigade command agent will reassess the situation and, if appropriate, new manoeuvre orders will be issued. After an appropriate delay time, these orders will determine which of the movement matrices should be used to calculate the BG movement probabilities. There are eight basic movement matrices to correspond to the eight different manoeuvre options. The BG movement threat map is applied directly to the appropriate movement matrix to calculate the desired movement vector. This threat-conditional movement matrix operation allows the BG to react to current threat while being controlled from a higher level of command via the manoeuvre options. The BG automata will have additional cohesion rules in the battlefield domain which will act in conjunction with the directives of the movement vectors. These cohesion rules will avoid the potential situation of BGs within the same Brigade splitting apart.
The movement calculation is a simple matrix multiplication which implements combined sector-wise rules in terms of IF perceived threat is X THEN movement should be along vector Y. An example of the movement calculation is given at Annex A.

4.6.3 Selection of the BG manoeuvre option

The trigger to select a new manoeuvre option depends on the overall PCPR situation and the corresponding trigger value. The PCPR is checked against the minimum and maximum force ratio trigger values. Any violation causes the commander to assume the role of the higher level commander and to select a new manoeuvre option (eg to effect a change from deliberate attack to withdrawal).

So the activation of the command trigger can occur in two ways according to whether the situation is going well or badly, (these will be called exploit and get-out activations respectively). In the prototype model an "exploit" activation will determine the change in the manoeuvre orders by using the manoeuvre transition matrix. A "get-out" activation will allow the BG commander to change the manoeuvre option by using the binary threat map (with BG range limits). The prototype will have the facility to exponentially smooth the PCPRs over time.
Figure 4-7: Schematic SAA flowchart.
4.7 Situation Appraisal Agents

The situation appraisal and data fusion modelling are the most important if we are to succeed in measuring the impact of RISTA. The route from battlefield activity to sensors through data fusion via the situation appraisal agents must be auditable. In the prototype model there will be three levels of SAA associated with the BG, Brigade and notional Divisional HQs. The Divisional SAA shall not perform any calculations of threat maps but will be present purely as a placeholder through which sensor reports from the wide area sensor will be fed before being fed down to the lower level SAAs. The flowchart for the SAA is given at Figure 4.7.

4.7.1 Sensor automata and reports

A list of sensor automata is given at Annex B. In the prototype model there will be airborne MTI/SAR, RPV, ground recce and own forces in contact. There will be two types of target: indirect-fire unit and direct-fire unit at company level. Other entities on the battlefield will not be reported in the prototype (eg sensor sites and HQs). Each sensor will report to one SAA at the appropriate level at regular intervals defined by its update rate. The format of a sensor report will be:

- time of sighting
- sensor identifier
- report confidence
- target identifier
- target position (x,y) grid
- perceived target strength.

4.7.2 SAA list of reported targets

The SAA will update a local list of reports of all targets seen using the unique target_id reference. More details are provided in Reference 2.

4.7.3 Confidence scoring

Confidence levels are attached to each sensor report and are simply recorded as HIGH=3, MEDIUM=2, LOW=1, NONE=0. (NONE is included to keep track of outdated reports.) Timeliness of the sensor report will be incorporated into the confidence measure in the prototype model. At each level in the CA/SAA hierarchy, three time periods will be defined: T1 when SAA reports are degraded by one confidence level, T2 and T3 for 2 and 3 confidence levels. For example, at Brigade level T2 may be 2 hours after which the confidence is degraded from HIGH to LOW. Confidence levels may also be exponentially smoothed.
4.7.4 Own force combat power

In addition to the enemy power calculations the SAA will take ground truth data about the current strength of its own forces from the battlefield domain. The own force strengths are passed to the CA as own force PCPs.

4.7.5 SAA output

There is a one-to-one correspondence between SAAs and CAs so that each CA has a dedicated SAA. The output of the SAA is the sector-by-sector PCP map, one for own force and one for the enemy force with its associated confidence score. The time of the SAA report compilation will also be recorded.

5. Current Status

The prototype model is currently under development. The CA and SAA modules are under test and once verified they will be incorporated into the model architecture and linked to the Battlefield Domain. The first full run through of the initial operational setting is planned for October 1995. The experimental programme is currently being organised and will begin in December 1995. The programming work will continue on the Graphical User Interface so that validation by military experts can be carried out during November 1995.

6. References


7. Acknowledgements

Most of the hard work on the specification of the HiLOCA model was done by Mike Saunders and Sean Richardson, the author of the original cellular automata model. We are all very grateful to Colonel Grant and Mike Nash at DGLW for answering our many questions regarding Tactical Doctrine, deployment, formations, manoeuvre, decision cycle times, etc. We would also like to thank Lt Col R'IA Braithwaite and Major D Halstead for their help in development of the command agents and their advice on the operational setting.
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ANNEX A: EXAMPLE OF BATTLEGROUP MOVEMENT CALCULATION

Assume that the commander of the attacking force is at the BG level and his force is in a deliberate attack manoeuvre. The smoothed overall confidence level of his enemy PCPs from the SAA is 2.

The own force (OFPCP) vector is:

(Back = 600, Left = 600, Rt = 800, Front = 3000, Deep = 900, Rear = 50)

The enemy force (EFPCP) vector is:

(Back = 0, Left = 0, Rt = 0, Front = 500, Deep = 300, Rear = 0)

The PCPR (enemy:own) vector for that commander is then:

(Back = 0, Left = 0, Right = 0, Front = 0.167, Deep = 0.333, Rear = 0)

Use the PCPR vector aggregated over all elements to give the overall power ratio. In this case only the Front and Deep sectors contain enemy forces and so the enemy force strength is 800. The own force aggregated combat power is 5950 and so the total power ratio is 800/5950 = 0.134. If the activation trigger is 0.333 then the command agent would continue in the current manoeuvre and the movement directive is calculated using the deliberate attack movement matrix.

Movement Matrix for manoeuvre: Deliberate Attack

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<td>0</td>
<td>0</td>
<td>0.5</td>
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</tbody>
</table>

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The enemy PCP vector is

\[(\text{Back} = 0, \text{Left} = 0, \text{Rt} = 0, \text{Front} = 500, \text{Deep} = 300, \text{Rear} = 0)\]

when normalised is

\[(0, 0, 0, 0.625, 0.375, 0)\]

and premultiplies the movement matrix to give

\[(0, 0, 0, 1, 0, 0, 0, 0)\]

which drives the movement forward in deliberate attack directly towards the enemy forces.
### UNCLASSIFIED

#### ANNEX B

#### AUTOMATA TYPES

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<td>IMINT</td>
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<td>Overhead</td>
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<td>RPV or UMA</td>
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<td>DF/classifier</td>
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<td>RPV or UMA</td>
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<td>Overhead</td>
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<td>Indirect fire subunit</td>
<td>Lt arty bty/tp</td>
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<td>FGA for CAS and BAI</td>
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DRA/LSS/LSC1/10/95/1.0
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### CIS DOMAIN

#### SITUATION ASSESSMENT AGENTS

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<td>Refined bde level</td>
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<tr>
<td>G4 (ops)</td>
<td>Simple</td>
<td>Refined Div level</td>
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#### COMMAND AGENTS

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<td>Refined bg level</td>
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<tr>
<td></td>
<td>bde level</td>
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<tr>
<td></td>
<td>bde level</td>
<td>Finished intelligence</td>
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12. Initial Distribution List

Internal:
- DRA Malvern
- DRA Malvern
- DRA Malvern
- DRA Malvern
- DRA Malvern
- DRA Malvern
- DRA Malvern
- DRA Malvern

- M C Burstow
- M J Saunders
- S B Richardson
- Dr B D Bramson
- Lt Col RIA Braithwaite
- Dr R N G Piercey
- File copy

External:
- DGLW
- DGLW
- DRA Portsdown
- DRA Fort Halstead
- SRP Panel J copies
- Spare copies

- Col Charles S Grant
- M Nash
- J Gadsden
- G Cran
- 5
- 5
This paper presents the functional specification for HiLOCA, a high level operations model using cellular automata for use in future RISTA assessment studies.
## Glossary

<table>
<thead>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ASTOR</td>
<td>Airborne STand-Off Radar</td>
</tr>
<tr>
<td>BG</td>
<td>Battle Group</td>
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<tr>
<td>C2</td>
<td>Command and Control</td>
</tr>
<tr>
<td>C2I</td>
<td>Command, Control and Intelligence</td>
</tr>
<tr>
<td>C3I</td>
<td>Command, Control, Communications and Information</td>
</tr>
<tr>
<td>CA</td>
<td>Command Agent</td>
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<tr>
<td>CAS</td>
<td>Close Air Support</td>
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<tr>
<td>CIS</td>
<td>Command Information Systems</td>
</tr>
<tr>
<td>HQ</td>
<td>Headquarters</td>
</tr>
<tr>
<td>MTI</td>
<td>Moving Target Indicator</td>
</tr>
<tr>
<td>PCPR</td>
<td>Perceived Combat Power Ratio (own:enemy)</td>
</tr>
<tr>
<td>RISTA</td>
<td>Reconnaissance, Intelligence, Surveillance and Target Acquisition</td>
</tr>
<tr>
<td>RPV</td>
<td>Remotely piloted vehicle</td>
</tr>
<tr>
<td>SAA</td>
<td>Situation Appraisal Agent</td>
</tr>
<tr>
<td>SAR</td>
<td>Synthetic Aperture Radar</td>
</tr>
<tr>
<td>S&amp;TA</td>
<td>Surveillance &amp; Target Acquisition</td>
</tr>
<tr>
<td>TGP</td>
<td>Tactical ground picture</td>
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<tr>
<td>UMA</td>
<td>UnManned Aircraft</td>
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