Enhanced Command and Control modelling within HiLOCA

Paddy Turner
Studies / Research Analyst
Defence Evaluation and Research Agency, St. Andrews Road, Malvern, Worcestershire.
WR14 3PS. United Kingdom

Abstract

This paper recommends an enhanced command and control model within HiLOCA (High Level Operations using Cellular Automata) based on the doctrinal Estimate process used by the British Army as a guide to command and control decision-making. In particular, the process of Intelligence Preparation of the Battlefield (IPB) provides a great deal of structure for situation assessment through the development of specific intelligence products. Moreover, these products may be considered the building blocks of plans; it is in this sense that they may be used in HiLOCA to drive decision-making. The development and use of the products of IPB is discussed with reference to a simple military exercise, and the nature of the resultant command and control decisions is explored.

Introduction

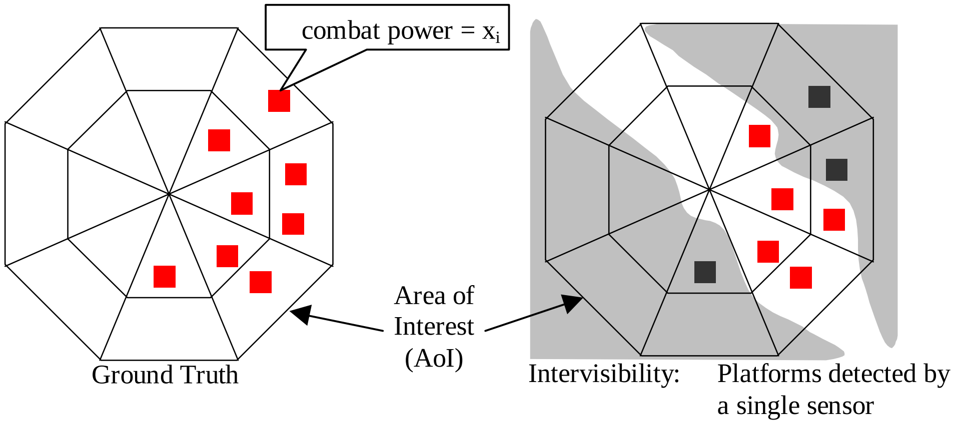
The UK MOD requires studies into the quality of military command decision-making under a wide range of factors. Current Operational Analysis (OA) combat models are insufficient for this task since they exclude many factors that are deemed critical as influencing decisions. This paper outlines the work of team of researchers from DERA Malvern during the first phase of development of an enhanced command decision-making model for implementation within HiLOCA (model of High Level Operations using Cellular Automata). The focus for the initial phase of work has been the development of modelling requirements based on the military decision-making process. The research has been conducted under the MOD Corporate Research Programme, Technology Group 5 (Human Sciences and Synthetic Environments).

HiLOCA

Overview of HiLOCA's Command and Control Model

HiLOCA is a fast OA combat model with an explicit representation of Command and Control (C2). Model behaviour is not scripted; instead, all command decisions are made locally according to simple rules, giving rise to globally complex behaviour.

Each modelled force comprises a number of decision-making automata representing command headquarters. Each automaton is triggered at intervals (dependent on command level) and is split, functionally, into a Situation Appraisal Agent (SAA) and a Command Agent (CA). Figure 1 illustrates SAA functionality; it should be noted that combat power is a model parameter and reflects the relative 'threat' of each platform.



Perceived Enemy Combat Power = Σx_i across all detected platforms for all contributing sensors

(identification from ground truth, duplicates removed)

Perceived Enemy Combat Power ≤ Actual Enemy Combat Power

Perceived Own Combat Power = Actual Own Combat Power

$$\text{Perceived Combat Power Ratio (PCPR)} = \frac{\text{Perceived Enemy Combat Power}}{\text{Perceived Own Combat Power}}$$

Figure 1; HiLOCA Situation Appraisal Agent

Tables 1 and 2 show CA functionality; the table entries are examples and are both user-definable and applicable at all levels of command modelled. Table 1 shows how the local operational mode is selected according to local PCPR. The impact of orders received from the superior HQ is shown in Table 2; these orders are represented by the superior HQ's operational mode and are resolved against the locally adopted mode. The output of the CA is the resolved operational mode that is disseminated to all of the HQ's subordinate commands and platforms, together with extra situational information concerning the threat's Centre of Gravity (CoG) and velocity. Platforms interpret this information in terms of detailed orders for movement and engagement through local rules.

PCPR	Battle Group Operational Mode
0-10	Advance
10-33	Attack
33-150	Defend
150-	Withdraw

Table 1; HiLOCA Command Agent: local operational mode selection (example)

Battle Group Command Resolution		Brigade Operational Mode			
		Advance	**Attack**	**Defend**	**Withdraw**
Battle Group Operational Mode	**Advance**	Advance	Attack	Defend	Withdraw
	Attack	Attack	Attack	Attack	Attack
	Defend	Defend	Defend	Defend	Withdraw
	Withdraw	Defend	Defend	Withdraw	Withdraw

Table 2; HiLOCA Command Agent: command resolution (example)

Requirements for development of the model

HiLOCA's command decision-making model is a transfer function representing the entire C2 function across all land tactical HQs. At the highest level it is essentially a pattern-matching algorithm that maps the set of *situational variables* (currently consisting simply of {PCPR}) onto the set of operational modes {advance, attack, defend, withdraw} for each HQ at each update time. It is important to note that this mapping is time- and force-invariant. What this means is that there is no way of constraining behaviour according to temporal goals or sub-goals, and all subordinate units receive the same orders from their superior in the same update cycle. A HiLOCA mission is specified only in terms of a geographical objective towards which forces manoeuvre if in advance mode. The only other constraints on model behaviour are low-level physical and organisational constraints.

Observations of HiLOCA simulation behaviour have generated a number of recommendations for model enhancements, the following of which coincide with the requirements of the current TG5 project:

1. A more powerful pattern-matching algorithm that can make further distinctions between different situations and select more realistic Courses of Action (CoAs) accordingly. This requires the extension of the situational variable and operational mode sets and the development of the mapping function itself.
2. The development of a deliberate planning function that provides the context within which command and control decisions are made. This requires an understanding of the impact of situational information on the development and use of plans, i.e.:

– What situational information is used in the development of the plan, and therefore forms the context for decision-making in battle?

– What situational information directly influences rapid planning (the largely reactive, bottom-up style of decision-making exhibited by HiLOCA)?

– What is the relationship between the goals and constraints of the plan and the rapid planning function at different command levels?

Better quality decision-making can only be captured in HiLOCA through the implementation of both rapid and deliberate planning functions; the absence of context for decision-making within the model is one of the main reasons that model behaviour deviates from reality. Discussions with military subject matter experts (SMEs) have indicated that the nature of decision-making in battle across command levels is fundamentally different. At higher tactical levels, command and control decisions focus more on the co-ordination of subordinate forces within the developed plan, whereas at lower levels (where the battle is actually being fought), mission goals and constraints are tighter and rapid planning dominates. Although similar planning and decision-making procedures are specified in British Army doctrine at all levels of command, the nature of deliberate and rapid planning at the lower tactical levels converges due to the shorter timescales available. It is not an unreasonable assumption, therefore, that lower tactical decision-making may be modelled as a reactive process.

In order to determine what type of situational information is used in both deliberate and rapid decision-making, the research team conducted a simple military exercise in which a team of subject matter experts (SMEs) conducted deliberate planning for two opposing Brigade level forces in a bounded scenario. The next section provides the military background for the exercise.

The Estimate Process

The British Army Estimate process (into which Intelligence Preparation of the Battlefield, described below, is an important input) is depicted graphically in Figure 2. The Estimate serves as a method by which a commander and his staff may analyse their superior's mission and the current situation to select an appropriate Course of Action (CoA) and develop the plan. As discussed above, in rapid planning, this process is condensed in time and may be modelled as a relatively simple pattern-matching process.

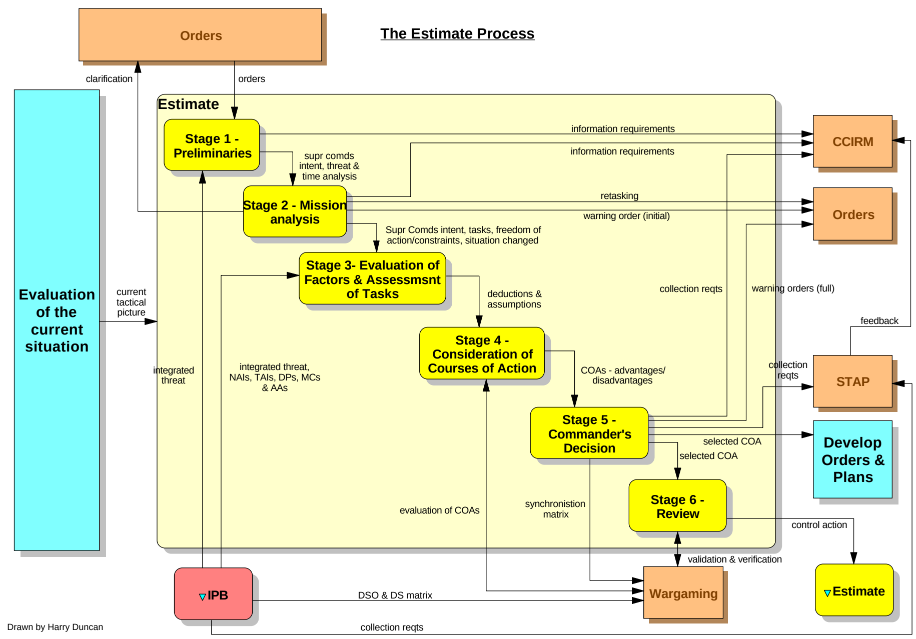


Figure 2; The Estimate Process

Doctrine provides a set of situational variables (termed 'factors') that should be assessed during conduct of the Estimate. At the lowest level, these include:

Ground	Terrain	
	Culture	
	Weather	
Enemy	Tactics	
	Organisation	
	Platforms (including capabilities)	Command and Control
		Weapons
		ISTAR
		Logistics
	Disposition	Location
		Velocity
		Mode
	Combat Effectiveness	
Friendly Forces (as *Enemy)*		
Time		

Table 3; Low Level Situational Variables

The situational variables included above are merely building blocks; some of the factors deemed important as influencing decision-making (e.g. relative strengths – or PCPR) have been omitted since they may be aggregated from those shown. In modelling terms, these situational variables define the basic template on which situations may be described. The Estimate process places these low-level situational variables in the context of the current mission and is heavily influenced by the experience and personalities of the commander and his staff. The following subsections detail some of the processes that map situational information onto decisions (in the form of detailed plans).

Intelligence Preparation of the Battlefield (IPB)
IPB is an integrated method of analysing the effects of terrain and the enemy on friendly forces' ability to achieve their mission. It is a dynamic process, since the relationship between these factors demands continual reassessment. IPB is commonly split into four

stages: Battlefield Area Evaluation, Threat Evaluation, Threat Integration and production of the Decision Support Overlay. Figure 3 illustrates outlines the IPB process and indicates how it is used in the conduct of the Estimate.

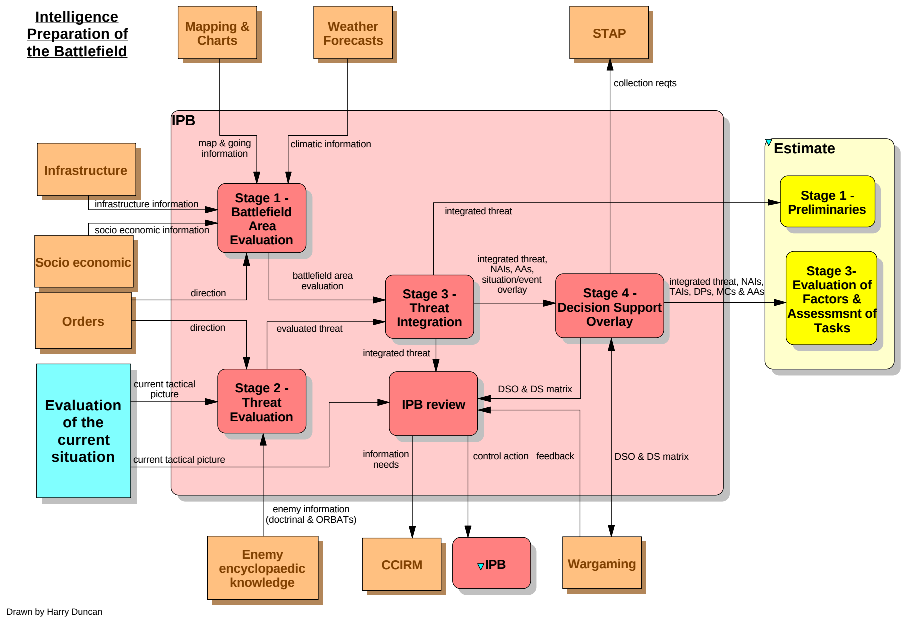


Figure 3; Intelligence Preparation of the Battlefield

Stage 1: Battlefield Area Evaluation (BAE) makes use of existing databases (primarily terrain and weather) to determine both the nature of the battlefield environment and how it may affect the conduct of operations. The product of BAE is the terrain overlay, reflecting the impact of terrain and weather upon mobility. Initially, areas of ground are classified as either GO, SLOW GO or NO GO. Mobility Corridors (MCs) may then be identified: a MC is a route along which a given force size may manoeuvre according to doctrinal norms, and are therefore determined by width and going.

Stage 2: Threat Evaluation is the process by which a commander and his staff draw on their encyclopaedic knowledge of the enemy, including his doctrine, tactics and capabilities, to deduce the nature of the threat they face. For a lesser-known enemy, doctrine may have to be elicited through the analysis of his characteristics, capabilities and activities. The product of Threat Evaluation is a Doctrinal Overlay. This is a graphical representation of enemy deployment, usually to two levels down, as unshaped by terrain. Against a conventional enemy about whom a great deal is known in advance, the process is straightforward: doctrinal norms are referenced to determine likely distances, frontages and depth of objectives.

Stage 3: Threat Integration places the evaluated threat in the context of the battlefield. Initially, BAE is combined with an assessment of enemy aims and intentions, known dispositions and doctrine to predict likely enemy Courses of Action (CoAs). To achieve this, a commander and his staff must place themselves in the mind of their enemy. The first product of Threat Integration is a Situation Overlay, which effectively modifies the Doctrinal Overlay(s) based on known enemy dispositions, assessed intentions and BAE. Multiple Situation Overlays may be required to reflect different enemy CoAs and different operational phases. The Event Overlay then identifies possible enemy events in space and time, the recognition of which will indicate which CoA(s) the enemy has chosen. It indicates where and when to look (and also what to look for) in order to confirm or deny enemy CoAs, and includes both Named Areas of Interest (NAIs) and Phase Lines (PLs):

– A *Named Area of Interest* is a geographical area in which events indicative of a particular enemy CoA are expected to occur.

– *Phase Lines* may be drawn across MCs reflecting doctrinal movement rates as impacted upon by terrain, weather and opposing force action.

Stage 4: Decision Support Overlay. The Decision Support Overlay (DSO) is used to identify possible enemy CoAs. It builds on the Event Overlay through the inclusion of:

– *Target Areas of Interest* (TAIs): areas where enemy force may be targeted in order to achieve a specified effect.

– *Decision Points* (DPs): points, in time and space, which trigger specific actions in TAIs.

The supporting Decision Support Matrix includes expected timings of enemy activity.

The Commander's Decision and the Synchronisation Matrix

At the conclusion of the IPB process a DSO representing each of the possible enemy CoAs is produced. The commander decides which one is most likely and uses this as the basis for developing his own options. Wargaming is used to compare and develop friendly force CoAs; the resulting friendly CoA is the commander's Decision.

The Synchronisation Matrix is developed by the G3 (Operations) staff with reference to both the DSO (and DS Matrix) and the Decision. Friendly objectives, tasks and constraints are mapped onto the same timeline as expected enemy activity; this allows all factors impacting upon decision-making to be considered together and friendly forces' CoAs are developed based on this evaluation.

Military Workshop

The aim of the military workshop was to understand the use of situational information in the conduct of the Estimate process. The Estimate (and IPB), although followed to varying degrees by different commanders in different situations, does provide a set of guidelines for good decision-making. By analysing the development of intelligence products during the exercise, and interviewing the SMEs immediately afterwards, the research team were able to make distinctions as to the nature of tactical decision-making across command levels, and the type of situational information used. It should be noted that although the battle was not actually fought between both sides, the plans developed did specify the critical factors that would influence decision-making when the forces were in contact.

Workshop assumptions

The workshop scenario concerned a blue (British-style) Brigade defence against a red (Soviet-style) Brigade advance over an arbitrary piece of terrain. ORBATs and doctrine for both sides were taken from British Army doctrine. The initial dispositions of forces were also agreed: red was massed immediately to the east of the border with blue forces occupying the entire valley from TOWN D in the west to the border in the east (see Figure 4). Red's objective was to capture the bridge over RIVER C at TOWN D within 24 hours of crossing the international border, situated some 40km to the east. Conversely, blue's objective was to prevent red from achieving this by delaying him in his advance west. Hence both forces' missions were *time-based*; this heavily influenced the development of the CoA.

For brevity, only the results of blue IPB are presented over the following sections.

Battlefield Area Evaluation

Figure 4, below, is a representation of the terrain overlay produced by the blue team. The effects of weather were assumed to be negligible and it was assumed that red Army Aviation would follow the same mobility corridors as ground-based assets.

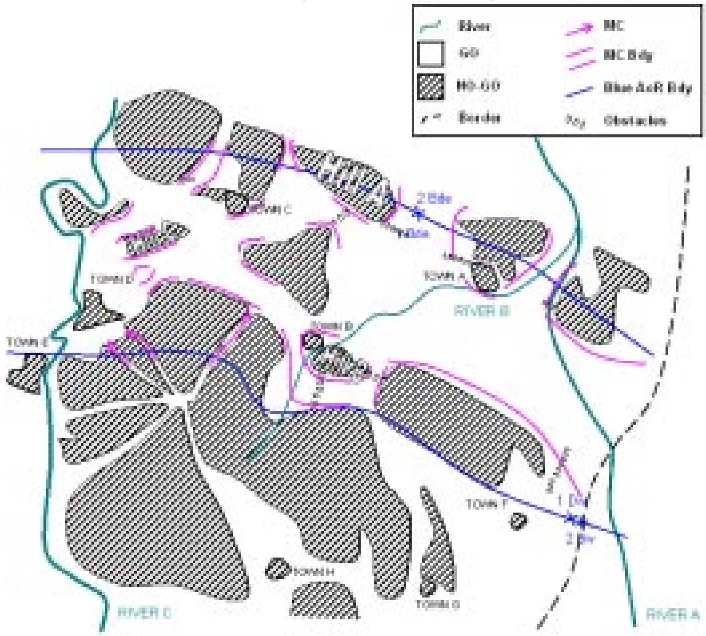


Figure 4; Blue Terrain Overlay

Threat Evaluation

Threat Evaluation was conducted quickly and implicitly by blue, who were familiar with red doctrine. Since Orders of Battle (ORBATs) had been agreed beforehand, Doctrinal Overlays could be extracted directly from doctrine manuals. However, general principles of Soviet warfighting were expressed. In particular, red's use of a second echelon force and the principle of 'reinforcing success' (i.e. providing additional second echelon combat power to the most successful axis of attack) were highlighted. These principles of warfighting had an impact later on during the development of the CoA.

Threat Integration

The blue team did express the view that, in light of red's mission and the nature of the terrain, red's main axis of attack would most probably be along the length of their Area of Responsibility (AoR) from the border to TOWN D. However, the possibility of red forces entering their AoR from the flanks was also taken into consideration and this thinking was reflected in the choice of NAIs on the Event Overlay (shown in Figure 5).

The complete set of NAIs was chosen to distinguish between specific red CoAs. The context within which the NAIs were chosen (highly constrained terrain, Soviet-style enemy with force disposition and objectives known) meant that patterns recognised within them were fairly specific, e.g. identification of the type of enemy unit only (other features became part of the fixed context for the scenario). The blue team did express what criteria would be used to identify particular unit types: key equipments. These are assets that characterise a particular size or type of unit. Further, the identification of a sequence of key equipments over time in an NAI can give further clues as to the exact ORBAT and posture of that unit. For the scenario in question, it was, not unreasonably, assumed that ORBATS were known. Within the fairly constrained terrain of the scenario two specific types of NAI were generated:

1. NAIs at 'choke points' in the AoR. Choke points are narrow mobility corridors with few options for manoeuvre. The blue team suggested that enemy force would not always be easy to identify except at choke points, where sub-units would be in close proximity; hence these NAIs are invaluable in confirming exact enemy presence.

2. NAIs at boundaries of the AoR. These were areas where mobility corridors cut across AoR boundaries, providing a possible route of manoeuvre for enemy forces on the flanks. By identifying all such NAIs, the blue team was satisfied that all enemy ground units passing into their AoR would be detected.

PL2 was seen as the line at which red would most likely deploy its second echelon. The choice of PL2 was dependent on the general type of terrain along the length of the AoR; the valley to the east of PL2 was wider than to the west and therefore offered less difficulty for mobility. As stated in doctrine, the PLs also assisted the blue team in calculating red's expected rate of advance; this intelligence was used later on in development of the CoA.

Decision Support Overlay

Although the choice of TAIs was largely shaped by the terrain, the time-based mission was also a determining factor. For example, TAI 1 was marked to the east of PL1. Although not an area without options for manoeuvre, it was identified as a good area to initially delay red, and its exclusion would have allowed a relatively easy passage beyond PL1, some 10km west of the border.

DPs were laid down along each route towards each TAI (see Figure 7). DPs are triggered by very specific enemy events; they may be thought of as simple switches that are activated when enemy force passes through them. DPs link events in NAIs with actions in TAIs. Activity in an NAI will both confirm enemy CoAs and prime specific DPs in its neighbourhood; assuming that the enemy CoA has been pre-empted, all that is required at the DP is the switching mechanism to trigger a preconceived blue response in the associated TAI.

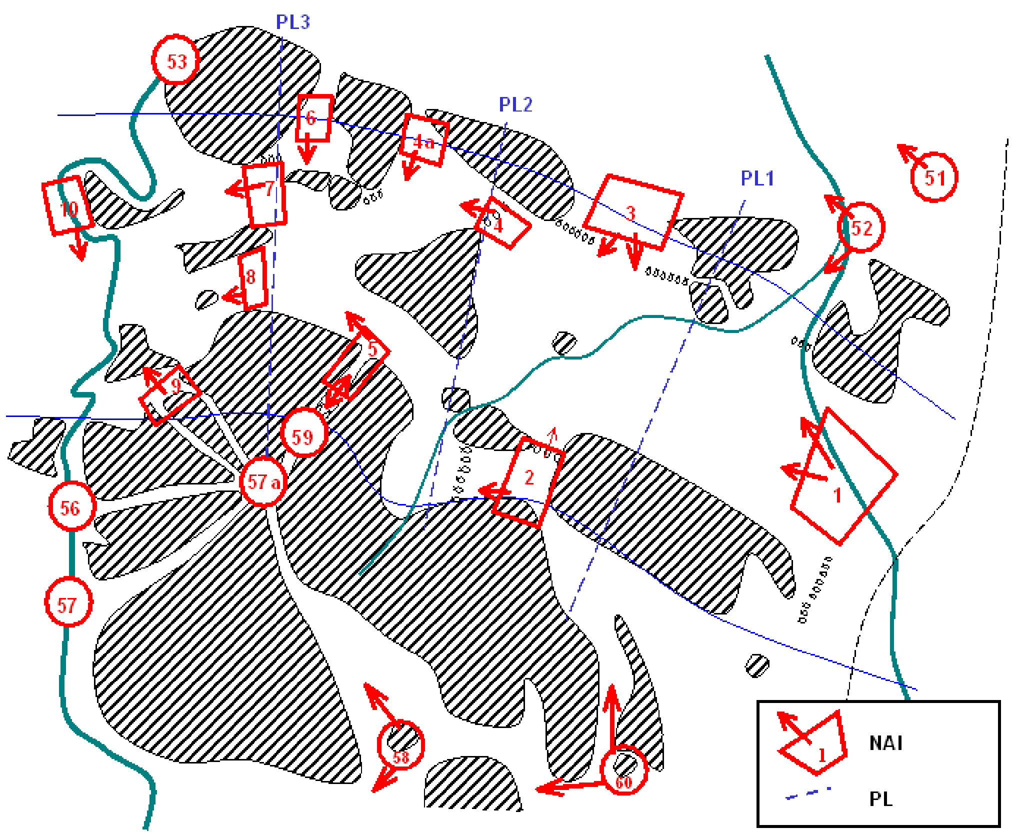


Figure 5; Blue Event Overlay

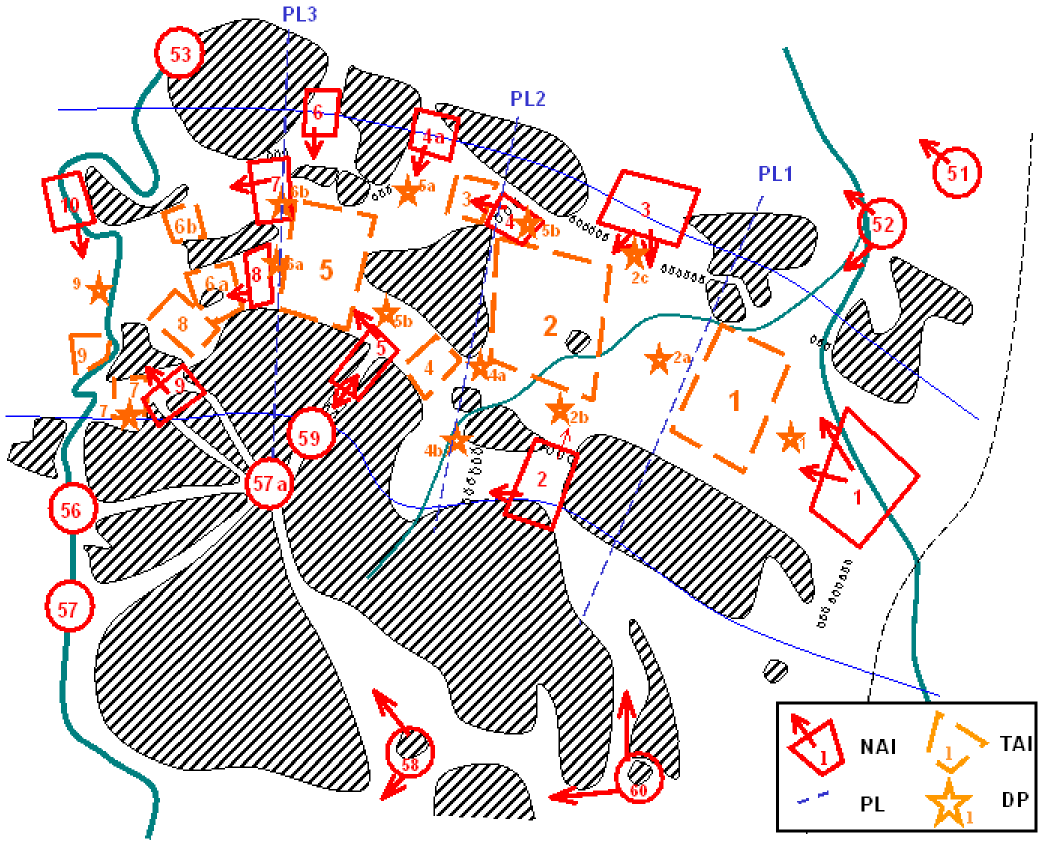


Figure 6; Blue Decision Support Overlay

The supporting Decision Support Matrix, shown in Figure 7 in the form of a network diagram, includes expected manoeuvre times (in hours) between NAIs and TAIs. Each DP was chosen at a location approximately one hour's manoeuvre from its associated TAI. The following assumptions were also made, based on knowledge of red's doctrine and mission:

1. The red Brigade would include seven combat Battalions, with combat support units including an Artillery Regiment and an Engineer Regiment. (For the purposes of the workshop, additional units such as an Air Defence Regiment were ignored);
2. Red would deploy a second echelon, roughly equal to half it combat strength, upon arrival of first echelon forces at PL2;
3. Red would deploy a descant (airborne assault) mission to a Landing Zone in the vicinity of TOWN D not before the deployment of the second echelon. NAI 10 was assumed to be the only viable route for this mission;
4. Although the blue AoR would probably be the axis for red's Main Effort, red units were expected to break into the AoR from the flanks.

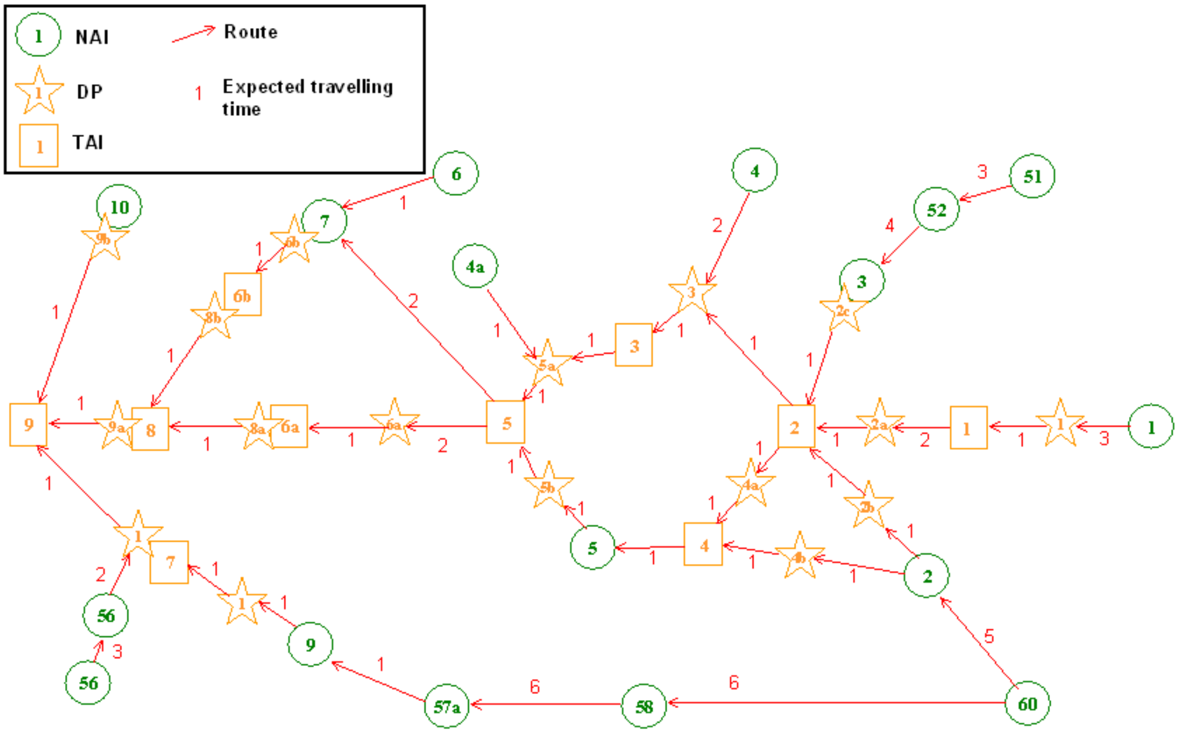


Figure 7; Blue Decision Support Matrix

Synchronisation Matrix

Having completed IPB, the blue team was able to construct a CoA that met with mission objectives. The doctrinally correct response to a superior advancing force is a mobile defence and this was blue's adopted posture. At the unit level, this involves a series of counter-attacks by different Battle Groups (supported by artillery), allowing other units to withdraw from contact. The effect this has on the enemy is to slow him down; by attacking him in short bursts, he is continually required to deploy from march formation into attack and vice versa (there are minimum times for deploying from one formation to another).

Blue's CoA consisted of a mobile defence against both red echelons; at the latter stages of the operation this involved simultaneous attacks on red in different TAIs. This can be seen in the Synchronisation Matrix (Figure 9). The reasoning behind this CoA was that the best way of achieving the mission was to both prevent red's second echelon from joining with the first and to attack the first echelon's logistics tail. This would break his cohesion and, if it were successful, force red into abandoning blue's AoR as the axis of Main Effort.

In order to determine red activity, and trigger actions within TAIs, it was necessary to specify the patterns expected in NAIs and link them to DPs. Figure 8, below, illustrates how this was done for NAI 1 and DP 1. These simple rules allowed NAIs to be activated, and DPs to be primed and activated, according to specific situational patterns observed, and are well suited for inclusion within HiLOCA. It should be noted that the patterns are extremely simple; this is because other situational information has already been accounted for (e.g. enemy tactics and organisation through Threat Evaluation, and force location through the choice of NAIs).

The link between DPs and TAIs is indicated in the Synchronisation Matrix itself (Figure 9).

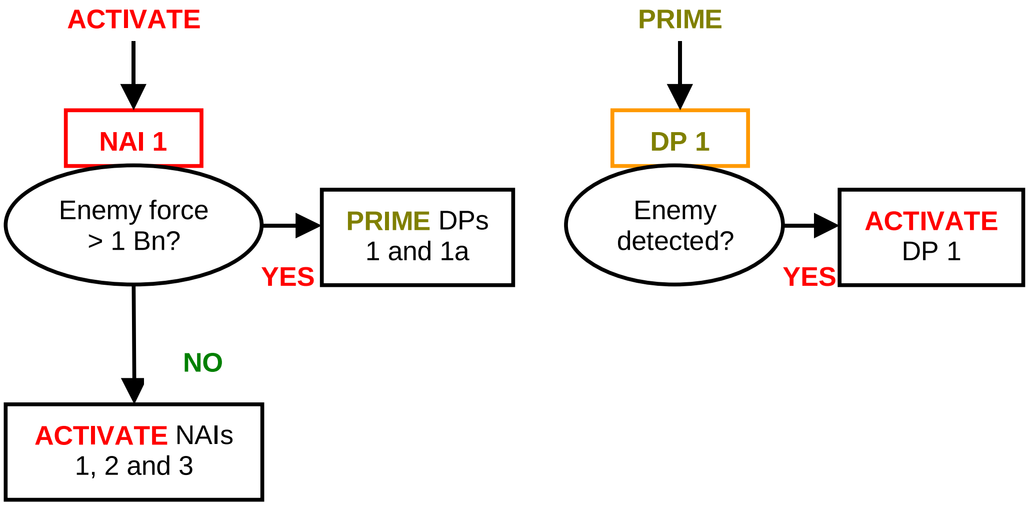
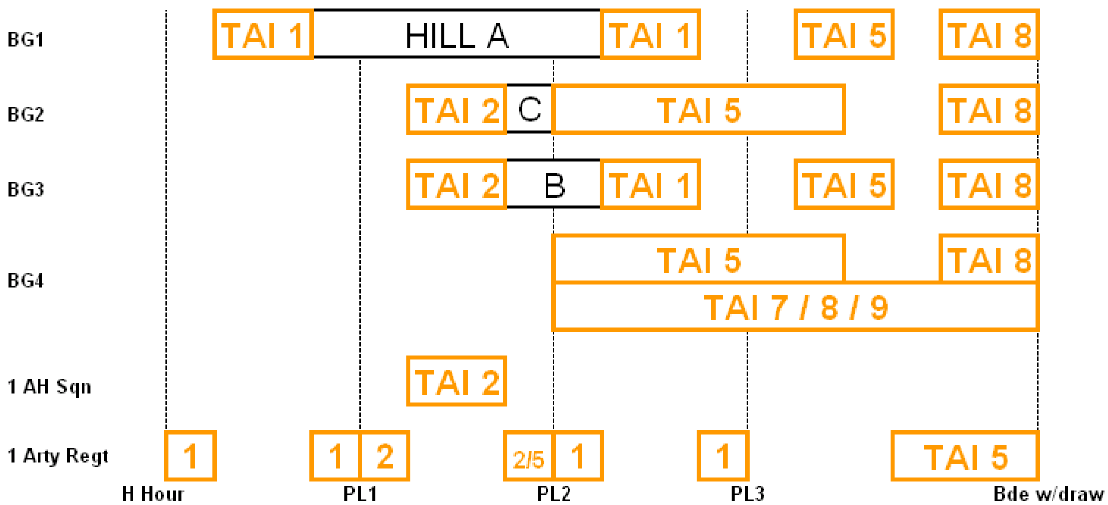


Figure 8; Relationship between situational information, NAIs and DPs



TAI	Trigger for attack (DPs 'activated')	Battle Group Mission Orders and criteria for withdrawal / cessation of attack
TAIs 1, 2, 5 (Arty, all phases)	DPs 1, 2a, 2b, 2c, 5a, 5b	Fire on each TAI until *either* earliest time at which blue forces are expected to attack *or* new DP triggered.
TAI 1 (BG 1, phase 1)	DP 1	Engage red forces until *either* red have completed deployment to attack formation *or* blue combat power < 80%
TAI 2 (BG 2, phase 2)	DPs 2a, 2b, 2c	
TAI 2 (BG 3, phase 2)		
TAI 2 (AH Sqn, phase 2)		Engage red forces until blue combat power < 80%
TAI 5 (BG 2, phase 3)	DPs 5a, 5b	Engage red forces until *either* red have completed deployment to attack formation *or* blue combat power < 80%
TAI 5 (BG 4, phase 3)		
TAI 7/8/9 (BG 4, phase 3)	DP 7, 8a, 8b, 9a, 9b, 9c	Engage red forces (descant) until blue combat power < 60%
TAI 1 (BG 1, phase 3)	DP 1	Engage red forces until *either* blue combat power < 60% (if red still attacking in TAI 5 in phase 3) *or* blue combat power < 80%
TAI 1 (BG 3, phase 3)		

TAI	Trigger for attack (DPs 'activated')	Battle Group Mission Orders and criteria for withdrawal / cessation of attack
TAI 5 (BG 1, phase 4)	DPs 5a, 5b	Engage red forces until *either* red are destroyed / have withdrawn / time > H+24 *or* blue combat power < 60%
TAI 5 (BG 3, phase 4)		
TAI 8 (BG 1, phase 4)	DPs 8a, 8b	
TAI 8 (BG 2, phase 4)		
TAI 8 (BG 3, phase 4)		
TAI 8 (BG 4, phase 4)		

Figure 9; Blue Synchronisation Matrix

The criteria for the withdrawal / cessation of attack by Battle Groups in Figure 9 are largely based on the requirement of the Brigade commander to preserve his Battle Groups. 80% combat effectiveness is an acceptable operating level whilst a Battle Group with 60% remaining combat effectiveness is considered combat ineffective (and hence *must* be withdrawn). The decisions of the Brigade commander to withdraw Battle Groups at 80% combat effectiveness are based on the requirements of the Brigade mission – if Battle Groups take too much damage then the entire mission may be at risk. It was assumed that blue forces would have logistics dumps hidden throughout their AoR so that Battle Groups could resupply and increase effectiveness.

Command decisions and control decisions

With reference to Figure 9, the Brigade commander's *command decisions* are realised in the mission orders for each of his subordinates; these orders are the instantiation of the commander's will and are framed in terms of the products of IPB. The decisions are a product of situational information, experience and mission context and the transfer function is extremely difficult to elicit. Additionally, there are a number of *control decisions* that have been made by the Brigade commander; these manage the risk to each of his subordinate forces and are expressed in the criteria for withdrawal / cessation of attack by each.

There are, however, other control decisions made by the commander. During the mission he is continually required to ask the question, "Has the situation changed?" to determine whether a reassessment of the adopted CoA is required. One suggested metric for measuring the change in situation for blue's time-based mission is red's rate of advance. The DSO provides a set of expected times for manoeuvre between specific areas within blue's AoR; the critical path between the border and RIVER C is 16 hours. Therefore, assuming approximately equal levels of attack in each TAI identified in the Synchronisation Matrix, blue needs to delay red by at least 2 hours in every TAI he has planned to engage him (apart from the attack on the descant mission, which has stricter criteria for success). Based on the timings in the DSO, it is possible to specify the earliest times at which red may pass through certain areas for no reassessment to be required. If red passes through any of these areas at an earlier time, the requirement may be triggered. Other triggers depend on different types of events. For example, the entire blue mission is at risk if red's descant mission is allowed to succeed. These triggers are shown in Table 4 below. What is not clear at this stage, however, is whether the original mission objectives remain achievable when the original CoA requires reassessment. In other words, is there a 'route back' to the original plan from the current state or is replanning required? With reference to Table 4, if red causes blue to withdraw from TAI before H+6, the original objective may still be achieved if the Brigade commander can adjust his Battle Groups to bring more force to bear on red across TAIs 2, 5 and 8. However, the failure to fix the descant mission in its Landing Zone may lead to the loss of the bridge at TOWN D, cutting off the escape route for blue forces within the AoR – this situation is more likely to demand completely new CoA.

Additionally, there are sources of situational variance within the scenario not directly under the Brigade commander's control yet about which he must be aware and be able to react to. The first concerns the ability of the Battle Groups to achieve their own mission objectives. This is a distinct case from the above – here we are discussing the possibility of a Battle Group having to abort its mission even if it has not fulfilled the criteria that the Brigade commander set for it to withdraw. The Brigade itself will be primarily concerned with the fulfilment of its own objective (using the triggers set out in Table 3) but the failure of a Battle Group mission will have a bearing on the achievement of this objective.

The final set of triggers for Brigade CoA reassessment concerns the level of red force within the AoR. The Event Overlay and DSO record NAIs outside the Brigade AoR yet within its AoI (which covers the flanking Brigades' AoRs as well as extending into enemy terrain). The detection of an enemy force within these NAIs will alert the Brigade commander to the possibility of a red flank attack. If this force is small enough, the commander may be able to adjust his CoA by reconfiguring his Battle Groups. If, however, the force is large enough, the Brigade commander will request support from his superior and may be given a new mission.

TAI	Trigger for attack	Criteria for BG withdrawal	Conditions for reassessment of Brigade CoA
TAI 1 (BG 1, phase 1)	DP 1	Red complete deployment to attack formation *or* blue combat power < 80%	Withdrawal at time < H+6
TAI 2 (BG 2, phase 2)	DPs 2a, 2b, 2c		Withdrawal at time < H+11
TAI 2 (BG 3, phase 2)			
TAI 2 (AH Sqn, phase 2)		Blue combat power < 80%	
TAI 5 (BG 2, phase 3)	DPs 5a, 5b	Red complete deployment to attack formation or blue combat power < 80%	Withdrawal at time < H+17
TAI 5 (BG 4, phase 3)			
TAI 7/8/9 (BG 4, phase 3)	DP 7, 8a, 8b, 9a, 9b, 9c	Blue combat power < 60%	Blue combat power < 80%
TAI 1 (BG 1, phase 3)	DP 1	Blue combat power < 60% (if red still attacking in TAI 5) *otherwise* Blue combat power < 80%	Withdrawal at time < H+17
TAI 1 (BG 3, phase 3)			
TAI 5 (BG 1, phase 4)	DPs 5a, 5b	Blue combat power < 60%	Withdrawal of BGs 2 and 4 from TAI 5 at time < H+17
TAI 5 (BG 3, phase 4)			
TAI 8 (BG 1, phase 4)	DPs 8a, 8b		Time < H+21
TAI 8 (BG 2, phase 4)			
TAI 8 (BG 3, phase 4)			
TAI 8 (BG 4, phase 4)			

Table 4; Brigade Control Decisions

Conclusions and Recommendations

The results of the military workshop demonstrate the diverse range of decisions made by a Brigade commander. The initial breakdown, into command decisions and control decisions, is a far richer set than is currently generated by HiLOCA and suggests a framework for model decision-making. In developing command decisions, we have made the important link between situational information and decision-making, through the specification of:

- Patterns to be matched against in NAIs;
- Rules for activating NAIs;
- Rules for priming and activating DPs;
- Rules for triggering actions in TAIs.

We have also developed a number of control decisions necessary for the successful monitoring of the plan.

The IPB process serves to filter the set of situational information required to make decisions by providing a great deal of structure for situation assessment, and thus provides an important input into the Estimate process. It is recommended that HiLOCA's command decision-making model be developed to include a simplified version of the Estimate, focusing explicitly on the encapsulation of the products of IPB.

An inherent difficulty in *closed-looped* C2 modelling (as opposed to C2 modelling with interactive human decision-making) is in the encapsulation of command itself. In the workshop, a great deal of experience was brought to bear in the development of CoAs and it would prove an extremely difficult task attempting to construct a model that produced realistic CoAs based on mission objectives and situational information alone. The current HiLOCA model addresses this problem by focusing on a small set of situational information with little use of either mission objectives or background knowledge. However, what *is* possible is the development of the model to reflect the actual doctrinal processes followed. By inputting a set of IPB products, and priming forces with mission orders of the form introduced above, it is envisaged that HiLOCA simulation behaviour will be more realistic.

The question remains as to how to handle decision-making across different command levels. As discussed earlier, lower tactical decision-making may be considered as more reactive than higher tactical decision-making. For this reason, it is recommended that the HiLOCA Battle Group command decision-making model is retained and that the Brigade command and control decisions are input based on the results of the military workshop.

Initially, however, further military workshops must be conducted across different scenario types to refine modelling requirements. It is suggested that this be done in tandem with model development, so that requirements may also be generated iteratively through the observation of model behaviour.