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Team 1: Maritime Force Protection Study using MANA and Automatic Co-Evolution (ACE)

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INTRODUCTION

This study investigated maritime protection using the Automated Co-Evolution (ACE) framework developed in Singapore. The scenario examined involved a frigate having to defend a high-value but poorly protected target vessel (HVT) from pirate or Fast Intruder Attack Craft (FIAC). The outcomes for the study were to determine whether ACE could come up with feasible tactics for both Blue and Red forces, and as a secondary objective, to gain insights into the scenario itself.

Additionally, a new version of the MANA model was used and evaluated for the work. This version, MANA 5, uses continuous coordinates and vectors to determine the position and movement of the agents in the scenario, rather than the cellular paradigm used in previous versions of MANA. This allows the model to represent both the long-range and short-range interactions in the scenario, without artifacts caused by coarseness of scale that would have occurred if earlier versions were used.

DESCRIPTION OF SCENARIO

In this scenario the Blue Force consists of a generic frigate and a troop carrying vessel with limited armament. In addition, Blue Force was given a group of Rigid Hull Inflatable Boats (RHIBs) for some excursions. While not well armed, the intention was that the RHIBs could act to determine Red Force's intent early. The Red Force consists of a group of seven FIACs, three of which are suicide bombers, and the remaining four armed with RPGs.

Additionally, neutral vessels were added as a scenario variation. These vessels could not be distinguished from the FIACs beyond visual range, and so served to confuse the Blue Force's situational awareness at long range.

Critically, the Red Force is not a conventional military threat, so its intention must be determined before Blue Force may engage it.

The version of the scenario used for the ACE runs included both the RHIBs and the neutral vessels, though it turned out that these did not play a large role in the tactical outcomes.

KEY ASSUMPTIONS

The critical assumptions for this scenario concerned the Rules of Engagement. Two factors would be at play for an actual operation of the type depicted in this scenario:

1. Under what conditions would Blue Force be allowed to begin engaging Red Force?
2. Given the presence of non-combatants, which weapons would be available to the frigate to use? (i.e. Is collateral damage an issue?)

For this analysis, it was deemed that Red Force's intent could be gauged if it came within 500m of Blue Force. Furthermore, no restrictions were placed on the weapons systems that could be used by the frigate, except as a later excursion.

We further assume that the Red Force is deemed successful if it causes any kind of damage to the HVT (i.e. it does not necessarily have to sink it).

Here we do not contend that these assumptions are realistic, rather the intention is to determine what each side should do given these assumptions.

KEY MODELING PARAMETERS

Blue Force. For the ACE runs, the Blue Force consisted of the frigate, HVT, and two RHIBs. The characteristics for these vessels were:

- HVT. The HVT was assumed to be lightly armed and could reach a top speed of 28 knots.
- Frigate. The frigate was modeled to be well-armed with a 5 inch main gun at the bow, a rear Phalanx CIWS 1B, as well as port/starboard stabilized 50cal guns. The frigate was assumed to be positioned randomly within 2km of the HVT. The frigate could also reach a top speed of 28 knots, with some inertia modeling.
- RHIBs. Two RHIBs were modeled as fast moving boats with light arms. Their main use was to scout for

adversarial presence and to inform the HVT and frigate early.

A summary of the key specifications of the Blue Force is listed below:

	HVT	frigate	RHIBs
Maximum Speed (knots)	28	28	35
Detection Range (m)	20000		
ID Range (m)	500		
Weapon Range (m)	1000		

Table 1: Specifications of Blue Force

Note: Detection for the RHIBs is assumed to be supplied by a comms link to the frigate. To save computational overhead, this was represented by giving the RHIBs the same sensor as the frigate.

Red Force. The Red Force consisted of seven FIACs. Four FIACs were armed with RPGs capable of launching attacks within 100m range while three FIACs were close-range suicide bombers. The FIACs were assumed to have a maximum speed of 35 knots. A summary of the modeling parameters used is listed in Table 2 below.

Maximum Speed (knots)	**35**
Detection/ID Range (m)	500
RPG Range (m)	100

Table 2: Specifications of Red Force FIACs

Neutral. More than 30 neutral ships were added to model the difficulty faced by the RHIBs in identifying hostile craft along a busy shipping channel.

METHODOLOGY

Refinement of Baseline Scenario

The team members first started with a round of discussion to fine-tune the baseline scenario. Several quick Red-Teaming runs were initially conducted on ACE to evaluate the modifications before arriving at the finalized baseline for Red and Blue force plans (illustrated on Figure 1 below).

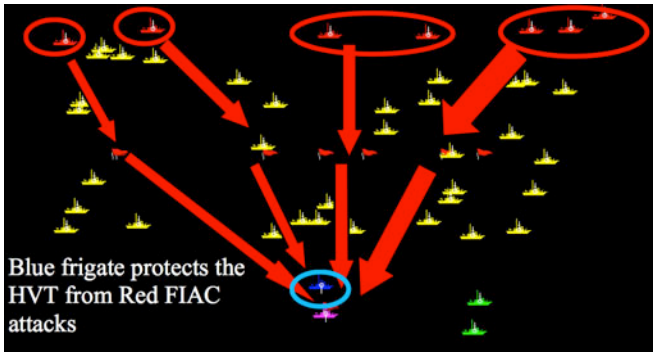


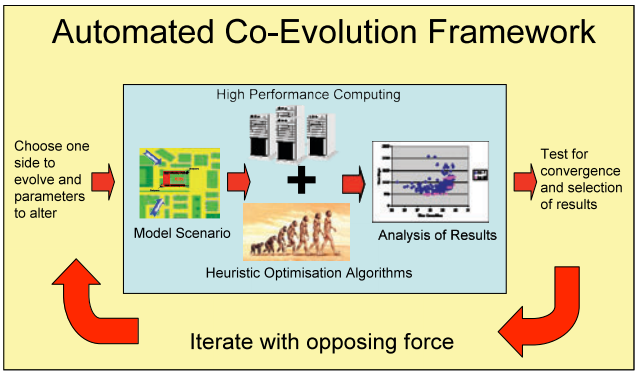
Figure 1: Baseline Blue/Red force plans

Automated Co-Evolution (ACE)

ACE[1] was developed by DSO National Laboratories, Singapore. It is a two-sided competitive co-evolution algorithm, which provides a vehicle for understanding the dynamics of competition in a military context.

The key benefit of this framework is to complement the manually intensive process of developing plans of action by automatically generating plans that perform well and are relatively robust even in the face of an adaptive Red adversary. Potential applications of ACE include supporting of military doctrine/tactics development, operational plan evaluation and acquisition programs.

An overview of ACE is shown below:



Applying ACE

A total of 5 co-evolutions, each constituting one round of Blue Teaming vs. Red Teaming, were conducted automatically using ACE. The two tables below show the ACE run settings, and the ranges for the MANA parameters that were to be evolved.

Co-Evolution Settings	Co-Evo Gen	5
	Comparison Size	1
EPGA Settings	Max EPGA Gen	6
	Max Individual	40
	Parents	10
Model Settings	Replicates	20
Total Runs		~28000
Time Taken	Condor Cluster	~ 20 hrs

Table 3: ACE run settings

[1] "A Co-evolution Approach for Military Operational Analysis" by Choo et. al, *2009 World Summit on Genetic and Evolutionary Computation*.

Blue Parameters	Min Value	Max Value
Dispersion of RHIBs	-100	100
Aggression of frigate against FIACs	-100	100
Cohesion of frigate with HVT	-100	100
Red Parameters	**Min Value**	**Max Value**
X-position of start point for each FIAC	1000 (Left boundary)	19000 (Right boundary)
X-position of waypoint for each FIAC	1000 (Left boundary)	19000 (Right boundary)

Table 4: Red and Blue Parameters for Co-evolution

MEASURES OF EFFECTIVENESS

As required by the heuristic optimization function within ACE, objective functions involving the MOEs were designed. Based on the scenario, it was decided that the function would depend on the following MOEs:

- Mean HVT attrition (Primary Objective)
- Mean Red Force attrition (Secondary Objective as a tie breaker)

Hence Blue Force would seek to minimise mean HVT attrition and maximise Red Force attrition. In contrast, Red Force would seek to maximise mean HVT attrition and minimize Red Force attrition.

RESULTS AND ANALYSIS

Baseline Scenario

Table 5 below shows a cyclic outcome from the 5 co-evolution cycles of Blue Teaming vs. Red Teaming.

No.	Pop Name		RedCas	HVTCas
1	BlueCoEvo	1	1.65	0
2	RedCoEvo	1	2.15	0.95
3	BlueCoEvo	2	2.35	0
4	RedCoEvo	2	5.3	0.85
5	BlueCoEvo	3	6.6	0
6	RedCoEvo	3	5.8	0.35
7	BlueCoEvo	4	5.25	0
8	RedCoEvo	4	2.5	0.35
9	BlueCoEvo	5	3.05	0
10	RedCoEvo	5	6.25	0.4

Table 5: Baseline Scenario MOEs

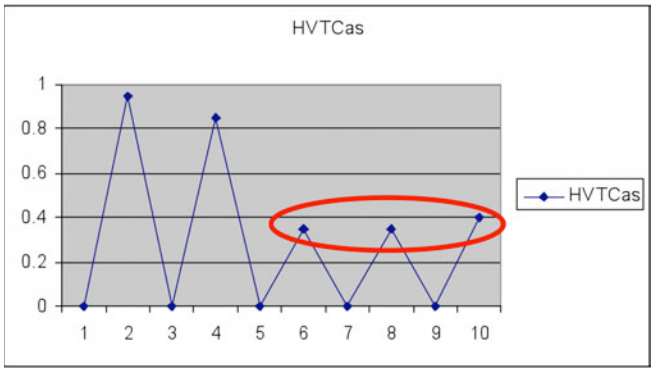


Figure 2: Evolution of Mean HVT Attrition

Cyclic outcome. Zooming in on the results for MOE 1 (Figure 2 above), the team observed that Blue Force could successfully evolve stable defensive tactics (after the 2nd co-evolution cycle) that resulted in less than 50% success for the Red Force counterattacks. MOE 2 (mean Red Force casualties) did not produce meaningful correlation to MOE 1 as it was included mainly as a tie breaker. The team observed surprising maneuvering tactics which saw the frigate purposefully following behind the HVT's escape trail. In addition to maintaining a constant watch and safety buffer distance for the HVT, this strategy successfully created open spaces for the frigate to separate the FIACs and to achieve higher kills against individual FIAC targets as illustrated in Figure 3 below.

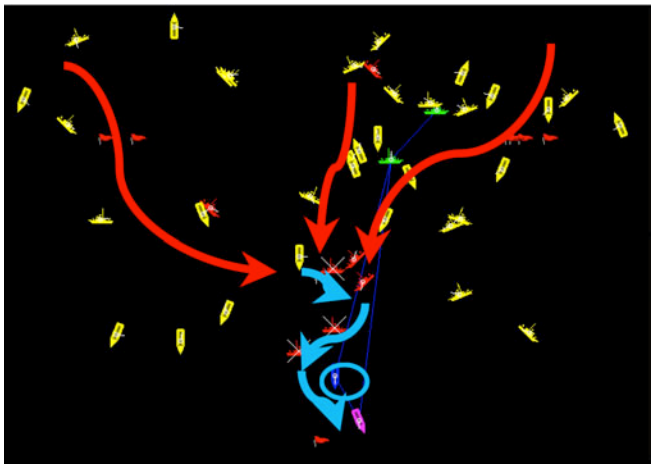
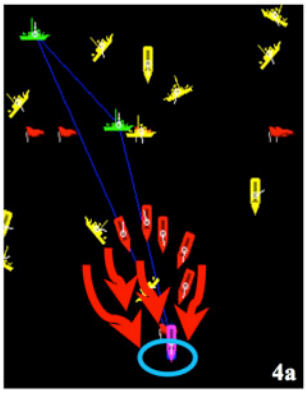
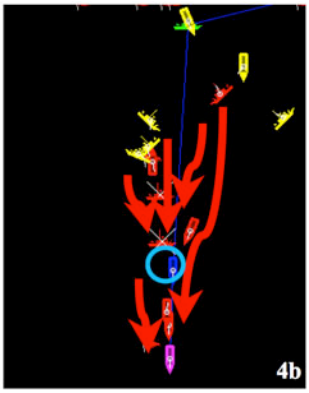


Figure 3: Co-evolved Blue plan

To counter this Blue Force tactic, Red Force's co-evolved plans were to launch synchronized saturation assaults. FIACs were observed to simultaneously swarm so that the HVT had little reaction time and space to escape (See Figure 4a). Another possible tactic would be to send waves of en masse attacks to overwhelm the frigate and thus creating possible openings for at least one FIAC to slip through and to charge towards the HVT (See Figure 4b).





Figures 4a & 4b: Co-evolved Red Force plan

Additional Scenarios

To further explore these findings, the team decided to create two variants of the baseline scenario to study the impact of splitting the FIACs so that they can attack from both North and South directions ("Split FIACs"), and to weaken the weapon effectiveness of the frigate to understand whether there can be tactical solutions for Blue Force to overcome this reduced performance ("Weaken frigate"):

		(a)Split FIACs		(b)Weaken frigate	
No.	Pop Name	RedCas	HVTCas	RedCas	HVTCas
1	BlueCoEvo 1	6.85	0.1	2.5	0.8
2	RedCoEvo 1	4.85	0.9	0.35	1
3	BlueCoEvo 2	6.45	0.35	0.85	0.85
4	RedCoEvo 2	3.25	1	0.15	1
5	BlueCoEvo 3	5.3	0.05	1.75	0.85
6	RedCoEvo 3	1.65	1	0.7	1
7	BlueCoEvo 4	6.8	0.1	1.45	0.9
8	RedCoEvo 4	4.4	1	0.55	1
9	BlueCoEvo 5	5.6	0.2	1.1	0.95
10	RedCoEvo 5	2.2	1	0.05	1

Table 6: MOEs for Split FIACs and Weaken frigate

(a) Results for Split FIACs scenario

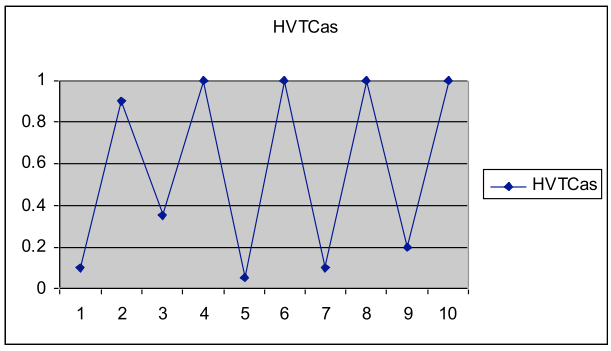


Figure 5: Evolution of Mean HVT Attrition (Split FIACs)

Cyclic outcome. With four FIACs coming from the north and three from the south, the results now showed a significant deterioration in the situation for Blue Force. For every Blue Force evolved tactic, Red Force was always able to find successful countering tactics to ensure close to 100% HVT attrition (seen in Figure 5 above). For every Red Force evolved tactic, Blue Force was unable to find countering tactics to ensure 100% HVT survivability. While the Blue Force's evolved tactics were similar to the baseline scenario, the FIACs' plan was to first draw the frigate towards the north to face the higher density of FIACs. Pre-occupied with the engagements, the frigate would likely lose contact with the fleeing HVT, thus allowing the remaining FIACs to easily flank the frigate and attack the unprotected HVT, as shown in Figure 6 below.

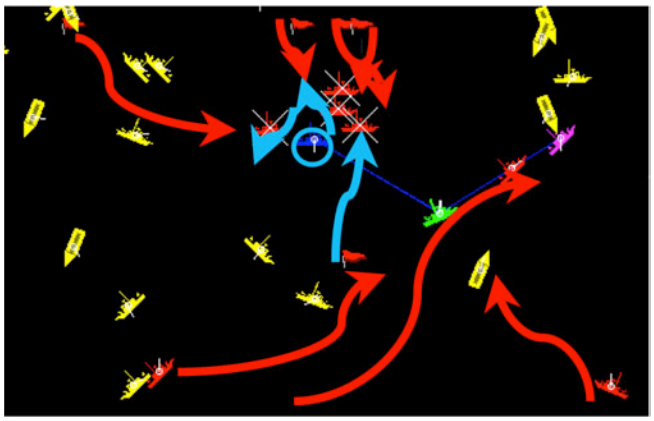


Figure 6: Co-evolved Red Force plan for Split FIACs

(b) Results for Weaken frigate scenario

Red Force dominant outcome. The team observed that the weakened frigate, without the 5-inch gun, was unable to perform the task of protecting the HVT. This could be seen from the trend of mean HVT attrition evolving towards the 100% level in Figure 7 below. Even though the frigate tried to remain close to the HVT, the frigate was regularly overwhelmed by the FIACs when the FIACs chose to attack in numbers. The results show that Blue Force was unable to develop good strategies to counter the Red Force, and even more so when the FIACs split up.

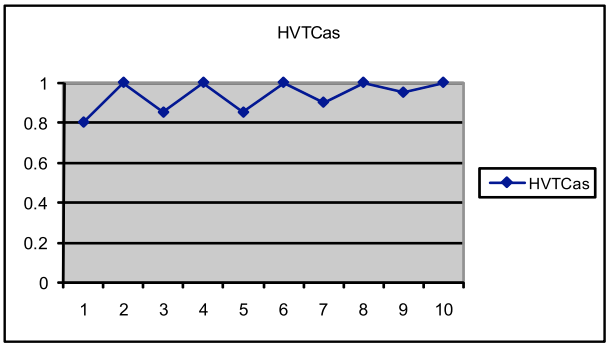


Figure 7: Evolution of Mean HVT Attrition (Weaken frigate)

SUMMARY OF FINDINGS

One-sided compared to Two-sided attack. The results show that the additional degree of freedom given to the FIACs in attacking from two sides rather than just a single side will pose a much greater challenge to the Blue Force. Instead of just trying to saturate the frigate (in the one-sided case), the FIACs can attempt to lure the frigate away from the HVT and then attack an unprotected HVT easily.

Performance of frigate weapon systems. The team assumed a rather optimistic weapon performance for the frigate against the FIAC class of targets. In the scenario of the weakened frigate, we noticed immediate dominance by the Red Force. This finding suggests that if sea trials show that the frigate's weapon systems have limited performance against FIACs, additional Blue Force capabilities may need to be introduced. Note however that the weakened frigate case reflected a much lower level of firepower than a frigate could potentially have (this was achieved by removing the frigate main gun and CWIS, as if these weapons could not be used due to the potential for collateral damage).

CONCLUSIONS

This work successfully demonstrated that ACE was able to generate sensible and optimized tactics for both the Red and Blue forces using MANA 5. This reinforces the findings of Workshop 14 where Singapore's Automatic Red Teaming (ART) was used to establish the feasibility of using evolutionary algorithms to develop tactics; on that occasion for a single side.

In short, the best tactics for the Red Force were to split up and attempt to lure the frigate away from the HVT. Alternatively, if possible the Red Force could attempt to overwhelm the frigate by launching a swarming attack. Conversely, Blue Force's best tactic was for the HVT to move away from the Red Force, but for the frigate to move more slowly, so as to become relatively closer to the Red Force, but when not engaging the Red Force to move back towards the HVT.

We note that this was an abstract scenario and did not necessarily represent accurately the true firepower of the frigate or FIACs. Furthermore, our assumptions about Rules of Engagement, acceptable tactics and objectives of each side may not be representative of actual situations in current operational theatres.

Nonetheless, they still provide some interesting insights into maritime force protection scenarios, and a good starting point for more detailed analysis. It is therefore believed that ACE results would make a useful contribution to mission planning and acquisition analysis.