A Fuzzy Evolutionary Simulation Model (FESModel) for Fleet Combat Strategies

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ABSTRACT
Computational simulations appear as suitable solution for training military forces with a reduced operational cost. Such simulations require solutions that include models that must be close to reality. This work proposes a solution for an important part of warfare simulation: strategy. Hughes [1] explains that in "Modern Warfare", the strategy is the highest level resource, because considers other integrated and non-precision variables. Using Genetic Algorithm (GA) and Fuzzy Logic (FL), this work aims to provide a combat strategy optimization, considering: improvement of the probability to cause damage on enemy fleet and minimization of two others variables: mission's cost and risk. The results indicate that model can be extended and incorporated into a real warfare simulation environment.

Categories and Subject Descriptors
I.6.3 [**Simulation and Modeling**]: Applications.

Keywords
Warfare Simulation, Genetic Algorithm, Fuzzy Logic.

1. INTRODUCTION
Warfare simulation needs to model many complex resources and their relationships, such as vehicles, weapons, sensors, etc.

This work intends to provide a hybrid simulation environment combining Genetic Algorithm (GA) and Fuzzy Logic (FL), to find an optimal battle strategy. Here, "strategy" is considered a set of vessels in allied's fleet, with some weapons, and conserving some distance from the enemy's fleet. This model, called Fuzzy Evolutionary Simulation Model (FESModel) is focused in looking for a strategy that optimizes the Measure of Efectiveness (MoE). The MoE adopted evaluates the probability of damage on enemy, considering i) probabilities of weapons in allied's fleet hit the enemy's vessels, ii) the financial costs of mission and iii) mission risk according to capabilities of allied and enemy fleet.

2. FESModel
The FESModel considers the resources (armament and radars) available for each force (allied and enemy) in fleet combat context. Each vessel has a limited number of weapons (1 to 5). Each weapon has a damage probability (function of target's distance), and a financial cost per fire.

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Each possible strategy takes different vessels from allied's fleet (with different armament) at different distances in a battlefield. The optimal strategy is chosen according to calculated MoE.

The chromosome is one possible strategy (solution). Each gene represents some vessel at some distance (nm – nautical miles). Chromosomes have variable length according to the number of vessels put into the strategy (figure 1).

Vessel 1 at 8 nm	Vessel 5 at 6 nm	Vessel 7 at 23 nm

Figure 1. Chromosome example.

The initial population is composed by 100 solutions. Tournament selection is used. Crossover is performed with 80% of rate. Mutation is performed with 10% of rate, (adding a not used vessel at random distance, removing one vessel or swapping a vessel with non-used vessel). Elitism is used. The best solution is chosen according to the MoE, which has three parts:

$$MoE = (MoE_{AcProbDamage}) + (1 - MoE_{AcCost}) + (1 - MoE_{Risk})$$

The first part of MoE ($MoE_{AcProbDamage}$) adapted from [2], calculates the probability of each weapon of some vessel hit the target, according to a Rayleigh distribution. The MoE of accumulated cost (MoE_{AcCost}) is related to the estimated financial cost of all weapons used in the strategy. The last part of MoE is the risk of strategy which is put as uncertainty and vagueness variable [3]. Fuzzy Logic is used and this model includes 9 rules using Mamdani inference approach [4] considering: i) the accumulated probability of itself detection by the enemy; ii) numerical superiority. The fuzzy functions were developed using a multi-logic framework proposed by Rangel *et. al.* [5, 6], and the set of 9 rules was discussed with a military expert.

3. TESTS AND RESULTS
This work presents two types of test: a proficiency test and comparable test. The proficiency test measures and demonstrates the quality of solution according to theoretical value that can be obtained from the MoE and the time to finish the algorithm. The second is related to compare the FESModel solution and human military expert solution.

3.1 Proficiency Test
A data set with 9 vessels and its resources was used – weapons and radars. That data set includes information about each vessel, its armament (each vessel has a set of weapons), lethality of each weapon [1, 2] and (approximated) financial cost of each fire.

The tests were made based on three scenarios. The first scenario refers to allied fleet and enemy fleet with equal resources (same number and type of vessels – 9 x 9). The second scenario imposes a numerical advantage of the allied (whole fleet) against a reduced force with the 4 most powerful vessels of the enemy fleet (9x4). The third scenario is similar, but the enemy fleet is a set of the 4 weakest vessels (9x4). Table 1 shows the scenarios review.

Table 1. Test scenarios.

Scenario	Allied fleet number	Enemy fleet number
1	9	9
2	9	4 (most powerful)
3	9	4 (weakest)

Each test was performed 20 times. The values presented in table 2 are the minimum, maximum and average time elapsed for process accomplishment, and the MoE value. The maximum theoretical MoE that can be obtained is 3.0. However this situation is unreachable because requires vessels with weapons with no cost. Thus is equally true to consider that is not possible to have MoE with value 0.0.

Table 2. Scenarios results.

Scenario	Min Time (ms)	Max Time (ms)	AVG Time (ms)	Min MoE	Max MoE	AVG MoE
1	1256	4823	1934	2.4783	2.76127	2.6575
2	856	2568	1493	2.3562	2.77436	2.5553
3	986	2987	1609	1.5034	2.35875	2.0568

In the first scenario test (a theoretical draw) the FESModel almost always suggests a strategy that includes all vessels. The best result (obtained in 85th iteration) was 2.76 for this strategy:

[Vess. 7/0.15nm; Vess. 4/0.24; Vess. 6/0.05; Vess. 5/0.15; Vess. 9/1.98; Vess. 2/1.8; Vess. 8/1.31; Vess. 3/0.30; Vess. 1/0.3].

The second scenario puts all the allied vessels against the 4 strongest vessels of the enemy fleet. The best solution obtained (2.77) refers to send 7 of 9 vessels of the fleet. It can be seen that this solution has prioritized to send vessels with low cost compensating the damage probability with the numerical advantage. The best solution was:

[Vess. 5/0.76nm; Vess. 7/0.73; Vess. 3/13.87; Vess. 4/0.22; Vess. 6/0.49; Vess. 8/0.19; Vess. 9/0.17].

The third scenario puts all the allied vessels against the 4 weakest vessels of the enemy fleet. Again, the best solution has prioritized to send many vessels with low cost. The best solution (2.36) obtained refers to send 6 of 9 vessels of the fleet:

[Vess. 6/1.62nm; Vess. 4/0.06; Vess. 3/33.86; Vess. 7/0.20; Vess. 5/0.09; Vess. 8/1.06].

It is possible to identify a pattern: Vessel 1 is often discarded as resource in the strategy. Vessel 1 has just one weapon which is the most powerful one, with high achievement and high cost. Lower cost and same accumulated damage probability can be obtained with other vessels with balanced armament.

All tests have had processing times that allow using into real simulations systems. We shall need to consider that the reduced size of fleets has inflicted a reduction of process time.

3.2 Comparable Test

In this test, a military expert was asked to solve the same cases intending to compare with our model (table 3). He has chosen the vessels and distances according to the same information that it has been used in previous tests. Intending to evaluate his solutions, the strategies drawn were put into the same software just for MoE calculation. The results are described below:

Table 3. Comparable Test.

Scenario	FESModel (Average MoE)	Military Expert (MoE)
1	2.6575	**2.756**
2	**2.5553**	2.359
3	**2.0568**	2.046

The test has shown that FESModel has obtained values as close as human decisions. Finally, no restrictions were applied by military expert about the solutions found by FESModel.

4. CONCLUSION AND FUTURE WORKS

This work has presented a hybrid model that use Genetic Algorithm (GA) and Fuzzy Logic (FL) to simulate strategy in a fleet combat. The model presented has reached good results in two types of tests proposed: a proficiency test and a test comparing the FESModel solution with a human expert solution.

Reality proximity can be reached with simulation model with constant evolution. For this purpose, more resources need to be considered. The inclusion of more scenarios with more vessels and armament can help to understand the complexity and behavior of strategy decision.

5. REFERENCES

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