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Modeling a naval force protection scenario in MANA

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Abstract

Force protection (FP) in the naval context is commonly understood as a vessel's self-defence against low-to-moderate severity threats, but stopping short of conventional warfare (such as missiles or torpedoes). These types of threats can have a high likelihood of occurrence and a high risk of mission failure, depending on the threat tactics involved. It is important to understand the possible effects of such tactics and the effectiveness of various FP responses in return. The presented study had two objectives. First, it was intended to test the suitability of an agent-based model called Map-Aware Non-linear Automata (MANA) to represent naval FP scenarios outside of conventional warfare. Second, it served to look at the potential benefits of using one specific directed energy non-lethal weapon against the threat's mobility, employed either alone, or in conjunction with a lethal option. The study confirmed the feasibility of MANA for these types of scenarios; it has also shown that, from the survivability perspective, there may be operational benefits to including FP capabilities that disable/stop rather than attempt to outright destroy the approaching threat. This is especially true if these systems enable targeting over an area rather than trying to pinpoint fast moving targets. Additional follow-on work is intended.

Keywords: Agent-Based Modeling, Non-Lethal Weapons, Force Protection

Introduction

In the current security environment, the self-defence of naval vessels must cover the full spectrum of threats. This includes asymmetric threats, such as from swarms of fast boats bearing small shoulder-fired missiles, small arms or loaded with explosives, land- (while in port), air- and water-borne improvised explosive devices, as well as conventional warfare threats (anti-ship cruise missiles, torpedoes, etc.) (Baart, 2014; Gammon, 2005; Greenberg, *et al*, 2006; Heginbotham, *et al*, 2015; Hunter, 2005; Lauren, *et al*, 2009; Abel, *et al*, 2009). Force protection (FP) is defined as "all measures and means to minimize the vulnerability of personnel, facilities, equipment and operations to any threat and in all situations, to preserve freedom of action and the operational effectiveness of the force" (Department of National Defence, 2016). However, this definition promotes a very broad interpretation of what activities constitute FP and does not distinguish between variations along the threat spectrum that could blur the lines into traditional warfare areas. As a result, FP in the naval context has been further specified as vessel self-defence against low-to-moderate severity threats, stopping short of conventional warfare (such as missiles or torpedoes). Incidentally, these types of threats can have a high likelihood of occurrence and a high risk of mission failure, e.g., due to a loss of key systems. It is important to understand the possible effects of such tactics and the effectiveness of various FP responses in return. Modeling a variety of scenarios provides means to validate operational concepts and effectiveness of weapon systems options without incurring the costs inherent to live trials and experiments.

This paper examines four FP options, consisting of typical existing surface combatants' capabilities such as a main gun and pinnacle-mounted machine guns, and a potential future directed energy capability, against the particular threat of a suicide attack by a swarm of small fast boats loaded with explosives (Dobias, *et al*, 2015). Such a threat is likely in many operational areas; particularly in straits, near or in ports, or in busy shipping channels (Greenberg, *et al*, 2006). In order to explore such a variety of options, the analysis employed an agent-based model developed by the New Zealand Defence Technology Agency (DTA) called Map-Aware Non-linear Automata (MANA) (Hunter, 2005; Lauren and Stephen, 2002; Lauren, *et al*, 2009). Due to their low implementation investment (in terms of both financial cost and time) agent-based models such as MANA are particularly useful for this type of exploratory study. These models represent real-life people, objects or systems as abstracted autonomous entities that behave in accordance with pre-defined heuristics, capturing nonlinear system dynamics inherent in multi-scale, multi-actor situations (Dobias, *et al*, 2016). The inherent complexity of these models enables a fairly realistic representation of entity behaviour and responses; at the same time, the abstraction of the modeled systems eliminates the need for high-fidelity technical information that may not be available for emerging systems. The low implementation investment required means that a large number of options can be assessed with little cost or time; thus these models can be used for exploratory studies with relatively little risk.

The purpose of the study was twofold. Firstly, it was intended to test the suitability of MANA to represent naval FP scenarios outside of conventional warfare, where it has commonly been utilized. Secondly, it served to look at possible benefits of using one non-lethal weapon – specifically, a directed energy system – against the threat’s mobility, employed either alone, or in conjunction with the lethal options. Because of the need to validate the use of MANA, this study was not intended to be comprehensive, and more follow-on work is intended.

The paper is organized as follows. The next section covers the considered scenario, range of threats, and possible defensive options that currently exist. Then, the implementation of the scenario in MANA is presented. Finally, the paper illustrates the results of the simulation, and discusses some implications and possible future work.

Scenario Development

The considered scenario consists of a single friendly (Blue) vessel transiting across a designated area that is swarmed by a number of enemy (Red) fast boats (Abel, *et al*, 2009). These Red craft were assumed to be loaded with explosives (i.e., suicide bombers, destroying both themselves and harming their enemies) that would be detonated once they got within 10 m of the Blue vessel. Between one and ten Red boats are considered; the scenario starts with the Red vessel(s) located approximately 1,000 m away from the Blue ship, where they then start approaching the Blue target from various directions at high rate of speed. In order to reduce the complexity of the analyzed problem, the presence of civilian traffic, though likely in this type of scenario, was not considered. However, it should be considered in follow-on work in order to account for possible collateral damage, as well as delays in the decision-making process.

In order to further limit possible scope of the FP options (Dobias, *et al*, 2015), it was assumed that the topography of the operational area limited maneuverability of the Blue vessel; for instance it could move through a narrow shipping channel within an otherwise shallow area. This limits the Blue FP options to the employment of onboard FP systems rather than maneuvering to evade the threat. It is further assumed that the Blue ship moves rather slowly relative to the threat. This scenario presents realistic constraints in the vicinity of many ports, in straits, or in other congested areas. The high volume of small vessel traffic in port areas and shipping lanes close to shore also makes it more difficult to determine potential adversarial intent, and provides cover and added complexity in an environment where heightened awareness is already required.

Four Blue FP options are considered here; two of which are lethal, one non-lethal, and one a combination of lethal and non-lethal measures, as follows:

1. Main gun (akin to the 57 mm cannon on the Royal Canadian Navy's frigates) (Department of National Defence, 2014)
2. Pinnacle-mounted heavy machine guns (Department of National Defence, 2014)
3. A radio-frequency (RF) “zapper” countermeasure (Department of Defence, 2014) intended to disable motors on the approaching small boats (e2v, 2016)
4. A combination of the RF zapper (from Option 3) and a machine gun (from Option 2)

The RF zapper is an electromagnetic pulse device, i.e., it functions on the principle of electromagnetic overloading of boat’s (or vehicle’s) electronic systems by an electromagnetic pulse. The typical range for a vehicle-mounted system is approximately 50 m, but the systems were tested out to 400 m and the manufacturer claims that the range could be extended further by using larger antenna and power source (which would not be a problem for ship-mounted systems). The system may not work against old boats without electronics, but it has been successfully tested against more modern vessels (e2v, 2016). The RF zapper was used only as an example of a non-lethal vessel-stopping capability, and other systems could be considered.

Table 1: *Notional weapons characteristics.*

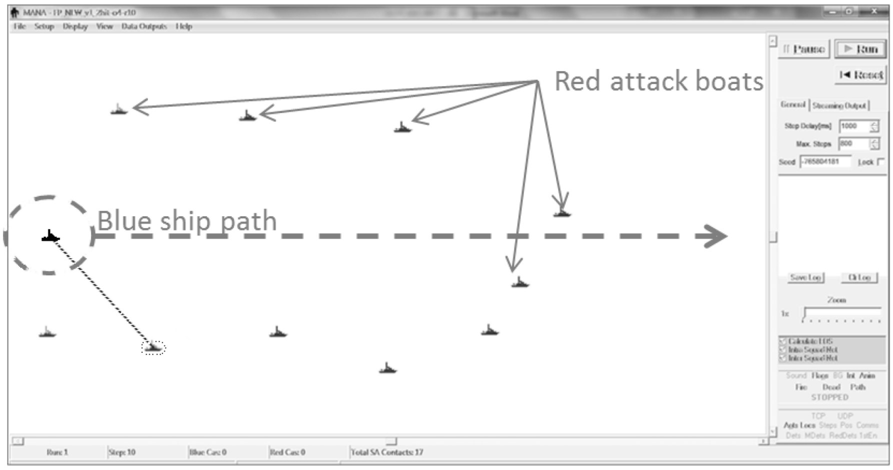
Option	**Weapon**	**Range**	***Pk***	**Area Coverage**	**Reversible**	**RF Effectiveness**	**Comments**
1	Main gun	1,000 m	0.05	n/a	N	N/A	Burst of 6 shots, repeat every 20 s
2	Machine gun	600 m	0.01	n/a	N	N/A	Up to 1,000 rounds
3	RF zapper	800 m	N/A	20 m radius around primary target	Y	100%	Continuous effect while applied
4	RF zapper + Machine gun	800 m / 600 m	N/A /0.01	20 m radius / n/a	Y / N	100% / N/A	Use machine gun if RF zapper failed

Table 1 details the weapon system characteristics considered in the scenario. These characteristics are notional (i.e., for relative comparisons only), and do not accurately reflect detailed performance specifications of any particular weapon system. The probability of hit and probability of kill for a single round (or a burst, if applicable) were combined into a single quantity called probability of kill (*Pk*). The effects of the RF system are reversible; that is, they only apply when the system is pointed at the target. However, it was assumed that, due to the nature of the electro-magnetic wave propagation, the RF zapper would cover a wide area; in other words, if there are multiple boats in close proximity, they all would be affected by the RF zapper. Once the RF zapper is applied to the approaching target, the target’s engine shuts down. The approaching boat would lose maneuverability and, depending on the initial speed, it may take some time to come to a stop. In reality, the ability of the Blue ship to target the approaching boats would generally depend on their speed and angle of approach. These factors were not considered in this paper; the *Pk* was assumed to be constant.

However, this assumption only impacted Option 4, in which two situations could arise: either approaching boats were moving, or, after the employment of the RF zapper, they would be stationary for a period of time.

Model implementation in MANA

MANA is an agent-based model and, as such, represents a rather abstracted version of reality. It is not intended to provide an absolute assessment of system effectiveness; instead, it can provide evaluation of relative performance of multiple systems (such as the cases considered in this paper). MANA entities move within predefined terrain; the terrain features are represented by a colour map associated with a terrain bitmap. In the considered scenario, it is assumed that the terrain – which was open water here – has no effect on ship movement or entity sensing capability. The agents then make decisions to move based on a predefined set of behaviours. In this scenario, there was one Blue frigate, which moved at a slow speed of approximately 2 m/s along a straight line through a small 2,000 m x 2,000 m area, simulating a slow transit through a narrow but sufficiently deep, navigable channel on an approach to a port. While frigates can theoretically move at much higher speed, the low speed value (corresponding to 5 kts) was chosen since it would be unlikely for a frigate to move at a high rate of speed through such a restricted navigational area, especially when approaching a port. Assuming the channel would be approximately 100 m wide (typical for many areas), a frigate with an average length of 130 m would not even be able to turn sideways; thus, severely restricting possible speed and maneuverability. The rest of the area was assumed to be shallows with insufficient depth for the large Blue ship, while imposing no limitations on small Red boats. This assumption forces Blue to continue its transit while Red attacks. There were a number of Red fast attack boats moving from many directions toward the Blue ship (shown circled in a dark grey line in Figure 1). The threat vessels were moving at approximately 6 m/s from approximately the same locations for each run. Since, due to their shallow draft, they would not be hampered by the navigation restrictions, and maximum speed of small boats can easily range up to 20 m/s, this was considered fairly realistic. Due to MANA abstraction, what was more important for the modeling purposes were relative speeds of the Blue and Red vessels, rather than their absolute values. No avoidance manoeuvres by the Blue ship were considered as such manoeuvres would risk grounding the vessel.



Step Delay(ms) 1000
Max. Steps 800
Seed -765804181
Lock ☐
☑ Calculate LOS
☑ Intra Squad Net
☑ Inter Squad Net

Run: 1 | Step: 10 | Blue Cas: 0 | Red Cas: 0 | Total SA Contacts: 17

Figure 1: *Example of the MANA scenario for Option 4; Blue (in a dashed circle) is engaging approaching Red with the RF zapper (indicated with the line between ships).*

MANA agents can also be equipped with various sensor and weapon systems. For simplicity, the agents were assumed to be able to detect (and identify) any vessel within the modeled area. The main gun and the machine gun on the frigate were both modeled as simple kinetic weapons; the value of *Pk* was considered independent of the distance, angle of attack, and speed of vessel. The main gun was assumed to fire in bursts of 6 rounds, each with *Pk* = 0.05. The machine gun was assumed to fire near continually, up to 1,000 rounds, with *Pk* = 0.01. The RF engine stopper was modeled as an explosive round impacting an area with a diameter of approximately 20 m, but unable to kill Red; instead, the target would react by stopping for 20 seconds. The application of the RF zapper was repeated every 10 seconds, thus it could engage two targets near simultaneously (or more, if the targets were within the coverage area of a single application). In Option 4, the machine gun was modeled as a secondary weapon; the range and the *Pk* were the same as for Option 2. However, MANA target classes were employed to allow for the machine gun targeting only the moving Red agents, rather than those stopped by the RF zapper. There were two reasons for this. The main reason was that a stationary vessel (i.e., the one that ceased to approach the frigate) was not considered a threat anymore. This assumption was made with the intent to test the ability to model the distinction between various small boat types for the future work involving civilian vessels that would be highly undesirable to target with lethal systems. The secondary reason was to avoid expending both weapons systems on a single target.

The Red boats had to get within 10 m of Blue to be within range of the explosives, and then they would detonate. As a result, all the agents (Red and Blue) within the 10 m radius would be hit; Red agents would be killed immediately, Blue required two hits to be killed. The latter was done in order to assess if multiple Red agents could get to the target. For each of the four options given in Table 1, the number of Red attack ships was varied between one and ten.

Results

Because the study looked at the FP issues largely from a theoretical perspective, focusing on general concepts rather than a performance comparison of specific weapon systems, MANA proved to be quite effective to simulate the desired scenarios. As is noted above, each Blue weapons option was replayed for 1-10 Red boats; each of the combinations was repeated for 1,000 simulation runs, leading to the 95% confidence interval for the casualty values of ~1-2% about the mean. This translated to 40,000 runs overall between all of the considered options.

Figure 2 (left) shows the probability of Blue being hit at least once (i.e., the probability of being damaged). If there were three or more Red attack boats, the Blue ship would be hit at least once in nearly all runs for all the options, except Option 1. In Option 1, the dependence of a single hit progressed fairly linearly up to five attack boats; for six or more Red the probability of at least one hit was above 90% and tapered off exponentially. This was likely due to relatively higher assumed lethality of the main gun compared to other systems. For three or more Red boats, they would hit Blue at least once in over 90% of the runs in Options 2-4.

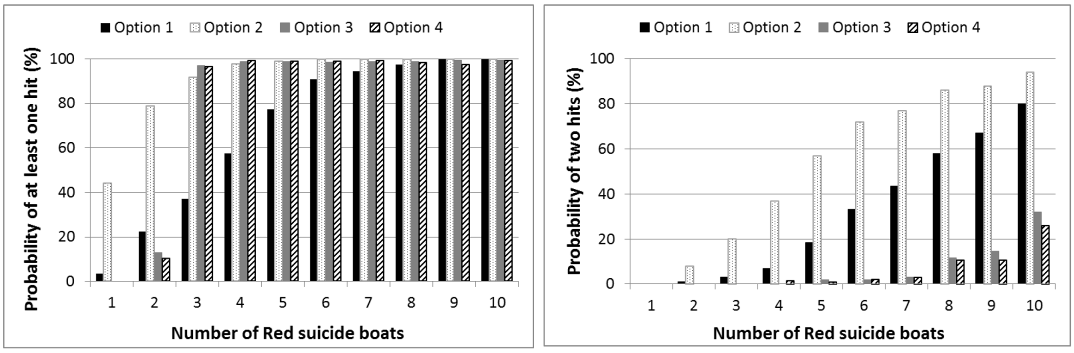


Figure 2: *Probability of the Blue ship getting hit by at least one suicide bomber (left), and two suicide bombers (right).*

The RF zapper worked well if there were only a few Red boats. For one or two incoming Red, Options 3 and 4 (i.e., with the RF zapper), performed best by reducing the probability of at least one hit to less than 10%. In the case of a single Red boat, it would not be able to hit the Blue ship at all. However, for three or more incoming Red boats the RF zapper, due to its directional limitations, was not able to stop all of them. More than one system, or wider area coverage than was modeled, would be required to mitigate this limitation.

The worst performance was observed for Option 2 (the machine gun). Due to its lower relative accuracy and shorter range, the machine gun was not efficient at eliminating the Red threats. Likely, there would also be increased risk of ricochet and collateral damage. Even in conjunction with the RF zapper, it was not able to take out the threats that were left by the zapper. Because the RF zapper was employed first, the machine gun was only used against targets unaffected by the RF zapper (i.e., those that continued advancing); this resulted in almost identical performance between Options 3 and 4.

The dependence of the probability of Blue getting killed (i.e., hit twice) on the number of Red for all four options is provided in Figure 2 (right). For Options 1 and 2, the probability of Blue getting killed increases quite rapidly; for eight Red it is over 50% for Option 1; for Option 2 it is over 50% for five or more Red. The probability is much lower for Options 3 and 4. It is almost zero for five or fewer Red; even with ten Red the probability of Blue getting killed remained below 30%. These results suggest that in scenarios with multiple threats swarming a ship the ability to slow or stop the approaching threat can provide value added, and could be considered as an efficient supplement to the lethal firepower. The benefits of the ability to stop the approaching threat could be likely explained by the increase in the decision-making/acting time provided by the ability to stop the approaching boats. Combining it with lethal firepower did not improve performance; however, this was at least in part due to a short duration of the vignette. Their permanent elimination would, in reality, provide enduring effects.

It must be noted though, that the study did not look at the dependence between the *Pk*, reload time, and survivability of the ship; this is something that may be addressed in future studies. In addition, the simultaneous employment of multiple lethal systems (e.g., main gun and multiple machine guns) was not considered. Also, the RF zapper was modeled as a near-point weapon; if, instead, it were to be used as an area weapon (e.g., sweeping across approaching threats), its effectiveness would likely improve as well. The potential presence of non-combatants was not modeled; all of the approaching vessels were considered threats and dealt with as such. In a more realistic scenario, there could have been a potentially large amount of background traffic, and thus the potential for collateral damage would have to be considered.

Summary

This study employed a New Zealand-developed agent-based model called MANA to model a simple ship force protection scenario. The study has shown that, from the survivability perspective, there may be operational benefits in including capabilities that disable/stop rather than outright destroy the approaching threat. This is especially true if these systems enable targeting an area rather than trying to pinpoint the fast moving targets. If the approaching threat continues attempting the approach despite having non-lethal capability employed against it, it can be targeted by the lethal force while slowed or even stopped. This would likely increase the *Pk* values of the lethal systems, since it would be easier to target slow or stationary targets compared to fast moving ones.

Future work should include considerations of the presence of civilian traffic, and thus potential collateral damage, modeling additional non-lethal and lethal systems, different types of the threats (e.g., shoulder-fired missiles), and possibly looking at the relationship between the Blue survivability and the range and effectiveness of their weapons.

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