Application of the MANA model to Maritime Scenarios

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Abstract

The MANA model, developed at the Defence Technology Agency, has been used to assist in the exploration of maritime surveillance scenarios relevant to the New Zealand Defence Force. The model has been used in the current study to show that long-range aircraft and a fast surface vessel are able to intercept with reasonable confidence a non-military threat in New Zealand's oceanic neighbourhood. Upgrade of the present radar system to imaging capable is found to provide a number of benefits including a decrease in: flight times, fuel consumption, and low altitude flying. The invariance of key parameters, such as flight time, with increased non-target vessel number is found to be a significant aspect to imaging radar equipped aircraft. This leads to savings in flight time of up to 15% and in fuel of up to 16% in the scenario studied.

1 Introduction

1.1 Background

Operational research has its genesis in military operations planning. Today a significant amount of effort is still expended on ensuring that military decisions are made based upon a robust framework backed up by scientific research.

This paper details a particular study that has been carried out at the Defence Technology Agency. Here we inquire into aspects of the maritime surveillance requirements of the New Zealand Defence Force. Particular attention is paid to the effect of replacing the current aircraft radars with an imaging capable radar system. Extensive use is made of the MANA model, developed at the Defence Technology Agency, to aid in this operational analysis work.

1.2 The MANA Model

The MANA model (Lauren & Stevens, 2002) has been developed at the Defence Technology Agency to provide a tool for a wide range of operational analysis tasks. It is based upon the interactions between a set of cellular automata as they move upon a grid. Each of these entities has particular attributes that cause it to interact with other entities in a distinctive manner. Weightings are applied to represent these tendencies in the model. MANA is non-deterministic in that each interaction between entities is based upon an appropriately weighted pseudo-random number. A large number of model runs must therefore be computed in order to determine “average” outcomes for variables of interest. This is known as the “Monte Carlo” method.

1.3 Scenario

Here we consider a specific scenario:
New Zealand authorities have been alerted to the imminent arrival of a vessel of interest (target vessel) within 500 nautical miles of the country.

Broadly speaking, this target could represent any number of vessels of a high level of political importance passing near to New Zealand. For example, it could contain: terrorists, a significant drug haul, a large group of illegal immigrants, or nuclear waste. While each of these variations would play out slightly differently, the basic capabilities required to intercept each are the same.

For the sake of this study, we will assume that the target vessel is believed to be intending to either enter New Zealand or pass near enough to cause some significant threat, but it is not known where or when the vessel intends to do so.

Figure 1 shows a screen shot of the scenario. Clearly, a single Naval vessel is unable to position itself at a given entry point without intelligence as to the direction the target vessel is heading. It thus requires intelligence from a reconnaissance asset.

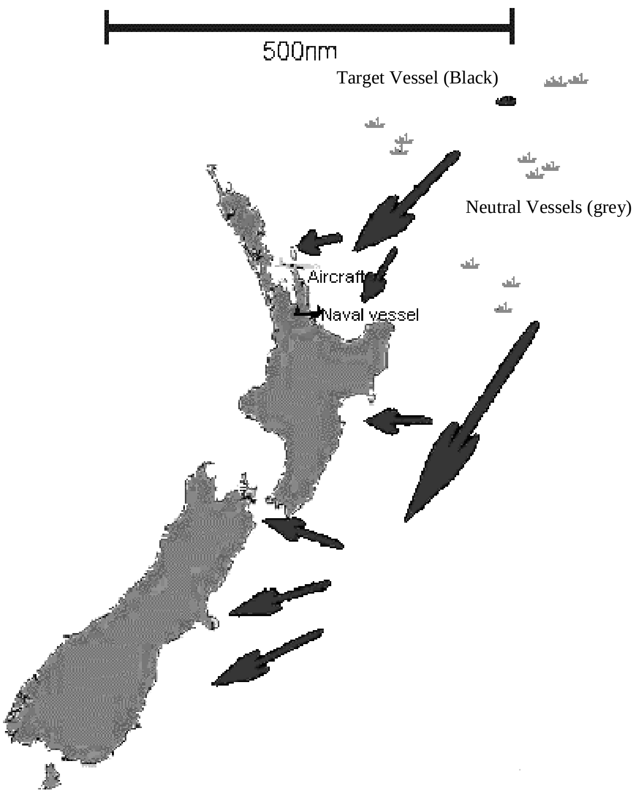

Figure 1: Screen image of MANA model for the scenario considered. Black arrows have been added to illustrate possible entry points for the target vessel (black). It can easily be seen from running the model that it is impossible for the Naval vessel to position itself at any given entry point without intelligence as to where the target vessel is heading.

A typical run of the model is described as follows:

- The search aircraft leaves Auckland and attempts to find the target vessel. Once in contact it then guides the Naval vessel to intercept it. Note that this is not supposed to represent that the Naval ship “boards” the target at that point; rather, it positions itself to shadow the vessel so that it may take action if necessary.
- It is assumed that the aircraft and ship must both detect and recognise possible targets. So, in the case of the aircraft, it may detect the presence of a vessel on its radar, then fly towards it. It only recognises it as the target vessel once it is close enough to do so.
- A standby aircraft is always ready to take over on station when the current aircraft needs to return to base for refuelling. Therefore the area of interest is always covered by a reconnaissance asset.

1.4 Variations

There are several scenario variations.

The base scenario considers the modelled aircraft to have similar capabilities to the P3-K Orion aircraft currently operated by the RNZAF. Thus, the model aircraft has these capabilities:

- Cruising speed 270 knots at 9,000 ft.
- Range equivalent to at least 10hrs flying time.
- Radar with detection range of 60 nmi (nmi = nautical mile) for a small trawler and 100 nmi for a container ship (within these ranges a 100% detection probability is assumed).
- Recognition by visual means (range 10 nmi).

The ability to recognise vessels at a greater distance than visual is a feature of SAR /ISAR (Synthetic Aperture Radar and Inverse Synthetic Aperture Radar) imaging capable systems. When these are used the aircraft may be required to visually confirm the identity of the target vessel once, and then can use the radar profile to covertly track the vessel. The imaging radar has the important advantage of being able to eliminate vessels that are obviously not the target without relying on visual means. In order to simulate imaging capability the recognition range is set equal to the detection range in the model.

Variations were then also run which consisted of increasing the number of non-suspect ships (from 12 to 24, then 36). Another set of runs was done where the dispersion of the (12) non-target ships was increased. This was achieved by doubling their home (placement) radius in MANA.

1.5 Model Settings and Parameters

The model used a 200x200 grid, with each cell representing an area of 5 nmi x 5 nmi. Each time step represented 1.1 minutes.

The key characteristics of the aircraft and the ship are summarised in Table 1. The radar range to non-target vessels is assumed, for the sake of the model, to be the same as that for target vessels.

Craft type	Speed (knots)	Target Vessel Size	Radar Range (nmi)	Recognition Range (nmi)
Aircraft (Standard Radar)	270	Patrol Boat/Small Trawler	60	10
		Container Ship	100	10
Aircraft (SAR/ISAR)	270	Patrol Boat/Small Trawler	60	60
		Container Ship	100	100
Naval vessel	20		20	10
Target vessel	10		N.A.	N.A.
Incidental vessels	10		N.A.	N.A.

Table 1: Capabilities for various crafts.

Within the model, the aircraft has a set of waypoints that it follows until it detects vessels. Figure 2 shows the flight plan determined for patrol in search of a container ship type target. Figure 3 shows a narrower-area covering flight plan designed to cater for the smaller sensor range associated with the detection of fishing trawler type targets. The patrol proceeds from the Home position (H) to the highest numbered waypoint and then the aircraft travels to waypoints in order of decreasing number. Unless a target is found the aircraft continues to loop around the flight plan once waypoint “0” is reached.

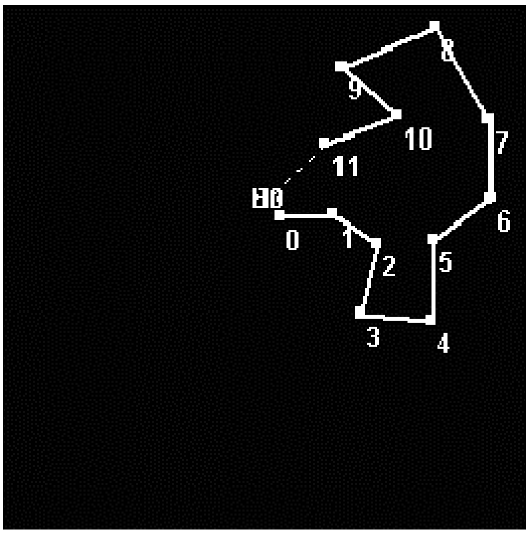

Figure 2: Container ship patrol.

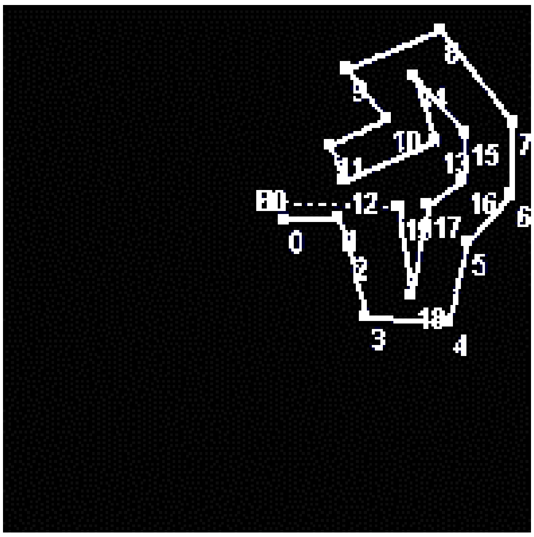

Figure 3: Fishing trawler patrol.

On contacting a vessel, it will approach it until it can recognise it. It does this by using the “refuelling” property of the model to indicate that an interaction has occurred between the two craft (i.e. it has been recognised). At that point, if the vessel is the target vessel, its threat level (as recorded on the situational awareness map) increases from 1 to 3. If the craft is not the target vessel, the vessel changes to the same allegiance as the surveying aircraft, so is no longer considered a threat or “enemy”.

Here a total of 600 separate model runs are made per scenario and the average values of parameters of interest are derived from these sets.

1.5.1 Low Altitude Visual Inspection

When an imaging radar capability is not present it is necessary to perform a low altitude inspection in order to confirm visually the identity of each radar contact.

Typically a low altitude inspection phase is expected to take up to 14 minutes, with 7 minutes allowed for each of the descent and ascent. The assumed change in height and in fuel consumption during this time is illustrated in Figure 4. An average fuel consumption of 4,850 lb hr^{-1} is assumed during this phase as compared with the more economic 4,500 lb hr^{-1} consumed when cruising at 9,000 ft. The average height during the 14 minutes of lower level flying is 5,000 ft and the increased aircraft body fatigue resulting during this time is assigned as occurring at this height.

The computer model does not directly allow for a change in speed when performing visual inspections. It is expected that the speed of the plane will change in a linear fashion from approximately 270 knots at 9,000 ft to 200 knots at 1,000 ft. A representative 2 minutes of additional time has been allowed per contact in the final total flight time when a non-imaging radar system is used – this allows for the decrease in speed of advance from 270 knots to the average 235 knots over 14 minutes.

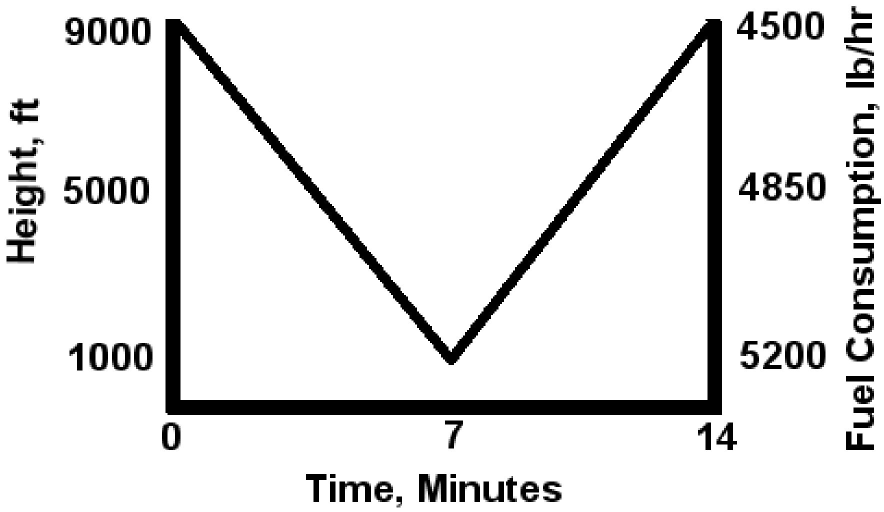

Figure 4: Low altitude visual inspection flight profile.

1.6 Results and Discussion

1.6.1 The Effect of Surface Vessel Number Density

A particular feature distinguishing aircraft equipped with imaging and non-imaging radar systems is their response to a change in the number density of vessels under surveillance.

Variations were tried with 12, 24, and 36, incidental vessels. Additionally the effect of dispersing 12 of these vessels within an area 4 times larger was investigated. A high probability of intercept was recorded in all cases.

Figure 5 shows that, for fishing trawler targets, there is no increase in the model time with increasing vessel number (to within ~10 minute uncertainty) when a SAR/ISAR system is used. A clear trend of increasing flight time with increasing vessel numbers is observed when a standard non-imaging radar system is used. Therefore the time savings obtained by replacing the latter with SAR/ISAR increase with vessel number: time savings of 4%, 7%, and 9%, are indicated for the cases of 12, 24, and 36, vessels respectively.

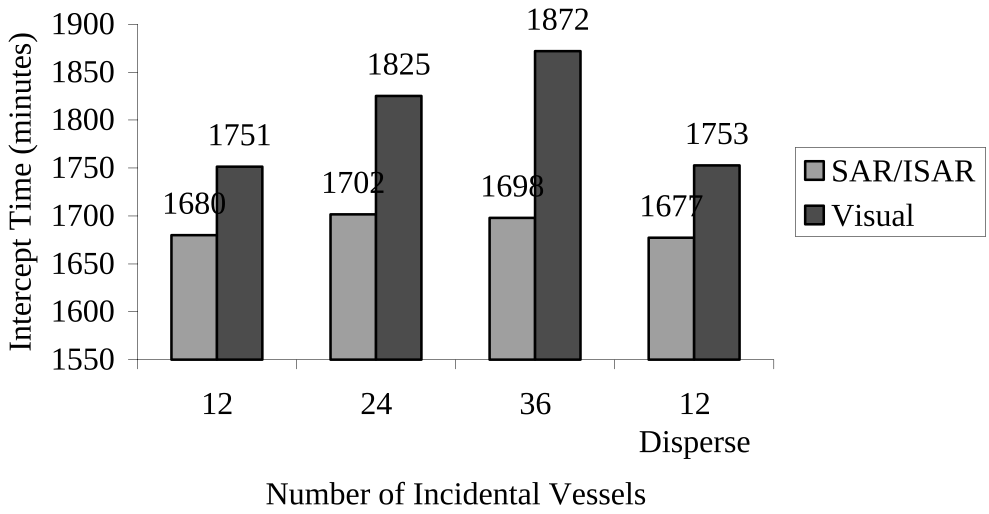

Figure 5: Effect of vessel density on fishing trawler intercept.

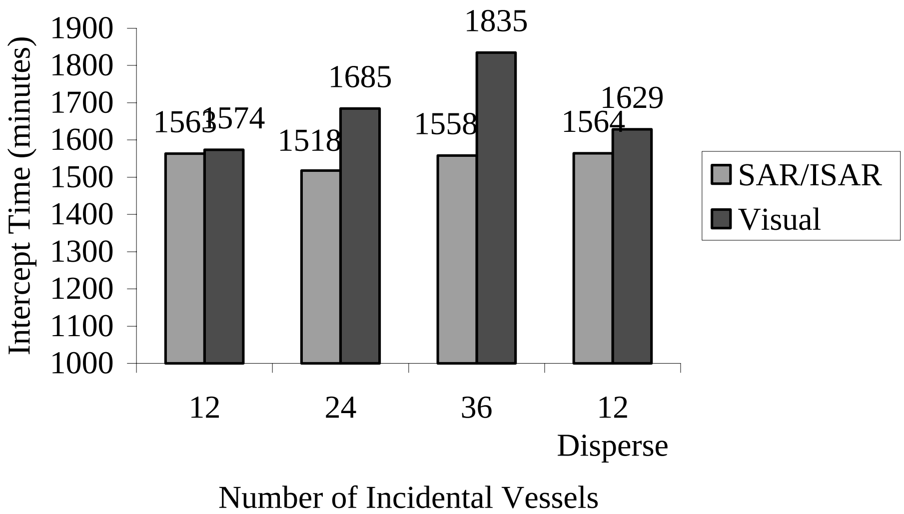

Figure 6: Effect of vessel density on container ship intercept.

A similar graphic is shown in Figure 6 for the detection of container ships. On comparing this with Figure 5, it is found that the larger sensor ranges associated with container ship detection enable a faster intercept in all cases than that determined for trawlers. Otherwise, the same general trends are found for container ships as were found for trawlers. The use of SAR/ISAR is found to save 1%, 10%, and 15%, of flight time for the 12, 24, and 36, vessel number densities respectively over that required when a standard radar system is used.

Generally the flight times are not found to change for both standard radars and SAR/ISAR when the 12-vessel dispersion is increased from that originally used in Figure 5. This dispersion only appears to affect non-imaging radars in Figure 6, where it serves to increase the flight time by a small amount. The imaging radar results can be understood in the context that the underlying vessel number density distribution does not affect aircraft using such instruments. The lack of time increase when non-imaging radars are used to detect dispersed trawlers may result from the fact that this increased dispersion will place some of the vessels in positions where the trawler related radar detection range cannot detect them. Another factor is that a smaller average deviation from the flight plan may be required for contact with the disperse trawler fleet as compared to that required from the wider flight plan followed for the container fleet. Further inquiry reveals an increase in the number of vessel contacts when the container ship dispersion is increased and a decrease in the number of contacts in the same situation for fishing trawlers. This appears to lend support to the hypothesis that the sensor range/flight plan combination contrives to make some of the trawlers undetectable by the aircraft while the sensor range to container ships is sufficient to allow detection of these disperse craft, and thus require large deviations from the flight plan to inspect them.

Figures 5 and 6 clearly show that the deviations from the flight plan to check on each vessel at low altitude take a significant amount of the total flight time. It is evident that imaging radar allows us to traverse much denser areas of shipping, when seeking a target, than might otherwise have been possible with a standard radar system.

1.6.2 Aircraft fatigue and Fuel Efficiency

Figures 5 and 6 have shown that less time is spent searching for aircraft when SAR/ISAR is available rather than a standard radar system. In the case of the latter some of this extra flight time is spent at low altitude, where the fuel consumption and aircraft body fatigue are increased. No low altitude flight is necessary when SAR/ISAR capability is available, apart from perhaps a single visual inspection to verify the identity of the target ship once it has been selected.

Figure 7 shows that up to 26% of the time is spent at low altitude when SAR/ISAR capability is not available. This low-altitude time causes greater aircraft body fatigue than would be found when flying at 9,000 ft and serves to increase the long term cost of running the aircraft.

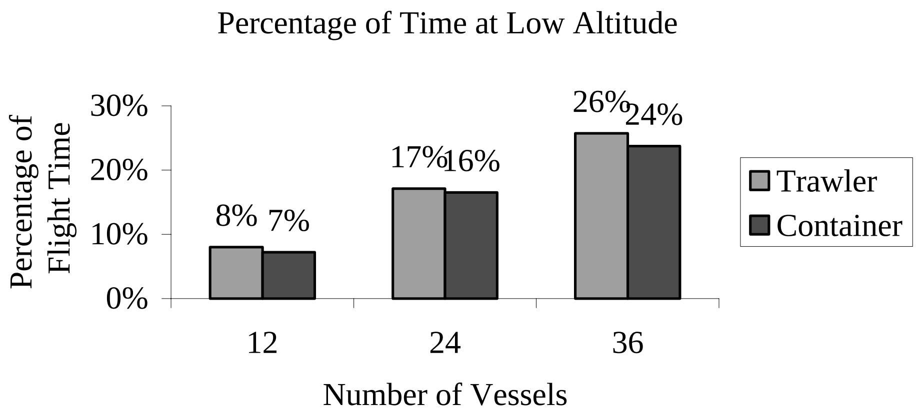

Figure 7: Percentage of flight time spent at low altitude visually inspecting vessels.

Figure 8 shows that savings of 5%, 8%, and 9%, are achieved when searching in areas with 12, 24, and 36, non-target fishing trawlers respectively. When searching for container ships in the same increasing number density, generally greater savings are achieved of: 2%, 11%, and 16% respectively.

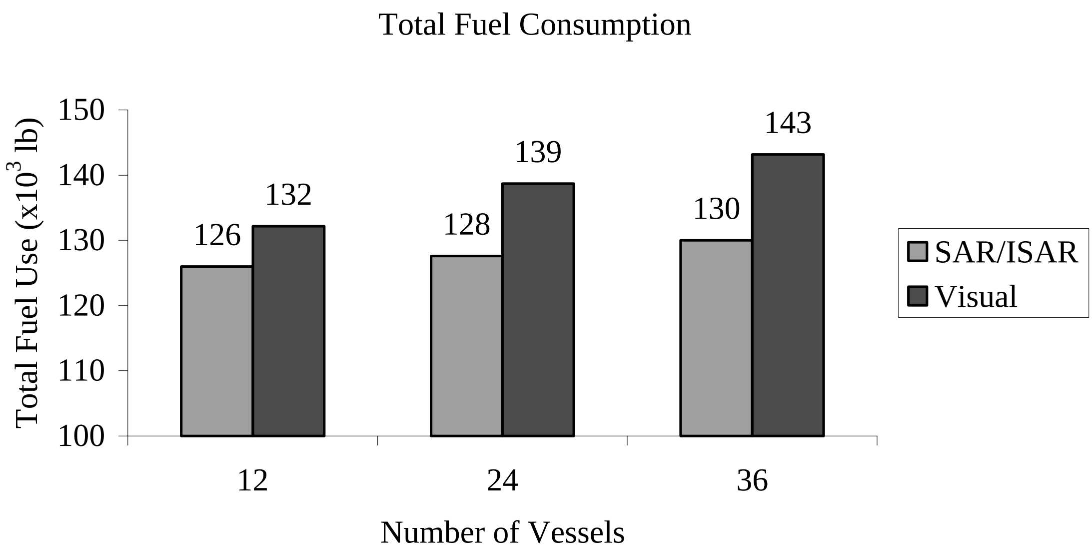

Figure 8: Average fuel consumption per trawler vessel intercept.

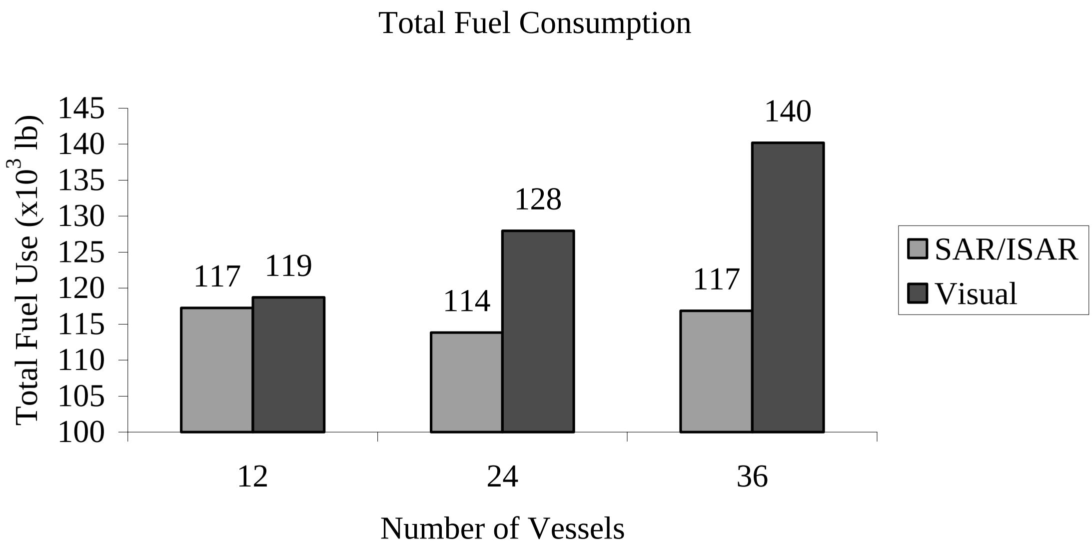

Figure 9: Average fuel consumption per container vessel intercept.

2 Conclusions

The utility of the MANA model in performing aspect on one aspect of Maritime Surveillance has been demonstrated. While this model was originally developed for Army operational analysis, it has been found to be easily adaptable to a scenario of interest to the other branches of the New Zealand Defence Force.

Clear benefit has been found from the upgrade of the current standard radar systems on the P3-K Orion flown by the airforce to imaging capable SAR/ISAR. These efficiencies include decreased flight times, increased time at higher altitudes (leading to lesser aircraft body fatigue and increased fuel efficiency), and the ability to survey areas with a high density of non-target vessels without difficulty. Without SAR/ISAR capability between 8% to 26% of the flight time was spent at low altitude where greater aircraft body fatigue serves to increase the long term running costs of the aircraft. Introducing this capability provided up to 16% savings in fuel and up to 15% flight time savings. These savings are dependent on the size of the non-target vessel population assumed.

3 References

Lauren, M.K., Stephens, R.T. 2002. "Map-aware non-uniform automata – a New Zealand approach to scenario modelling", *J. Battlefield Tech.*, **5**(1).