

# Application of the non-stationary travelling salesman problem to maritime surveillance

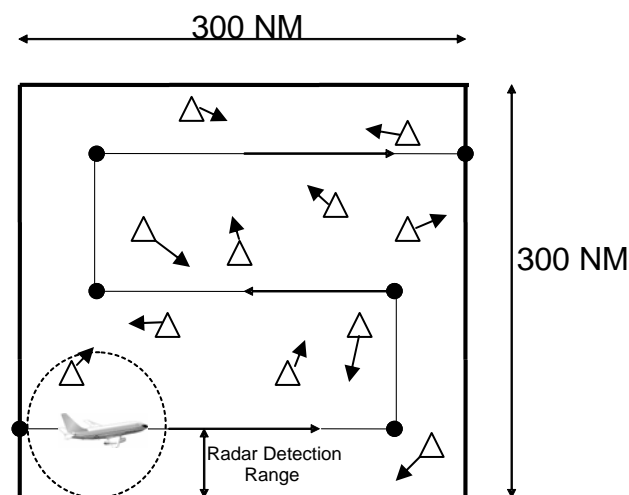
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## Introduction

Australia is surrounded by a vast expanse of ocean. Movement of vessels within this area is of great interest to the Australian Government. The responsibility for surveillance - detection and tracking – of ships within this area is shared between Defence and civilian organisations.

The surveillance problem may be reduced to the need to classify (to the level of ship type) all ships within an Area of Interest (AI). The surveillance aircraft flies a pre-planned flight route. The search spacing is pre-briefed and is based on the expected radar detection range for the particular ship type of interest in that scenario. The surveillance aircraft maintains a list of contacts (priority contact list) that need to be flown towards to be classified. The Travelling Salesman Problem (TSP) is used to decide in which order these contacts should be addressed.

The surveillance platform must plan to fly to the contacts that have not yet been classified. The pre-briefed waypoints should also be flown to in order. The platform will deviate from the pre-planned flight routes to fly towards contacts that need to be classified. The priority contact list will change as tracks move in and out of radar detection range and as the contacts are classified by the surveillance aircraft.



*Figure 1: Diagram showing indicative flight path for maritime surveillance aircraft with waypoints. Ships are shown as triangles moving in random directions and at random speeds. NM is the abbreviation used for nautical miles.*

An indicative diagram showing a standard search path for a maritime surveillance aircraft in an AI is shown in Figure 1. It should be noted that the AI is a subset of a wider region of interest in which other maritime surveillance aircraft may be operating, each with their own AIs.

If other information on the disposition of ships is available and the ships are assumed to be stationary, the problem resembles the traditional TSP. This additional information on the positions of the “cities” (ships) can be continuously provided to the surveillance platform. However, it is often the case that the surveillance platform does not have any assistance from other sources and must undertake the search alone, so the initial positions of the ships are unknown. Additionally, the ships can travel at speeds up to 30 knots, which questions the validity of the stationary ship assumption, especially if a relatively slow-moving aircraft (such as a helicopter travelling at around 100 knots) is performing the surveillance.

### **Current methodology**

The current methodology involves considering only the section of the AI between the current waypoints. Contacts on the priority contact list are those contacts between the current two waypoints up to a specified maximum distance from the line between the two waypoints. The ships are assumed to be stationary. The ships on the priority contact list are first sorted by range from the surveillance aircraft and the next waypoint is added to the list of priority contacts and considered as a “ship”. Then, a simple TS algorithm (single-swap crossover genetic algorithm (GA) with no mutations and with a limited number of iterations) is used to try to optimise the ordering. The TSP is solved for the current known unclassified contacts at the following times: a) soon after commencing the scenario; b) if it has not been updated after a specified time; c) when a new track is formed; d) when the highest priority track is lost; e) when a track is classified; f) when a waypoint is reached.

### **Reasons for submitting the problem to MISG**

The aim for DSTO in submitting this problem is to seek assistance in determining the best flight path the aircraft should undertake to search the area of interest such that:

- The distance travelled (and thus time taken) by the aircraft is minimised, and
- The number of targets detected and classified is maximised.

The model used to implement the algorithm is part of a larger model that incorporates other aspects of the maritime surveillance system, e.g. radar performance and the human operators. Thus run time of the model is also important. Too much complexity in the algorithm in seeking the most precise solution may render the model useless due to an impractical run time. However, at the other extreme, over-simplifying the algorithm through assumptions (such as with the current case of assuming stationary ships perhaps) may create an invalid representation of reality which also makes the model worthless.

While the traditional TSP is well studied and various techniques have been proposed for solving it, the variations described here add extra layers of complexity to the traditional TSP and there is relatively little information in the literature about it. A recent ADFA paper [1] is probably the most relevant to this problem.

## Inputs

The problem inputs are as follows:

- Surveillance aircraft speeds (100 to 350 knots).
- Surveillance aircraft radar detection range (e.g., 100 NM). This can vary from scenario to scenario depending on environmental conditions and the contact types of interest.
- Surveillance aircraft classification range (0 to 20 NM). This can vary from scenario to scenario depending on sensor performance for a particular mission.
- AI size (100x100 NM to 300x300 NM). This can also be rectangular-shaped within these limits.
- Number of ships (initially set between 10 and 100). This can also vary *within* a scenario as tracks are generated, or as they exit or enter the AI.
- Individual ship speed (0 to 30 knots).
- Individual ship direction (0 to 360°).
- Presence of additional information on ship disposition.
- Waypoint position.

## Constraints

There are two primary problem constraints.

1. The aircraft must stay within the area of interest at all times.
2. The aircraft must visit all waypoints in order.

Both of these are designed to keep the aircraft from straying too far from the search path. The aim of the first constraint is to prevent the aircraft from chasing a ship that is deemed to be heading out of the AI by the time the aircraft reaches it. The second constraint is designed to prevent the aircraft from flying too far from a waypoint.

## Measures of effectiveness (MOEs)

The MOEs for this problem are:

- The percentage of targets in the area of interest detected and classified.
- The time taken for the area of interest to be traversed.
- Solution run time.

## Potential issues to address

Examples of some questions to help break down the problem are given below.

- At what ratio of surveillance aircraft speed to ship speed does the assumption of stationary ships not apply?
- Should different algorithms be used for different numbers of ships (e.g., exact solution for less than 10 ships, algorithm A for 10 to 30 ships, algorithm B for 30+ ships)?
- What frequency of update of the ordering of the priority contact list is required (e.g., when a contact is classified, when a new contact is detected, when a new contact is detected that is closer than the highest priority contact, every X minutes. etc)?

## References

1. Q. Jiang, R. Sarker and H. Abbass, "Tracking moving targets in the non-stationary travelling salesman problem," *Complexity International*, **11**, p171-179, 2005.