Real-time Decision Support for the Anti-Air Warfare Commander

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Abstract

The Defence Evaluation and Research Agency (DERA) are investigating innovative real-time decision support concepts to aid the Anti-Air Warfare Commander (AAWC). The AAWC has responsibility for the Command and Control of force level assets such as Combat Air Patrol (CAP) aircraft, Medium Range Surface to Air Missiles (MRSAMs) and long range Electronic Warfare (EW) systems.

The primary objective of this research is to implement and evaluate the military benefit of a decision support system for the AAWC. The system is referred to as an 'Action Tool' (AT) as it provides the AAWC with a number of support functions that will assist the command decision making process during the 'action' phase of the AAW battle.

This paper provides a functional overview of the laboratory prototype system which is being developed at DERA as part of the Co-ordinated Air Defence Integrator and Scheduler (CADIS) Applied Research Programme (ARP). The laboratory system is specifically being developed to support an experimental programme where one or more ATs can be realistically evaluated with multiple users including live data recordings. The longer term objective is to integrate and test the functionality within a real combat system during operational sea trials.

1. **Introduction**

The Maritime Command and Control Group at the Defence Evaluation and Research Agency (DERA) is working on an Applied Research Programme (ARP) sponsored by the UK MOD Director Equipment Capability (DEC). The research supports the Control and Denial of the Above Water Battlespace (AWB) Operations Capability Working Group (CWG) which states the requirements and priorities for research into Maritime Air Defence, Surface Warfare, Fire Support and Crisis Response.

At CCRTS2000 in Monterey we presented a paper describing a number of algorithmic based decision support concepts. These concepts are based on the requirements for future AAW operations where improved integration and co-ordination of defensive actions across multi-national forces is a prime objective. The concepts have been specifically developed to support multi-ship operations using generic data exchange for interoperability of platforms with disparate weapon characteristics and capabilities. Timely exchange of weapon performance information could lead to a significant improvement in the ability of the force to generate a deconflicted and synergistic multi-threat response.

The paper provides an overview of the AT research prototype that is being developed as a proof of concept Technology Demonstration (TD) system. The research is focused on the real-time implementation of a set of algorithms that process threat and own force information to generate a force response in harmony with the Command.

The work forms a core element of the CADIS project which is addressing complex AAW issues through research and demonstration of medium risk technology to provide advice on the procurement of improved systems and functionality for both current and future RN platforms.

1.1 *Research Scope*

The AT research is addressing the following areas;

(a) display of battle information to the command that can be easily assimilated, reasoned and actioned upon;
(b) rapid evaluation of threats at the force level;
(c) generating and analysing complex force response options involving combinations of both hard and soft kill weapons (HK/SK);
(d) providing the command with a set of prioritised response options (recommendations);
(e) continuous engagement monitoring, assessment and re-allocation across the force;
(f) fully automatic capability for complex and/or time critical situations;
(g) distributed implementation for improved speed and robustness;
(h) real-time implementation;
(i) HK/SK co-ordination techniques;
(j) information exchange requirements.

1.2 *Technology*

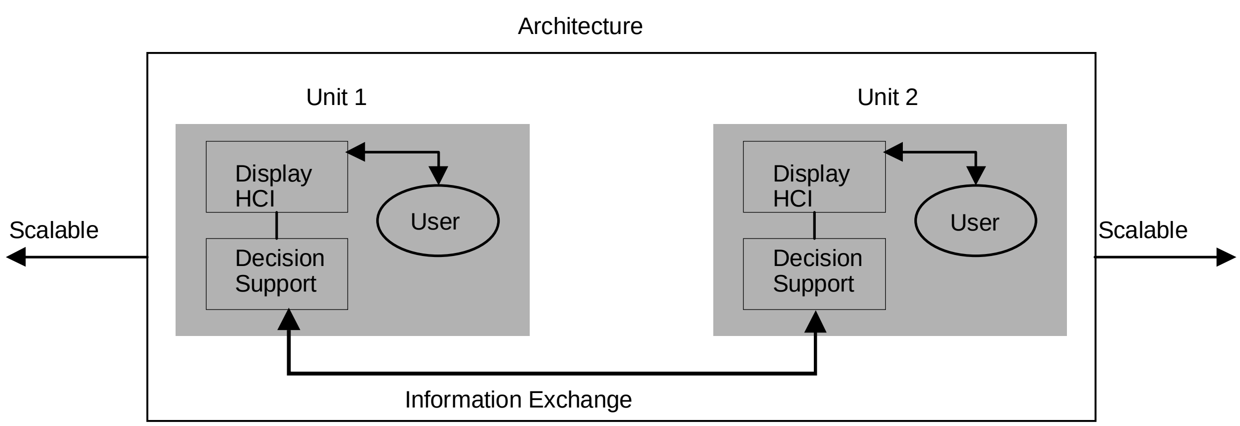


Figure 1. Technology Areas

Figure 1 shows the main elements of the research from a technology perspective. Units 1 and 2 represent two generic instances of an AT which can share information to form a distributed solution. The research is addressing how single or multiple ATs could be used effectively within the AAW domain. Our generic approach should enable the AT to be integrated with other warfare domains to support joint operations.

2. **System Overview**

2.1 ***Laboratory System***

The research laboratory at DERA Portsdown West is shown in Figure 2. The picture shows a number of ATs in operation with the AAWC's display being projected on to the wall. The laboratory configuration is used for both system evaluation and demonstration.

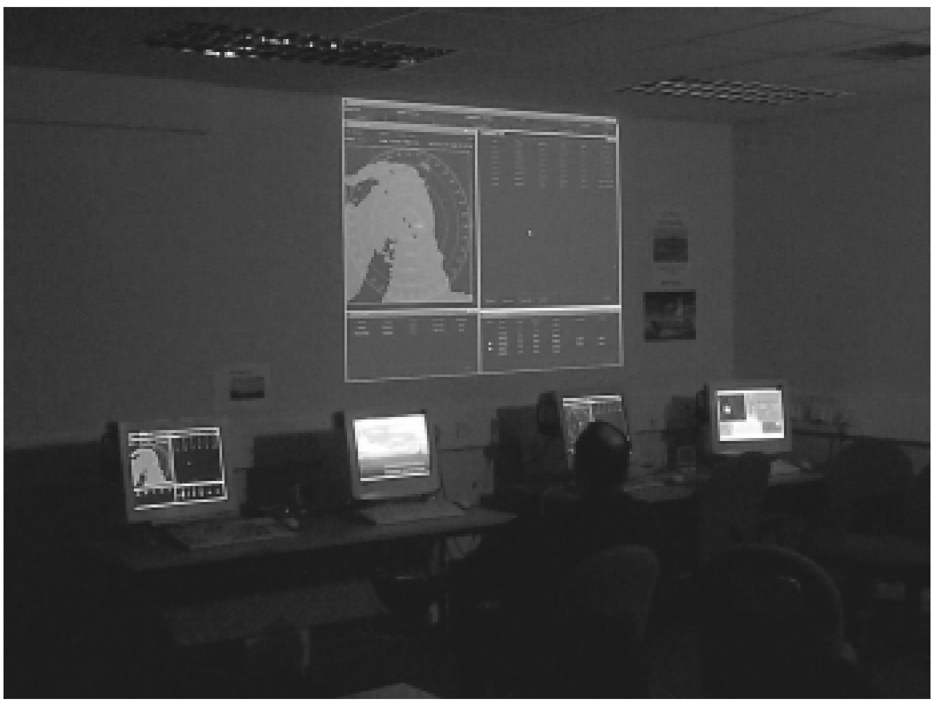


Figure 2. Research Laboratory

The laboratory system architecture is shown in Figure 3. The system can be divided into AT application and simulator components. The application is being developed such that it can be detached from the simulator 'test harness' and integrated into other environments including real equipment. The laboratory system currently allows a 3 ship network to be evaluated.

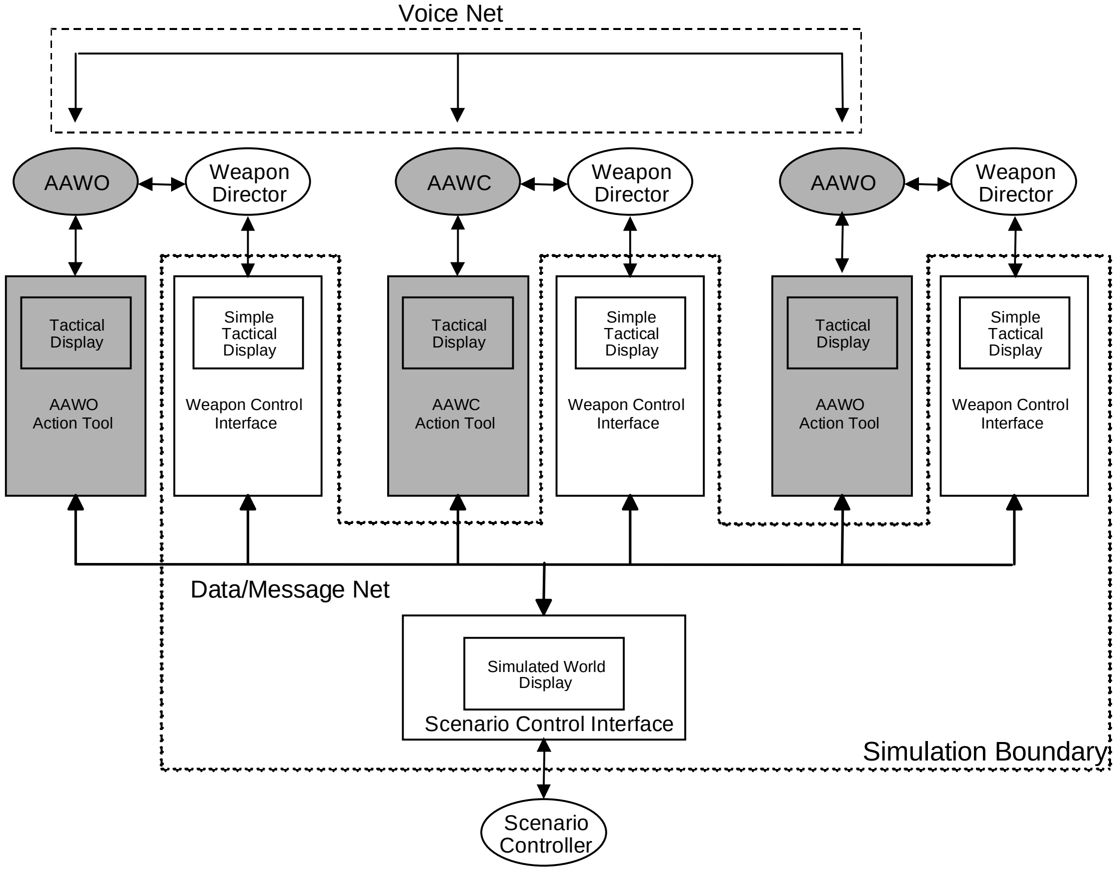


Figure 3. Laboratory System Architecture

2.2 ***Application***

The application elements are shown by the shaded areas in Figure 3. In the normal configuration one application is used by the AAWC the other two are used by AAWOs. The system also enables each user to interact with a Weapon Director (WD) who is responsible for control and scheduling of the ship weapons in accordance with the command's direction. In a real operations room the WD would be replaced by a number of weapon controllers, each responsible for different types of weapon.

2.3 ***Simulation System***

The Enhanced Simplified Simulation System (ESSS) is a distributed client server application written in JAVA using the Borland integrated development environment. The ESSS provides the 'test harness' for the AAWC and AAWO ATs applications.

The ESSS is designed to support multiple 'client' platforms that connect to the main simulation server at start up. Each client comprises the CADIS application element (AAWC or AAWO AT) and associated WD. A simulation controller client also connects to the ESSS server at start up and provides scenario management functions. The various elements of the ESSS are described below;

(a) core simulation software that executes on the Local Network Server. The ESSS server is written as a JAVA application and performs the following;

- (i) supplies tactical picture data to the AAWC and AAWO applications;
- (ii) supports the communication of data messages between multiple AAWC and AAWO ATs;
- (iii) simulates multiple own force units and threats, weapons, sensors and C2;
- (iv) provides scenario set up and management facilities via a remote user interface (scenario controller display);
- (v) supports platform weapon responses via multiple remote user interfaces (weapon director displays);
- (vi) data and event recording for off-line analysis.

(b) a scenario controller user interface which runs on a single network machine and is implemented as a JAVA applet using RMI

- (i) enables user to create and manage both enemy and own force units;
- (ii) enables user to manually manage the effectiveness of force and platform level engagements.

(c) a WD user interface that runs on a single network machine and is implemented as a JAVA applet using RMI

- (i) enables user to schedule and control platform weapon responses against multiple threats;
- (ii) provides each AT (AAWC or AAWO) with the means to respond to the threat.

3. **Functional Description**

A functional block diagram of the AT system architecture is shown in
Figure **4**. The top two shaded areas in Figure 4 show how the AT can be partitioned into group (or force) and ship elements. This boundary is an important area of research. The AAWC or AAWO will interact with the AT(group) element and the WD will interact with the AT(ship) element. The lowest shaded area represents the simulation layer where AT commands are enacted. Any change to the environment (i.e. tactical picture) is then reflected through the AT interface.

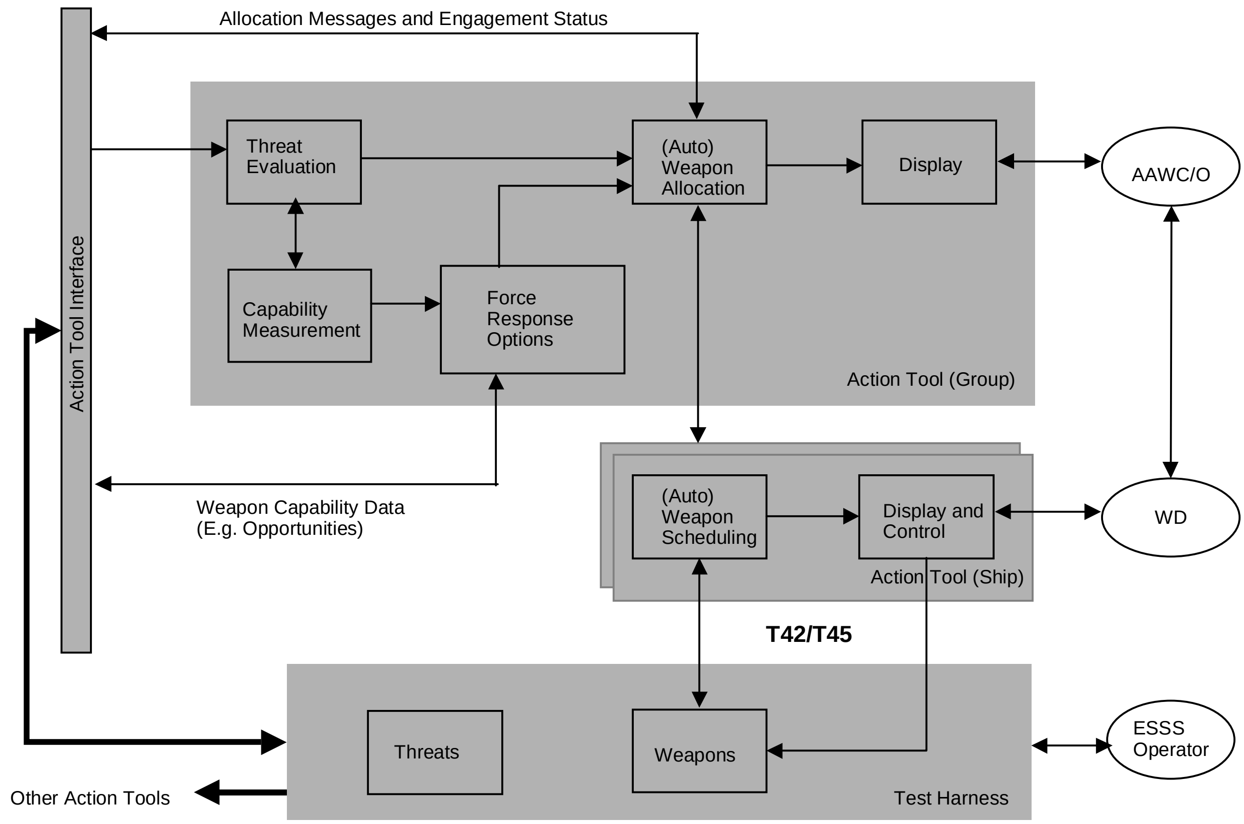


Figure 4. Functional Architecture of Action Tool and Related Elements

The AT (group) is broken down into 5 main functions;

(a) Threat Evaluation - Interacts with tactical picture data to prioritise threats.
(b) Capability Measurement - Measures capability of force assets against each threat using a predictive model. This model could be simple data in the form of look up tables or a complex real-time assessment capability.
(c) Force Response Options - Stores set of possible force response options for each scenario threat. At this stage no account is taken of response interactions such as resource usage. This is also referred to as the Force Capability Matrix (FCM).
(d) Weapon Allocation - Searches and analyses Force Response Options to determine optimum multi-threat responses taking into account resource usage and other constraints.
(e) Display - displays tactical picture data and force response options to the command.

These functions are described more comprehensively in the following sections.

4. **System Assessment**

4.1 ***Man and Machine***

Following his initial situation assessment (SA), the AAWC will determine the best course of action to take for unknown, suspect and hostile tracks. If further action is required on a track, the AAWC will wish it to be appropriate, timely, and with minimal side effects to the force. In the time between initial SA and the allocation of resources, the AAWC is assessing the force capabilities. The results of his assessment will determine which sensors and weapons he will allocate against the track of interest.

In order to carry out system assessment effectively the AAWC will need to correlate information from many sources. Whilst this is a difficult task, the more complex environments of the future will make it increasingly pressurised, due to factors such as information overload, and greater Rules of Engagement (ROE) constraints. Over time, it will become necessary for the AAWC to become more reliant on machine assistance to relieve this pressure and help him use his time more effectively.

One of the key objectives of the AT is that it should not duplicate the AAWC's thinking, but compliment it. To do this, the tool needs to fill in gaps in the AAWC's capability. Some of the key capabilities of man and machine are shown in Figure 5.

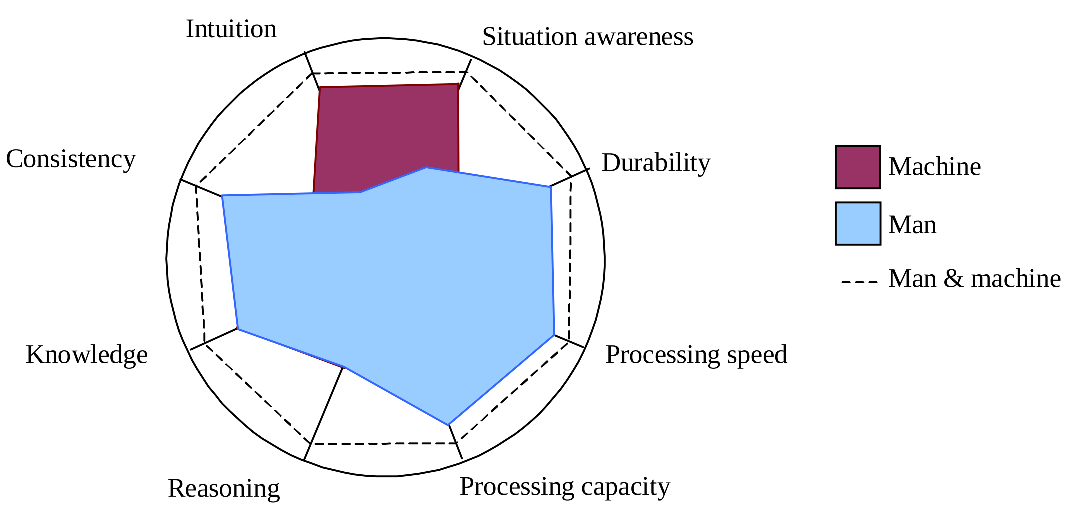


Figure 5. Man and Machine Comparison

Figure 5 shows that although the man will outperform the machine in areas which require experience and perception, the machine will easily exceed the man's capability in speed and capacity of calculation. Using this information, one clear method of integrating man and machine in an area such as system assessment is to use the machine to provide the AAWC with a quick and comprehensive judgement of force system performance against any track of interest. The AAWC is then able to use this information to inform his subsequent decisions regarding the best action to take.

Supporting the AAWC's system assessment process is a major part of the core functionality of the AT. In order to implement this functionality successfully, many important issues need to be considered. These issues can be grouped into four areas;

(a) how the AT measures and evaluates system performance;
(b) how the tool interacts with the AAWC such that the AAWC will have confidence in the information he is being presented with;
(c) how the tool will interact with other platform systems which may already have their own self-assessment functions;
(d) how the tool will interact with other ATs.

4.2 *Direct and Indirect Assessment*

Determining the best way in which the AT supports and interacts with the AAWC is central to the research. At one end of the scale the AAWC may wish to carry out his own system assessment, but use the machine to warn him of complex problems he may have limited time to consider, such as mutual interference. At the other end, the AAWC may want to rely totally on the machine's judgement. Given that there are a large number of different situations the AAWC may have to deal with, the tool should have the flexibility to provide different levels of assistance.

To provide a comprehensive system assessment, there are two key paths that the AT must be capable of following. One method of obtaining this information is to receive it directly from other platform systems that already have their own self-assessment functions, e.g. an electronic warfare command and control system. The tool's main role in this case will be to draw together information from these individual systems and present it to the AAWC in a force context. This method is referred to as direct assessment and is shown in Figure 6.

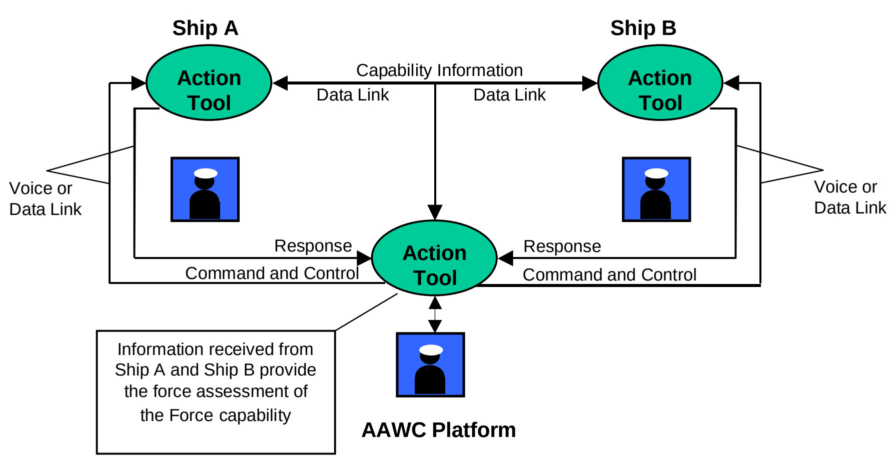


Figure 6. Direct Assessment

The second method requires the tool to have its own assessment functions. This method is termed indirect assessment and is shown in Figure 7. These functions will be used to generate an assessment for those systems unable to provide their own.

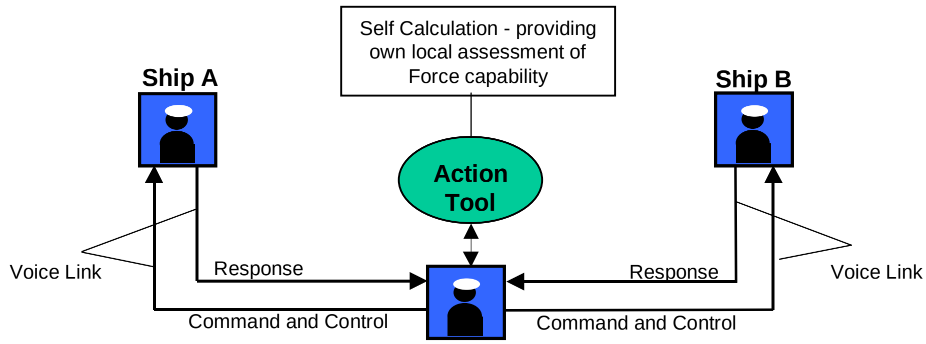


Figure 7. Indirect Assessment

In both the direct and indirect cases, the amount and type of information that the AT is receiving will be highly dependent upon communications within the force, and whether or not other platforms will also have ATs. It is possible that the tool may have to operate entirely independently, and thus be able to form its own judgement of other platform's capabilities. Conversely, if there are other tools operating within the force, they may be exchanging assessment information in a network centric fashion.

The AT algorithms that carry out system assessment are currently carried out at two different levels of complexity. The algorithms operating at the simplest level use basic information and output a basic answer. The next level uses more detail, and can thus output a more detailed answer. As more levels are implemented, the machine will gain the capability of taking more detail into account during the assessment process. This 'levels' approach will give the man the capability to follow the machine's method. The alternative is to use complex algorithms only, which could potentially leave the human entirely confused about how the machine arrived at a particular assessment. In this case the human is unlikely to have confidence in the machine.

4.3 ***Assessment Levels - Opportunities and Performance***

The AT system assessment requirements fall into two areas, namely air and platform assets. Together, they form a suite of AAW assets that the AAWC has at his disposal and that he can use to defend the force. In the current version of the AT, air assets include combat air patrol (CAP) aircraft, and platform assets include Hard Kill (HK) weapon systems and electronic warfare (EW) systems. Physically, the two areas have a natural boundary as shown in Figure 8, and are referred to as 'inner' and 'outer' layer systems.

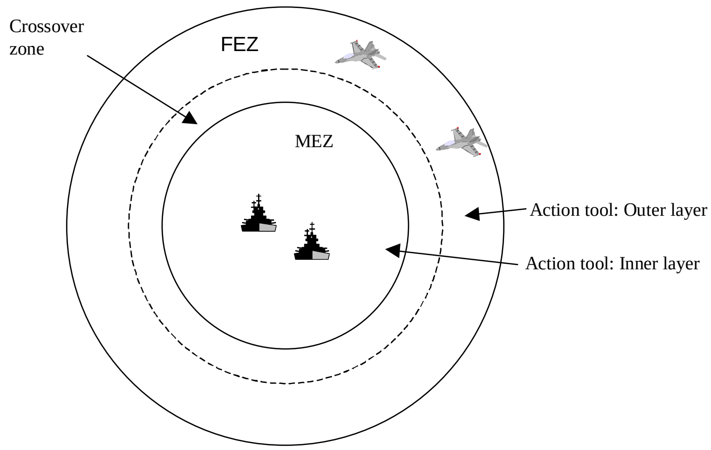


Figure 8. Boundary between Air and Platform Assets

NB MEZ = missile engagement zone; inner layer, FEZ = fighter engagement zone; outer layer

The systems for which an assessment measure needs to be applied differ greatly in their operation. For simplicity, at a high level, the assessment concepts implemented within the AT are so generic that they can be applied to any system. However, the definition of and use of each is subtly different according to the specific system operation. The two levels of assessment within the tool are called ‘Opportunities’ and ‘Performance’. For the purposes of discussion, the implementation of these two concepts will be shown with respect to a hostile track.

The Opportunities and Performance measurement concepts provide a means of determining the omni-directional strength of defence with respect to the target for multiple air defence platforms. This is the converse of other methods, such as HK isoleths, which measure the strength of defence with respect to a single air defence platform.

The opportunities concept corresponds to whether or not a platform can carry out an action against the threat. This concept has many uses, of which two in particular are important. Firstly, opportunities is a method that can be easily related to by a human, and thus provides an explanation of the results of more detailed calculations. Secondly, it can act as a filter during calculations such that the machine does not go on to more detailed calculations for a particular platform system if it does not have an opportunity to use it.

For example, a platform with an area defence capability will have a HK opportunity when the threat flies through the weapon system engagement envelope centred on that platform as shown in Figure 9a.

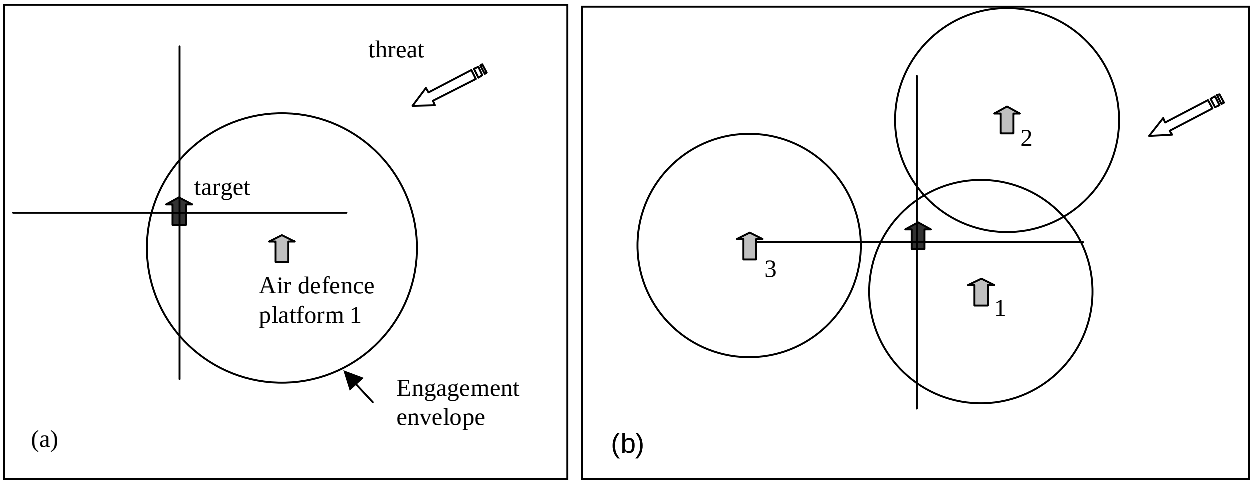


Figure 9. HK Opportunities Concept

In Figure 9a, it is seen that the target lies within the engagement envelope of the air defence platform, thus the platform is said to have a HK opportunity. Figure 9b shows the case for three air defence platforms with identical HK capabilities. As before, platform 1 will have a HK opportunity. Although the target does not lie within the engagement envelope of platform 2, it will still have an opportunity as the threat will have to fly through this envelope on route to the target. Platform 3 will not have an opportunity. Thus, for this case, there are two HK opportunities.

Opportunities provides a discrete method of system assessment in that it will result in a simple yes/no answer. However, it does not present the AAWC with any detail regarding how good the opportunity is. The next level of assessment provides a means of discrimination using a simple measure of performance for the system as a whole. Where the AAWC will use his judgement and expertise to estimate system performance, these calculations are able to use similar methods but apply them in more detail. In addition, the algorithms will explore different alternatives e.g. strength of defence if the hostile track were to change target. The output of the system performance calculation is a probability of success for the action.

For example, for a HK system, the performance assessment currently uses the closest point of approach (CPA) as a system performance measure as shown in Figure 10.

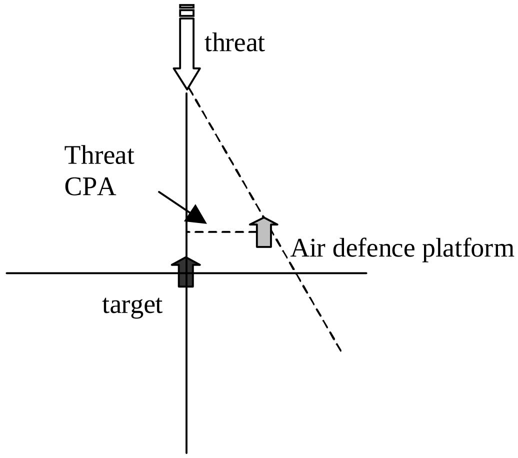


Figure 10. HK Performance Assessment using CPA

The performance calculation is of the form: $P_S = P_K * (1 – threatCPA / maxCPA)$,

Where P_S is the probability of success, P_K is a measure of the HK system performance, threatCPA is as shown in Figure 10, and maxCPA is the maximum CPA of the HK system. When the air defence platform lies on the threat axis P_S will be equivalent to the performance of the HK system, P_K. When the threatCPA is equal to or greater than the maxCPA, P_S will be 0.

In addition to system assessment, the AT is also capable of determining where problems may arise when taking particular actions. The tool can thus advise the AAWC of potential conflicts. Such problems include ‘danger areas’, i.e. when actions taken may lead to potential danger areas being formed, e.g. fly-through zones as a result of an electronic warfare action.

The information that the calculations generate is fed into the Force Capability Matrix (FCM). The FCM is the AT’s knowledge base and dynamically stores all information regarding each platforms defensive capabilities for each threat. The resource allocation process exploits this information and advises the AAWC accordingly.

5. **Resource Allocation**

5.1 ***Allocation and Scheduling***

Current practice within the RN treats certain assets such as GWS30 (Seadart) as force assets that are then allocated at the force level whereas other assets such as GWS26 (Seawolf), CIWS and decoys are dealt with at the platform level. The AT supports research into a more flexible approach. In this case the most appropriate assets to use from the force perspective are allocated and the distinction between force and platform level assets is less clear. Thus, even if a threat is expected to fly over a platform with a GWS26 capability (i.e. self defence), it may still be more appropriate to allocate the threat to that platform when viewed from the force perspective.

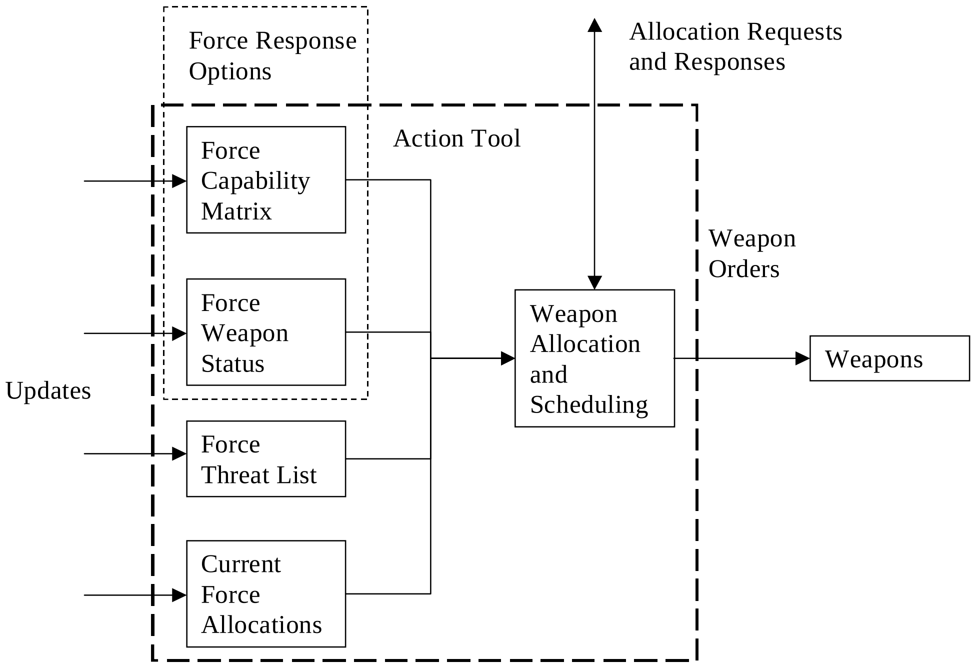


Figure 11. Allocation Algorithm Data Requirements

With the current version of the AT the allocation function uses four sets of data in order to make a recommendation as shown in Figure 11.

(a) The Force Capability Matrix (FCM) which stores descriptions of the capabilities of platforms (HK and EW) against each threat
(b) The Force Weapon Status (FWS) which stores the current status of assets across the force. At present this is limited to force assets such as GWS30 (HK) and a COTS jammer (EW)
(c) The Force Threat List (FTL) which holds the list of current threats
(d) The list of current force allocations which detail extant engagements.

The recommendations are generated after each decision cycle using the threat list. A recommendation will be generated for any threat for which there is no ongoing HK engagement. The recommendation consists of the platform to perform the action, the threat against which the action is to be taken and the order to be taken (currently either HK or seduction jamming). If the AT is in manual mode, then the user has the choice of whether to use the recommendation or not. However, if the AT is configured to generate allocations and is in automatic mode, the recommendation will either lead to an allocation request to another platform or to the host platform where the action is scheduled by sending an order to the appropriate weapon system. Thus, in the latter case, there is no clear separation between allocation and scheduling.

The research will address the separation of the force allocation and platform scheduling functions and the information exchange requirements as shown in Figure 12.

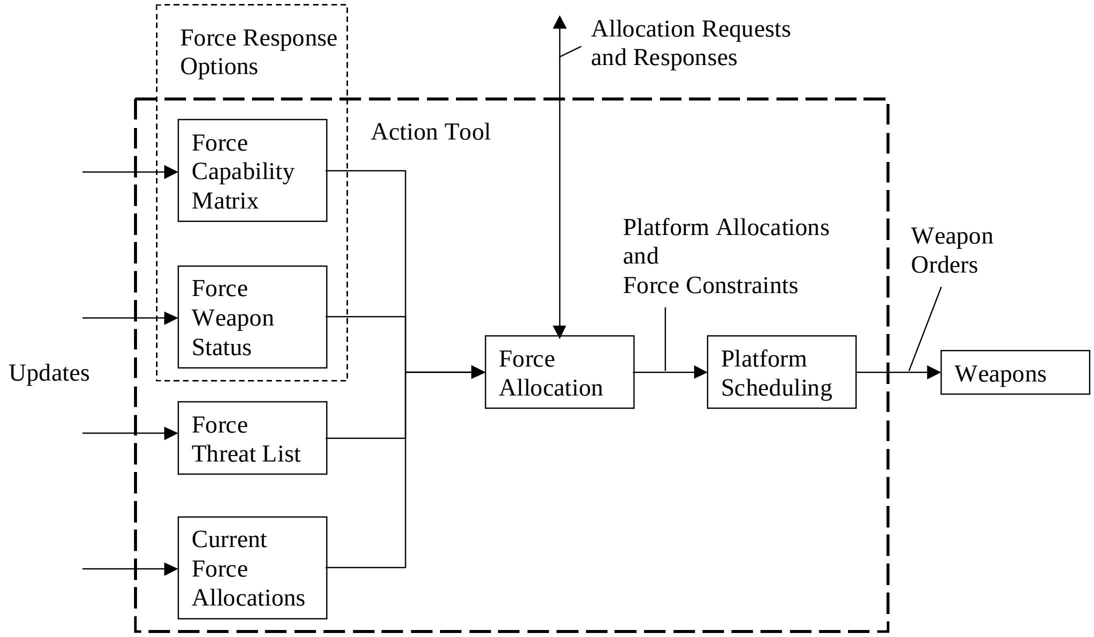


Figure 12. Separation of Allocation and Scheduling Functions

Figure 12 shows how the force allocation function would determine which threats are allocated to which platforms and the force constraints under which a platform will perform its tasks (e.g. constraints to avoid decoys causing fly-through). These force allocations and constraints would be passed to the platform scheduler. The platform scheduling function would have a number of roles:

(a) determine the exact sequence of HK and EW actions, including timings, that the platform would take in a co-ordinated manner in order to meet its allocations.
(b) interact and interface with the platform's weapon systems.
(c) inform the force allocation function of any problems with its allocations and force constraints.
(d) provide a standard interface with the force allocation function even though the architecture of the platform's weapon systems varies for different types of platforms.

Thus, it is intended that the platform scheduler would hide the platform specific issues from the force allocator. For some platforms it would compute the full schedule of HK and EW actions with their associated timings. For other platforms it would interact with the engagement plans generated by HK or EW systems. This would allow them to take automatic responses and enable the scheduler to apply vetoes and/or constraints where necessary.

5.2 ***Dynamic Co-ordination***

One of the AT's main functions is to facilitate research to improve the way co-ordination is performed within the Maritime Air Defence domain. Current practice in the RN may lead to the assignment of ships and aircraft to pre-defined zones or areas of control. In addition, it utilises pre-defined lists of actions, called ZIPPOS, in order to help determine the sequence of reactions to take against a threat. One noted advantage of this approach is that the crew of the individual platforms know what they should be doing. Disadvantages of this approach are its inherent inflexibility and that the sequence of pre-defined actions specified in a ZIPPO may not work well for multiple threats. Thus the move towards dynamic co-ordination techniques. Again, it is the function of the AT to help in the evaluation of dynamic co-ordination techniques in order to determine the benefit with respect to current practice. The AT supports a dynamic approach to co-ordination that incorporates the following principles:

(a) determine which platform has the best capability to defend the force from the force perspective at a given point in time;
(b) include the current status of free/available assets;
(c) include other important scenario factors including how threatening specific threats are to the force objectives (this would be high if the threat is very capable and targeting a mission essential unit);
(d) include the current actions being taken.

It is the function of the force allocator to dynamically co-ordinate the force using the above principles. It does this by utilising an algorithm that makes uses of the appropriate data.

5.3 ***Recommendation Algorithm***

Each instantiation of the AT incorporates a decision cycle in which an algorithm searches the FCM and FWS for the most appropriate force response.

An initial algorithm has been implemented which uses either a sectored, opportunistic or performance based approach. For each threat for which there is no current EW action, the AT determines whether seduction on to a platform to improve HK effectiveness is possible. If so, a seduction recommendation will be made. If there is already an EW action ongoing, then the AT searches for the current, best HK option and generates a corresponding recommendation. Recommendations are recomputed during each decision cycle and displayed to the command until an action is ongoing. When an AT is in automatic mode it uses the recommendations to generate the allocations directly.

The following example shown in Figure 13 illustrates how the performance algorithm would work.

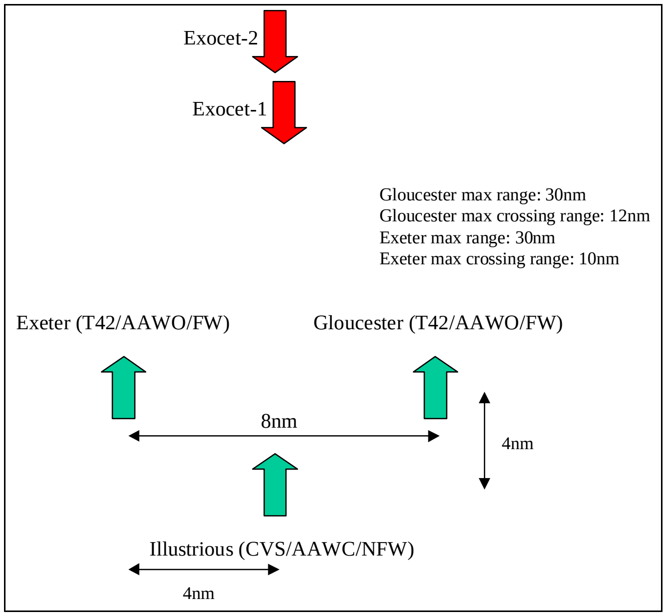


Figure 13. Example Scenario

In the above scenario, two Exocet missiles target Illustrious which is defended by two Type 42 destroyers with Air Defence capability. Exeter has the better peak HK performance but its performance falls off more rapidly with the crossing range.

The following tables show the FCM and FWS entries that would be generated for the second threat using a performance based algorithm.

Platform id	Threat id	Threat target id	HK	EW
Gloucester	Exocet-2	Illustrious	0.6	0.75
Gloucester	Exocet-2	Exeter	0.4	0.75
Gloucester	Exocet-2	Gloucester	0.8	0.75
Exeter	Exocet-2	Illustrious	0.5	0.9
Exeter	Exocet-2	Exeter	0.9	0.9
Exeter	Exocet-2	Gloucester	0.1	0.9

Table 1. FCM entries for 2nd Threat - 1st threat already being engaged

Platform	Free HK Channels	Max HK Channels	SAMs In Launcher	SAMs In Mag.	Max SAMs	Free Jammer Capacity	Max Jammer Capacity
Gloucester	2	2	2	28	30	5	5
Exeter	1	2	2	26	30	4	5

Table 2. FWS entries– Exeter has already jammed and started firing at Exocet-1

Platform id	Threat id	Engagement Type
Exeter	Exocet-1	EW
Exeter	Exocet-1	HK

Table 3. Current Engagements

In future the algorithms should enable the allocator to exploit more than one concurrent HK or EW option against a threat in order to achieve a specified goal. Other enhancements include:

(a) combination of opportunities and performance (using opportunities as a first parse to determine the possible options and performance to then select the best option).
(b) generation of a prioritised list of responses for each threat.
(c) implementation of an algorithm that gracefully degrades as the data quality reduces or is unavailable.

6. **Man Machine Interface**

6.1 ***Usability and complex information***

As the capability of sensors and other information gathering equipment improves, there is vast amount of data that becomes available to the command decision making process. It is therefore important to only show the user the information that is required and to display it in an understandable format, i.e. the right information, the right time, the right format.

When operating in a hostile environment, the information needed for the decision process can be grouped into 2 areas; information relating to the threat and information relating to force capability. Threat information requires the track numbers, ranges, bearings, TTI and targets. The force capability information consists of availability, status and capability for each air defence platform.

Once the decisions have been made and the orders passed to the force, then the essential information changes. The threat and force system information takes a secondary role to the status of the ongoing engagements. The AAWC's attention switches to the locking up of FCRs, launching of SAMs, seduction away from HVUs and the ultimate destruction of the threats.

The AT display is shown in Figure 14.

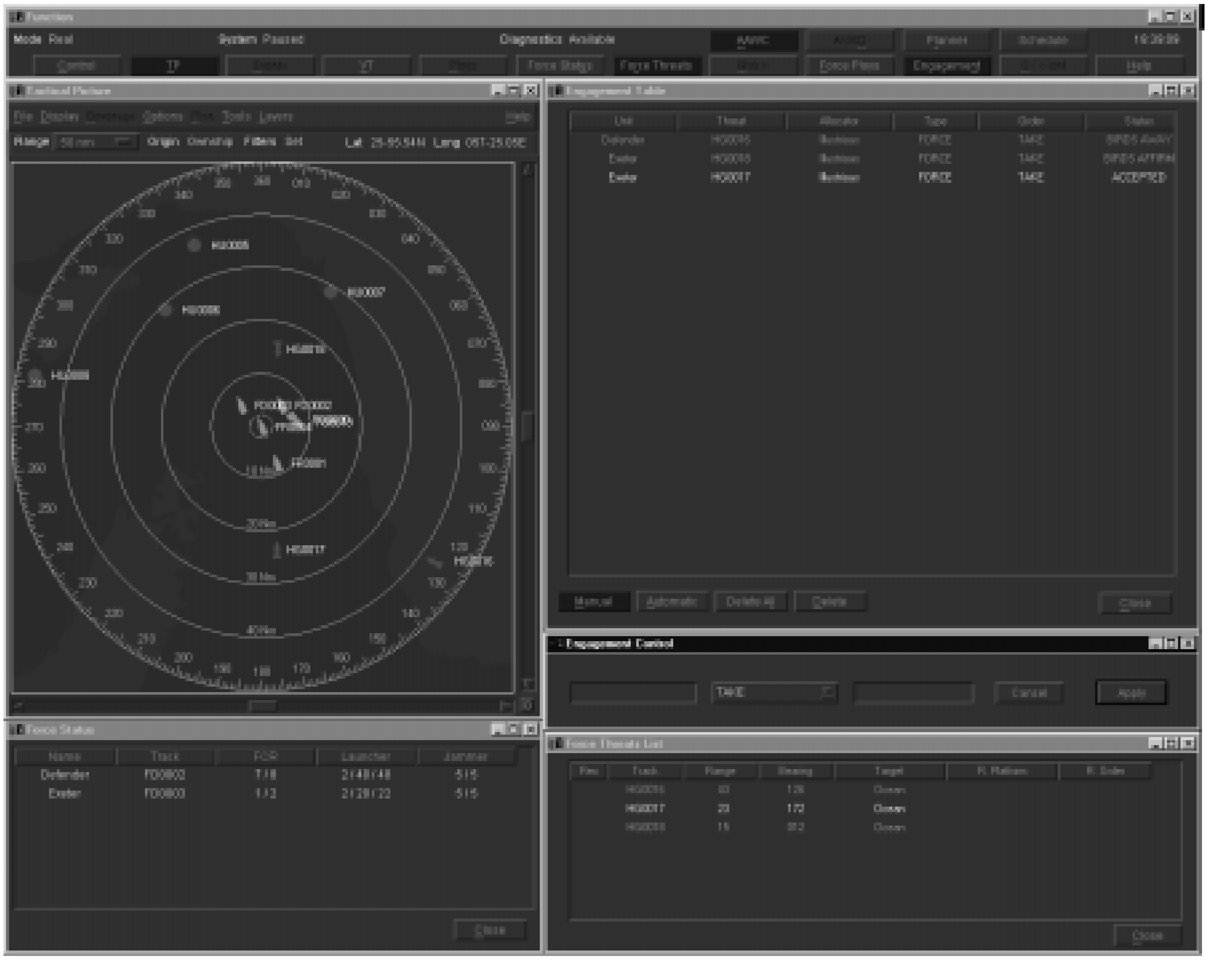


Figure 14. Multiple Windowed AT Display

The windows from top left in clockwise order are System Control (ST), Engagement Table (ET), Engagement Control (EC), Force Threat List (FTL), Force Status (FS) and the Tactical Picture (TP).

6.2 ***Tactical picture***

The TP provides the operator with a colour visualisation of the area of operations. At a basic level, the TP provides the user with force tracks using associated labels. By extending the label associated with a track, additional information can be displayed including machine recommendation data. In Figure **15**, the extended label for an incoming threat is shown In this case the seeker is active and the ESM equipment has classified the threat that an Exocet missile. A performance recommendation has been generated and, based on Ocean as the target, shows the HK and EW performances (0.7 & 0.5 respectively). The next set of values show the performance values for an alternative target (Exeter).

Figure 15. Extended Label

The addition of optional overlays can display further information, visual representations of engagement orders and allocation lines to represent the status of current engagements. Figure 16 shows the TP with allocation lines displayed. The use of colours for the lines follows a set style for the entire HCI. Different orders and statuses use different colours. When a HK engagement order is sent and the unit accepts the line appears solid and yellow. Once the FCR has locked up, making birds affirm, the colour changes to blue and the line becomes dotted. When SAMs are launched the colour changes to green. In Figure 16, FD0003 (HMS Exeter) is BIRDS AFFIRM with track HG0018, a dotted blue line, and has ACCEPTED an engagement on HG0017, a solid yellow line. Track HG0016 has been fired upon by FD0002, which would be shown as a dotted green line.

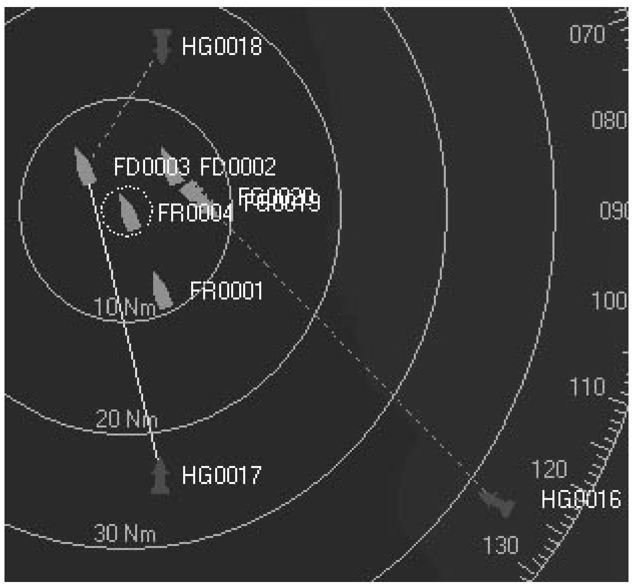


Figure 16. Allocation Lines

The colour scheme used consistently within the TP, FTL and ET windows. Yellow for pending or accepted orders, green and blue for birds affirm and birds away respectively, orange for force jamming and white for other orders such as cover, hold fire and cease fire.

When decision support is selected, it is also possible to display this information in an overlay as well. Figure 17 shows a performance plot for the force against the threat in the sector. The lines show the HK capability of the air defence units in the force. The lines do not represent range but the performance capability in that direction.

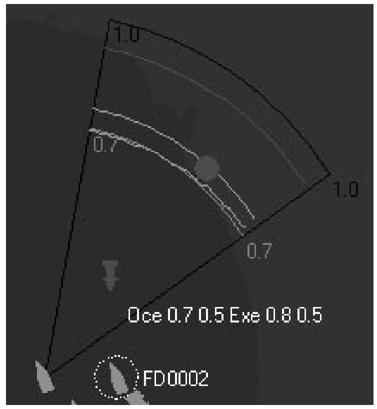
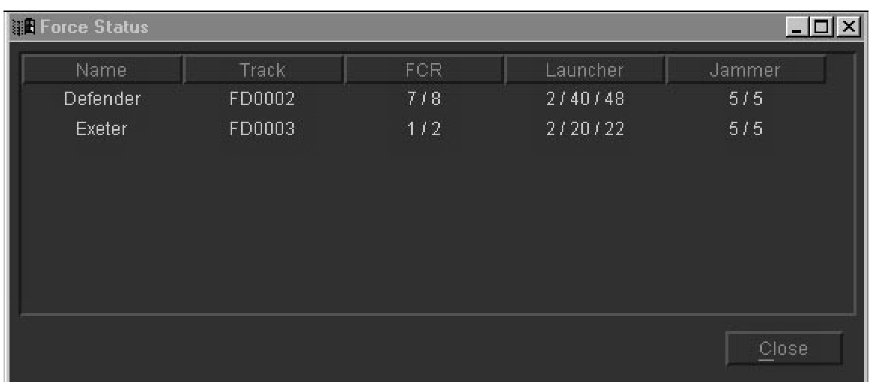


Figure 17. Displaying Capability Data

6.3 ***Status information***

Below the TP is the Force Status Window (FSW) which provides the user with a display of the systems status across the force. The example FSW shown in Figure 18 details two platforms, HMS Exeter and HMS Defender. The FSW shows that Defender has locked up with one of its FCR, represented by the 7/8 value in the FCR column, and has 42 of 48 SAMs remaining represented by 2/40/48 in the launcher column. The launcher column shows the number ready to launch (2), number in the magazine (40) and the total number it can carry (48). Exeter has also locked up with one of its FCR but has yet to fire. The jammer column shows that neither ship is using a jammer, hence both have 5 out of a maximum of 5 channels available (5/5).



Name	Track	FCR	Launcher	Jammer
Defender	FD0002	7 / 8	2 / 40 / 48	5 / 5
Exeter	FD0003	1 / 2	2 / 20 / 22	5 / 5

Figure 18. Force Status Window

6.3 ***Displaying Recommendations to the Command***

Figure 19. Machine Recommendations using the FTL

The FTL window is shown in Figure 19 which provides the user with available threat data. When the decision support module is active, a symbol appears to indicate that there is a recommendation for a specific threat. To select the recommendation, the user simply clicks on the entry in the FTL. This populates the EC window with the recommended action.

6.4 ***Weapon Allocation***

The EC window is where manual engagements can be created and sent to units within the force. Three pieces of information are required to generate an engagement, the unit, the action and the threat. To populate these fields, the operator selects the unit and threat via the mouse in the TP. The required action is selected either in the EC window via a drop down menu, or from a similar menu that appears when either the unit or threat are selected in the TP. The user can change any of the entries until he is satisfied.

Figure 20. Engagement Control Window

The EC window is shown in Figure 20 where HMS Exeter has been selected to engage track HG0016. The user has activated the drop down menu and is presented with a list of available actions for the unit to undertake. Once selected, the user can either clear the engagement before sending it via the cancel button, or send the engagement to Exeter using the apply button. The same drop down menu appears when using the TP.

6.5 ***Engagement Table***

Once the engagement as been sent to the unit, it automatically appears in the ET. This is above the EC and to the right of the TP. When the engagement is first sent, it appears in the ET with a pending status. When the allocated unit responds to the order the status will change. The options available to the allocated unit are accept, reject or birds negat. If the allocated unit accepts the order, then the status will change to accept, and, as events relating to the engagement change, the status is automatically updated.

Engagement Table

Unit	Threat	Allocator	Type	Order	Status
Defender	HG0009	Illustrious	FORCE	TAKE	SPLASHED
Defender	HG0016	Illustrious	FORCE	TAKE	BIRDS AWAY
Exeter	HG0011	Illustrious	FORCE	TAKE	SPLASHED
Exeter	HG0010	Illustrious	FORCE	TAKE	ACCEPTED
Exeter	HG0018	Illustrious	FORCE	TAKE	BIRDS AFFIRM
Exeter	HG0017	Illustrious	FORCE	TAKE	ACCEPTED

Figure 21. Engagement Table

The ET is shown in Figure 21 where there are 2 engagements in progress and 2 waiting. Defender has launched a SAM on track HG0016. Exeter is waiting to launch on HG0018 and has accepted take orders for threats HG0010 & HG0017. Both ships have successfully completed SAM engagements against HG0009 and HG0011 where the status is shown as SPLASHED.

7. **Architecture**

7.1 ***Basic Architecture***

The basic architecture of the system has three main elements as shown in Figure 22; the user, the AT and the WD. The user obtains his situation awareness from the information provided by the AT, and then uses the AT to convey his orders to the rest of the Force. The WD is a generic instance of the weapon systems contained on the platform and although these roles would normally be carried out by a number of different operators, putting them into a single WD unit enables the simulation of appropriate actions and responses to the decisions made by the AAWC.

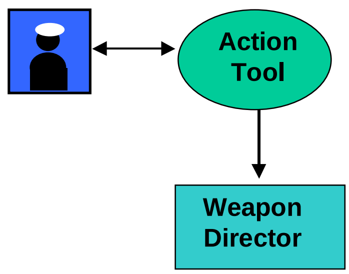


Figure 22. Basic AT Architecture

This single instantiation of the system is scaleable across the force and is currently set up as shown in Figure 23 where the scenario controller executes and controls the simulation.

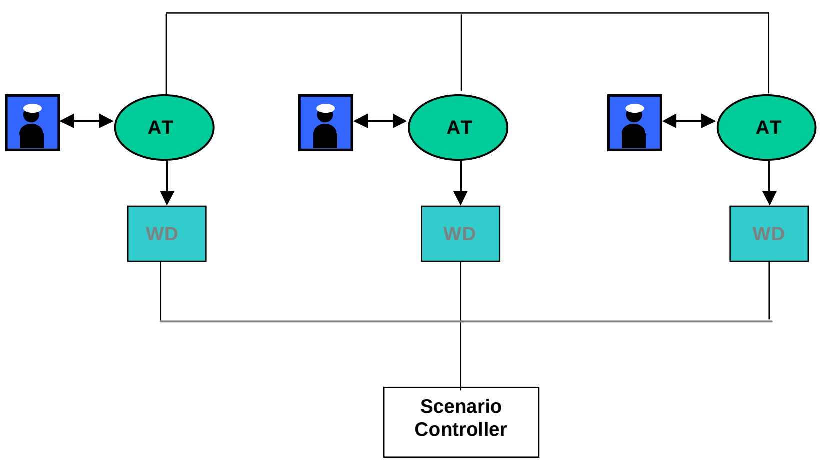


Figure 23. Multiple Action Tools

In Figure 23, the central AT is currently configured as the AAWC platform. The other ATs act as Air Defence platforms within the force and are operated by AAWOs. This is the most common configuration although the system enables any combination of platforms.

7.2 ***Levels of Automation***

Under certain conditions it may be necessary for the system to carry out actions automatically, especially where response times are short. To address this, the system has been designed to support different levels of automation.

Both the AT and WD can be operated in a fully manual or fully automatic mode. Figure 24 shows all ATs and WDs in manual mode. This 'baseline' reflects current practice and will be used to measure relative improvements in system performance.

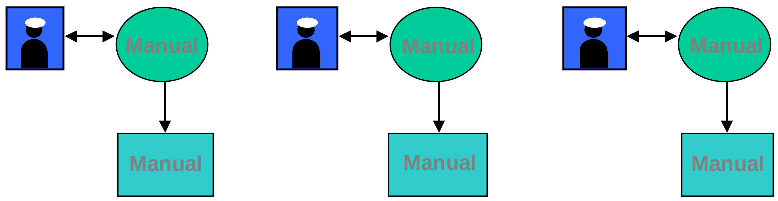


Figure 24. Manual Mode

The second level of automation is shown in Figure 25 where the WDs are set to automatic. As soon as the designated platform has accepted an order the appropriate action is automatically carried out by the WD. An example would be an air defence platform being given the order to ‘take’ a threat. Once the air defence unit has accepted the order, the WD station will automatically begin locking up with the appropriate Fire Control Radar, and, when ready, will automatically fire at the target.

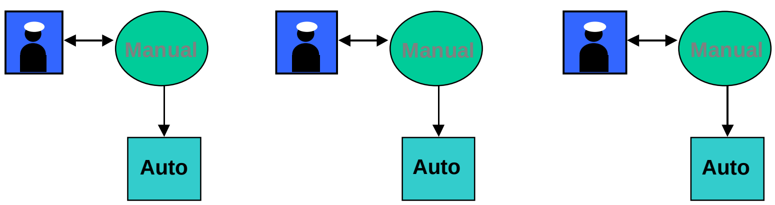


Figure 25. WDs in automatic, ATs in manual

The third level of automation involves the AAWC operating in manual mode with the air defence units both operating in fully automatic mode together with their WDs as shown in Figure 26. Any order the AAWC allocates to the air defence units will be carried out automatically without any input from the AAWO. The ATs on the air defence units are now making machine based decisions as to whether they can carry out the AAWC’s orders.

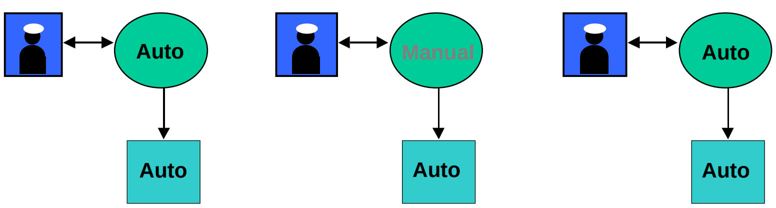


Figure 26. AAWC AT in manual mode - AAWO ATs in automatic

The final level of automation shown in Figure 27 where all elements of the system are in automatic mode. All decisions and actions are carried out completely by the machine. The system continuously monitors what is happening, with the AAWC station requiring constant feedback from the two air defence platforms concerning their engagement status.

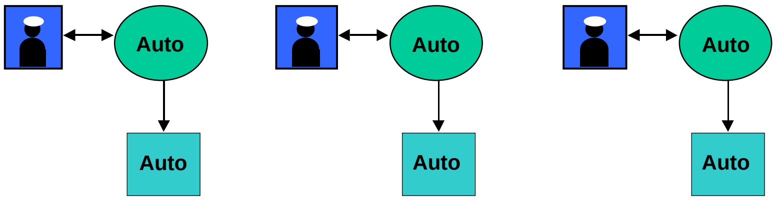


Figure 27. Full Automation

It will be possible to carry out research into how the different levels of automation will affect the outcome of different scenarios and how machine decisions may differ from that of the AAWC. The outcome of research carried out in this area will show whether it is possible to strike a balance between the level of automation provided by the machine and the command. It will also show how different scenarios affect this balance and how the level of automation may impact command decisions.

7.3 *Centralised and Distributed Approaches*

Current practice within the maritime air defence domain relies on the AAWC using his situation awareness to assess and react to the unfolding situation. He is responsible for all decision making and the processes leading up to those decisions. This is a very centralised approach. A more distributed approach could generate significant benefits. The following tables show two areas of the AAW process and list some of the differences between the two approaches. Table 4 describes centralised and distributed threat evaluation. Table 5 describes centralised and distributed weapons assignment. The AT will enable different approaches to be compared.

	Centralised Evaluation	Distributed Evaluation
Security Classification	Designated platform can be limited by national equipment security classification.	Own platform performance assessment permits full consideration of equipment capabilities.
Assessment Quality	Single evaluation source results in overload in dense scenarios and fall off in assessment quality.	Distributed evaluation means reduced loading and higher quality of assessment.
Assessment Flexibility	Pre engagement definition of equipment performance does not allow evolution with the scenario.	Performance evaluation based on present equipment performance and present scenario status.

Table 4. Threat Evaluation

	Centralised Weapon Assignment	Distributed Weapons Assignment
AAWC Loading	With the AAWC involved in detail with all engagements perspective can be lost.	Reduced loading allows the AAWC to take a wider perspective of the engagement.
Redundancy	If the AAWC is incapacitated, weapons selection reverts purely to own ship assignment.	If the AAWC is incapacitated, weapons selection can still be assigned by optimisation across the ship group.

Table 5. Weapons Assignment

The AT uses three co-ordination schemes. When one of these is set, information is passed between platforms and the process of steps carried out within each AT that leads to an allocation is shown in Figure 28.

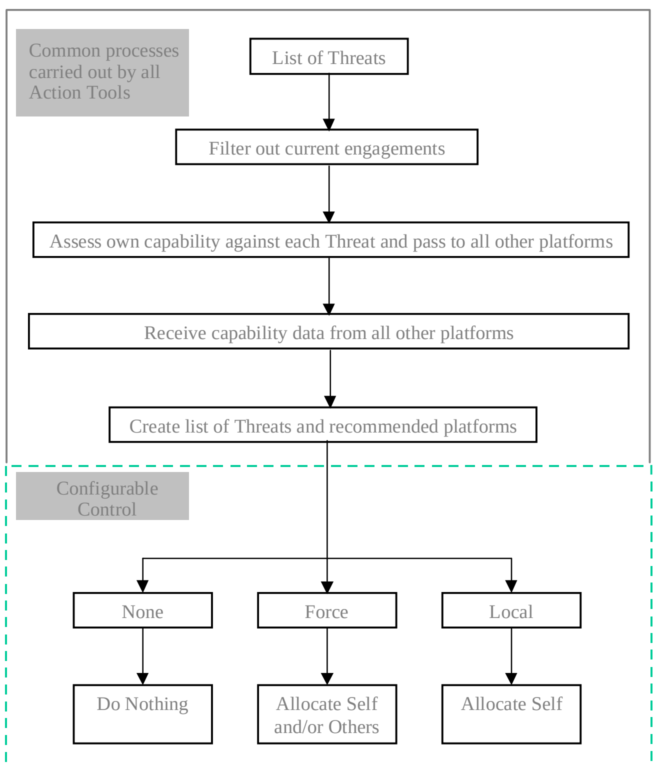


Figure 28. AT Processing and Allocation Control

As threats appear in the TP, each AT compiles an ordered threat List. If any threats are involved in a current engagement they are filtered out of the process. Although this step does not reflect what would happen in reality, it has been used as a starting point for evaluation. Each platform then assesses its own capability against each threat and broadcasts this data to all platforms. As a result each AT then receives capability data from other platforms. A list of threats together with the recommended action is then generated. All ATs carry out this process of steps, but it is from this point that the configuration of the AT can be changed. There are currently three control options available, None, Force and Local. Figures 29 and 30 show two different control configurations and how the decision making process in each one is carried out. If a platform is set to ‘None’, then, once the list of threats and recommended platforms has been created, the platform will do nothing more. When set to ‘Local’ each platform will make its own decisions but will only be responsible for its own allocations. When a platform is set to ‘Force’, the platform is also able to generate allocation requests for other platforms.

Figure 29 shows distributed control with all platforms set to local. Each platform is now a decision maker in its own right and will make its own allocations based current information. P1, P2 and P3 denote the three platforms and T1, T2 and T3 denote three threats. Each platform has allocated itself to one of the threats.

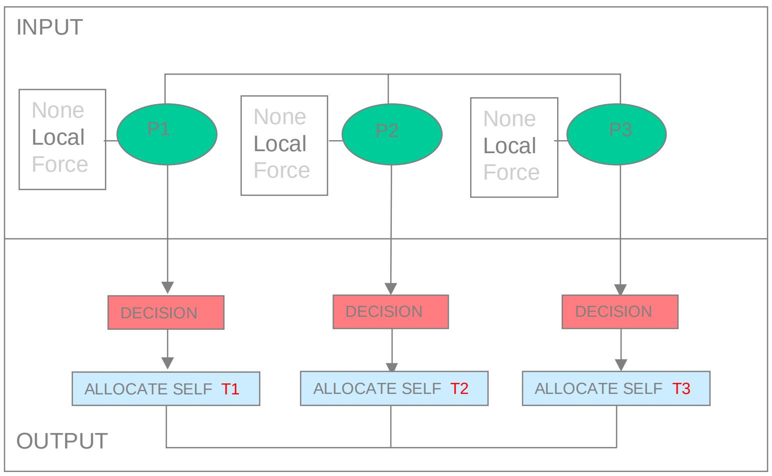


Figure 29. Distributed Control

Figure 30 shows centralised control with the central platform set to ‘force’ and all other platforms set to ‘none’. The central unit now has control over the force and will make all decisions and allocations for the force. Another possibility is to set ALL platforms to force.

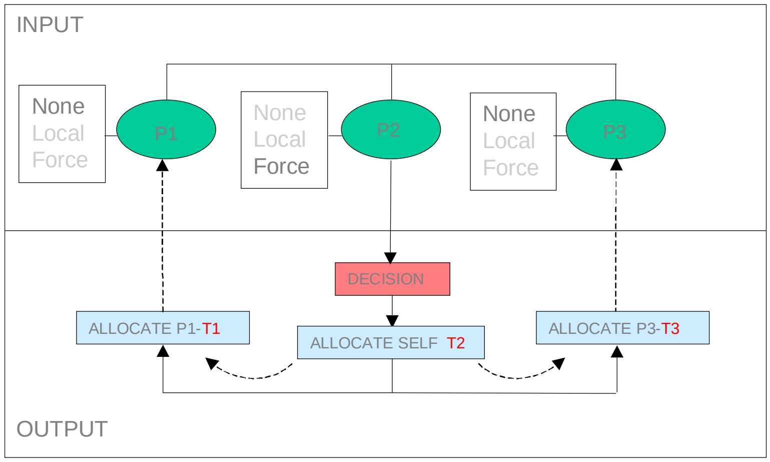


Figure 30. Centralised Control

To implement more robust solutions to both architectures, it is necessary to look at the different message sets and information needed by the two different approaches. It is also necessary to study the frequency at which these different types of information are sent. With the centralised control approach it may be necessary to generate more command and response type data/messages whereas with the distributed control architecture more recommendation, allocation and capability data may be required in order to provide a robust solution. It may be possible to use a hybrid architectures. As the system has been developed to enable both centralised and distributed architectures to be easily configures it will be possible to evaluate the trade-offs.

7.4 *Communication Requirements*

The system currently reflects two forms of communication; voice and limited data communications. Data communications is implemented by passing messages between platforms across the network. The system uses four main message sets which are shown in Table 6.

Message Type	Typical Contents	Flow Direction
Allocation Orders	Cover, Take, Cease Fire	AAWC to AAWO
Acknowledgement	Accepted, Birds Negat	AAWO to AAWC
Engagement Status	Birds Affirm, Splashed	AAWO to AAWC
Capability Data	Performance data	AT to All other AT's

Table 6. Message sets used by the Action Tool.

A simple message protocol has been designed and implemented based on error free communications.

Currently, the system does not represent any particular type of communications link, but it is likely that Link 16 would be the most probable system over which to transmit and receive AT data and messages. Although some of the message sets used by the AT are not supported by Link 16, the research aims to identify the performance trade-offs between different link capabilities.