Integrated Maritime Picture for the efficient and effective surveillance of the coastal region

by

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Abstract

Three quarters of the world's surface is covered in water meaning a significant portion of the world depend on the sea for trade and transportation with vessels of various types some of which are platforms for weapons. Safe and efficient navigation of these vessels can reduce to a minimum the risk involved in marine accidents, the casualties as result thereof and the economic losses as well as environmental pollution.

The sea is a very important part of African life and has an integral role to play in making sure that we can provide a better life for all, not only in South Africa but also on the continent as a whole. The resources it has to offer can contribute to the building of the wealth of Africa. South Africa has an estimated 94% of the imports and exports passing through her ports, therefore a disruption to trade due to poor maritime surveillance will have a serious negative effect on the economic wellbeing of South Africa. Proper and effective surveillance of the maritime areas can provide the early warning required for an appropriate response to any emerging threat to be provided.

This document plans to first evaluate the current system being used for maritime surveillance of vessels weighing more than 400 tons. Then a literature study that will offer techniques used in tackling similar problems. The tools and techniques to be researched will be primarily simulation, mathematical programming techniques and engineering economy used for the Cost Analysis. This document concludes by showing how these tools will be used to propose a concept for a cost effective system to used by South Africa to incorporate the limited resources both human and machinery to ensure the proper and effective surveillance of the maritime environment is done.

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1. Introduction and Background

1.1 Introduction

The continent of Africa is typical in the way that the majority of the states have access to the sea. Of the 52 states on the African continent only 12 capitals cannot be reached from the sea, therefore making the continent heavily reliant on the sea for transportation in terms of export and import of goods in order to sustain the economies on the continent. In addition to the potential of disruption of trade, our continent faces the new threats of poaching, drug smuggling and human trafficking, which have increased over the past few years. Knowing what is happening in and around the Continent will allow countries to respond in time to the developing security threats that face them individually or collectively.

Surveillance is an important step towards ensuring that an awareness of the maritime environment is achieved. The maritime environment is those areas that are surrounded the sea. Resources in South Africa to conduct surveillance of the maritime environment are generally limited, therefore states with developed resources would be called upon to support any initiative for comprehensive surveillance in order that South Africa can benefit. From effective surveillance of the maritime environment comes a comprehensive plan to make use of to make sound decisions.

In order to provide uninterrupted comprehensive surveillance of the environment as a whole, a collective strategy should be developed with the aim of ensuring that all participants have access to the specific surveillance information. Surveillance would then be the tool that ensures that these states are fully aware of the developments within their areas that they are responsible for. For the purpose of this project only the maritime surveillance of vessels weighing more then 400 tons will be considered. These vessels are being looked at since according to law, the vessels must be fitted with an Automatic Identification System (AIS).

1.2 Background

In 2002/2003 the SA Navy raised an ROC 01/0117 for an Over-the-Horizon (OTH) Radar Capability and initiated a study into this technology at IMT (Institute for Maritime Technology). Studies focused on HF Radar technology, in particular, HF Surface Wave Radar (SWR) and it briefly looked at Sky Wave OTH Radar.

In studies it was found that the requirement was not specifically to acquire HF SWR, but to rather address the issue of Wide Area Real-Time Maritime Surveillance (WARTMS). This was based on inputs from users from the SA Navy and other government agencies and the study alluded to different technological solutions being available to assist in meeting this requirement.

During these studies these technologies were briefly identified, but the main thrust of the study recommendation were that this wide area maritime surveillance needs to be investigated in greater detail. It was also recommended that more detailed investigations into HFSWR, sky-wave HF Over-the-Horizon (OTH) radar and aerostat-based radar be conducted.

2. Project Aim

The aim of the project is to provide a cost effective and holistic system that can be used by South Africa taking into to account the limited resources in terms of Manpower and Equipment that can be utilized to perform proper and effective surveillance of the maritime environment for vessels weighing more then 400 tons. The aim well executed will enable the following to be achieved: Early warning to possible threats, quicker response time to possible threat and optimization of limited resources.

3. Project Scope

The scope of the project covers the deliverables outlined in the document.

- **Resource Allocation Plan**- an accurate resource allocation plan will be formulated with constraints. This will be a mathematical model defining the problem constraints and catering for any limitations and specifications.

- **Network Distribution Diagram**- the area where the surveillance needs to be done and the resources allocated to that areas needs to be looked at and mapped on a interface and this will result in a Network Distribution diagram.

- **Operational Control System**-Design a centralized unit where all the surveillance can be observed and the surveillance that has been observed can be analyzed and sent to relevant participants.

- **Maritime Surveillance System-** A maritime surveillance system will be developed. A shore-based system that detects tracks classifies and identifies surface and air targets throughout Exclusive Economic Zone.

- **Cost analysis**- analyzes the cost implications of the recommended modification of the current system, and performs a study to evaluate if such modifications are justified. The current cost of running the maritime surveillance system without any new machinery, technology or other resources will be computed. The estimated costs supported by facts, of the new system encompassing the project deliverables, and formulate a comparison matrix.

4. Literature Review

4.1 Resource Allocation

The high level of resource allocation problem for 400-ton vessels made it apparent to come up with a resource allocation plan.

We are exploring the use of genetic algorithms in place of searching the weapon allocation tree. Such algorithms may speed up the generation of allocation plans and converge on the reasonable plan more quickly than searching the allocation tree, especially for the large allocation problems. (J Slagle, 1985)

The two mathematical algorithms (resource allocation and scheduling) will be required help with sending the resources where they are more critically needed This will have an impact on the time, investigation into how mathematical programming can solve both problems will also be done.

Dynamic Programming often solves resource-allocation problems in which the limited resources must be allocated among several activities. To use linear programming the following assumptions must be made:

- The amount of resources assigned to an activity may be any non-negative number.
- The benefit obtained from each activity is proportional to the amount of resource assigned to the activity.
- The benefit obtained from more than one activity is the sum of the benefit obtained from the individual activities.

Even if the first and second assumption does not hold dynamic programming can still be used to solve resource-allocation problems efficiently when the third is valid and when the amount of the resource allocated to each activity is a member of a finite set. (Winston 2004:763).

4.2 Simulation model development

"All models are wrong but some are useful"

4.2.1 The process of simulation modelling

The building of a simulation model to perform continuous improvement initiatives has numerous benefits. The following are main benefits from simulating a problem (Hlupic and Robison 1998:1365):

- A simulation model can be easily changed to follow changes in the real system.
- Experimentation with a simulation model is rather than implementing changes in the real processes reduces the risk of making wrong decisions.
- The process of model building facilitates a better understanding of the processes being modelled.

The process of developing simulation models can be divided in several distinctive steps that have to be followed from the identification of a need for developing a simulation model of business processes to providing recommendations on the basis of simulation model output (Paul et al, 1998).

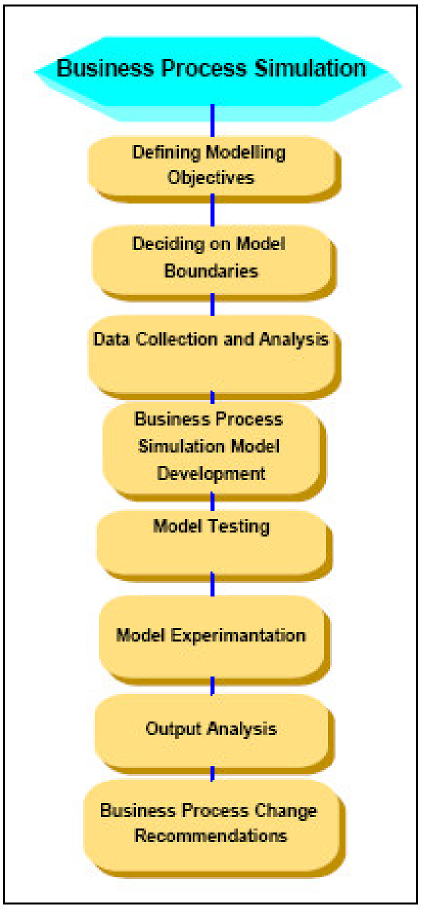

Figure 1: The process of simulation modelling (Hlupic and Robinson 1998)

The first stage is the determination of model objectives this relates to what is the desired outcome of the model and the information required from the model. The next stage "Deciding on modelling boundaries" deals with which processes should be incorporated in the model. Data collection and analysis then follows with data being collected from various sources. This data is then collected and analysed using standard statistical procedures such as distribution fitting.

The development of the simulation model relates to the development of the model using appropriate simulation software. This is done through an iterative process where a simple model is initially developed; this is then expanded and refined until an acceptable model is obtained.

With every iterative step in model development the "model in progress" should be tested using verification and validation techniques. The model experimentation then comes in where different alternatives of doing the same process are run through the model. The experiments should be designed in a way that allows for a wide range of alternatives to be included so that recommendations can be of a wider range.

The penultimate step is the analysis of output using statistical techniques. On the basis of the out analysis the recommendations will be made on the improvement or the change in the process (Hlupic and Robinson 1998:1365-1366).

4.2.2 Types of simulation models

Discrete event

This is a simulation model that changes state only at discrete, but possibly random, set of time points (Schriber and Brunner 1999:73).

System dynamic

This is a simulation that represents a system that evolves over time. In this situation the simulation can be either stochastic (containing one or more random variables) or deterministic (containing no random variables) (Winston 2004:1147).

4.2.3 Types of simulation software

The table 1 shows a few examples of commercial software packages that can be used for simulation purposes. The two software packages that are available for use in this document are Arena and Anylogic.

Optimisation Package	**Vendor**
AutoStat	Auto Simulations Inc.
OptQuest (Arena)	Optimisation Technologies Inc.
Optimiz	Visual Thinking International Ltd.
Anylogic	XJTEC

SimRunner	Promodel Corp
Optimizer	Lanner Group Inc.

Table 1: Commercial software packages

Arena

AnyLogic

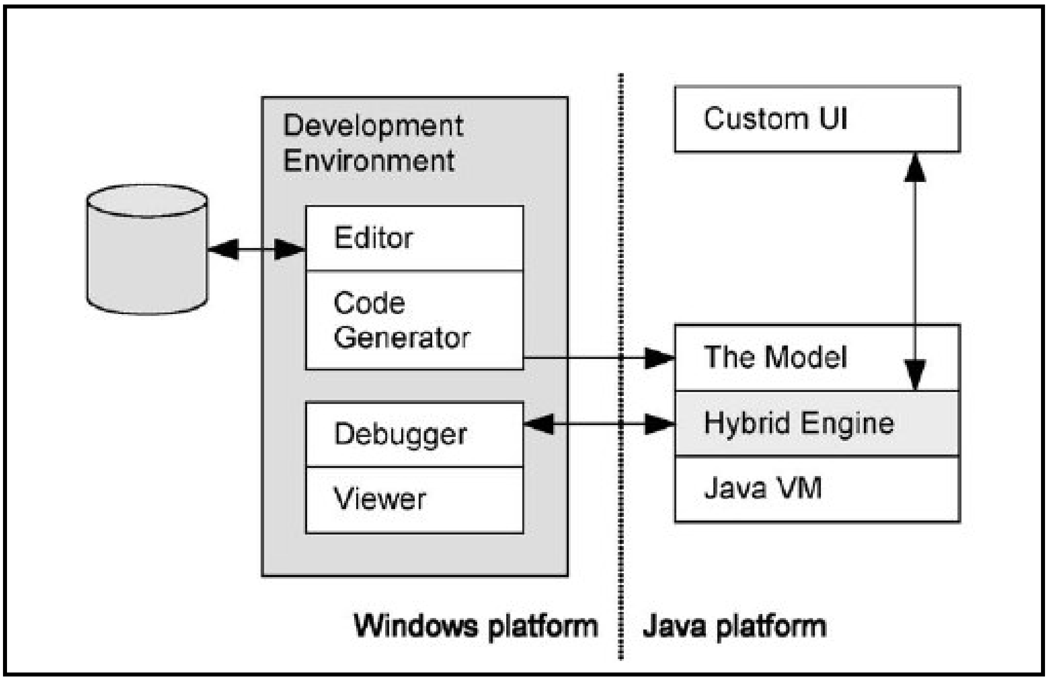

Figure 2: Architecture of Anylogic Borshchev et al

The figure 2 shows AnyLogic architecture and the interaction between the Windows platform and the Java platform. The model runs on any Java platform on the top of AnyLogic hybrid engine.

Advantages of Anylogic are that for simple systems the software is easy to use, many applications and has powerful tools for creating system animations. Its drawbacks are that it crashes during animation runs, switching between Java and Math can be awkward.

The simulation software to be used in this project will be Arena as it is inline with the outputs.

4.2.4 Simulation optimisation

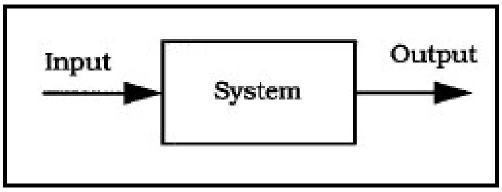

Figure 3: Black box approach

The black box approach (see figure 3) is a common approach to simulation modelling whereby the solution procedure is separated from the system being optimised (Glover et al 1996:146). This is its major disadvantage and only allows for use over a wide range of systems. In figure 4 it is observed that the output from the simulation model is used in the optimisation procedure to evaluate the outcomes of the inputs.

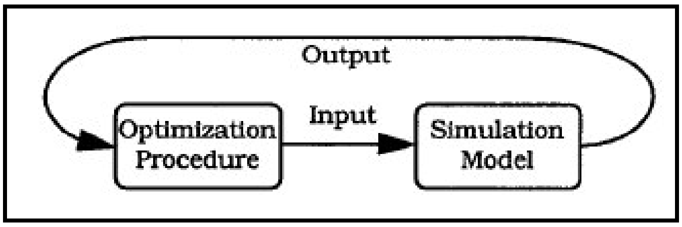

Figure 4: Coordination between optimisation and simulation

The optimisation procedure is designed to generate inputs to produce differing evaluations though not all are improving (Glover et al 1996:146). Hence the solution obtained by heuristics method.

4.2.5 Simulation model result verification and validation

The validation of a simulation model can be defined as "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model"

(Schlesinger et al. 1979). It is often too costly and time consuming to determine that a model is absolutely valid; figure 5 shows the relationship between costs, value of the model as a function model confidence.

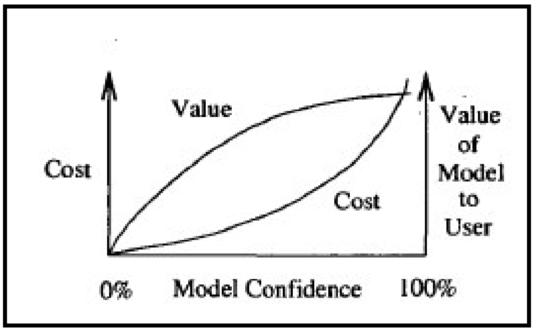

Figure 5: Model Confidence (Sargent 1999)

The basic approaches to determining model validity (Sargent 1999:40) are:

- The development team makes a subjective decision to the determine validity based on various tests and evaluations made during the model development process.
- The independent verification and validation where a third party is used to conduct the model validation. This is a costly and time consuming process as the third party at times has to evaluate the whole modelling procedure.
- The use of a scoring model uses the weights obtained subjectively and then combined to determine category scores. Validity is then obtained if a certain pass mark is attained.

The actions used in the validity of a simulation can be classed into face validity (inquiring from knowledgeable people about whether model behaviour is reasonable), testing assumptions and input output transformations.

To simulate the problem Arena will be used as it is more accessible and easier to use as well as will not compromise the results of the study.

4.3 Integrated Maritime Surveillance

Countries with substantial coastal regions greatly enhanced systems to monitor activity occurring within their Exclusive Economic Zones (EEZ). Activity will include isolated or grouped moving and/or anchored surface targets and low-flying aircraft. The targets may be military or commercial, friend or foe, small or large.

Such a system has been developed and is under evaluation on Canada's East Coast. The Integrated Maritime Surveillance (IMS) system uses a variety of electronic sensors and communication devices to provide a complete overview of activity within the EEZ.

4.3.1 The IMS System and HFSW Radar

The IMS System with HFSWRs as primary sensors consists of the four basic segments:

- Radar Surveillance is provided by a number of long-range HFSWRs
- Direct Identification is based on Automatic Dependent Surveillance (ADS) systems
- Indirect Identification is obtained from communications, patrol crafts and mandatory reporting procedures
- Multi-sensor Data Fusion automatically correlates tracks derived from HFSWRs with ADS and other information.

An integrated Maritime Surveillance System with high frequency surface-wave radars as the main sensors is a good Maritime Surveillance System to consider for the project.

4.4 Network Distribution Diagram

The Network Distribution diagram will give a picture of exactly how all the resources have be allocated and also depict how all air and ground resources are incorporated to provide the maritime surveillance system. The figure below depicts how a network distribution diagram for the maritime surveillance system looks.

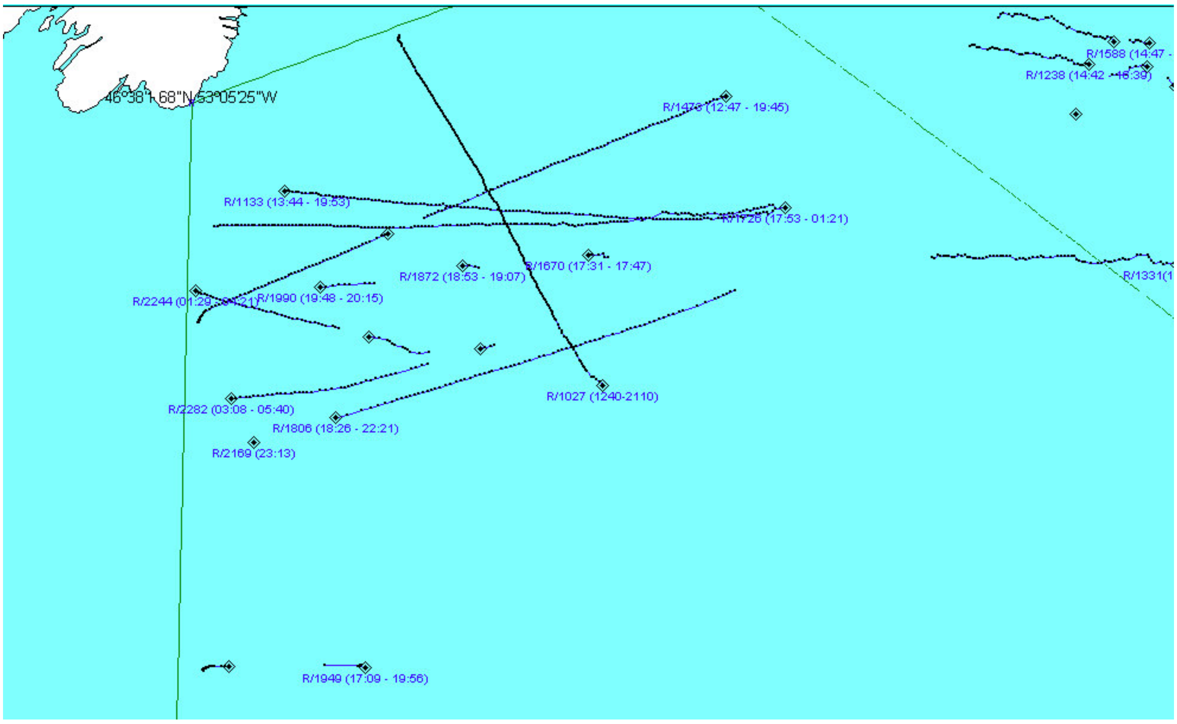

Figure 6: Proposed Network Distribution diagram (Ponsford, 2001)

The knowledge from the literature study will be used in conjunction with learned Industrial Engineering methods, tools, and techniques to formulate, evaluate and develop concepts. Concept designs will be discussed in detail in the next chapter.

5. Conceptual Design

5.1 Introduction

The literature review process above equips us with knowledge that we can use through Industrial Engineering methods and tools to effectively solve the problems outlined in the scope. Table 3 lists the deliverables and the tools that will be utilised in fulfilling them.

5.2 Concept Design

Deliverable	Method and Tools
Resource Allocation Plan	Mathematic modelling
Maritime Surveillance System	Operations Management and Systems Engineering Approach
Operational Control System	Operations Management and Systems Engineering Approach
Network Distribution Diagram	Operations Research and Operations Management
Cost Analysis	Engineering Economy

Table 2: Deliverable Designing Tools

5.2.1 Resource Allocation Plan

We have (w) = units of a resource and (T) = activities to which the resource can be allocated. If the activity t is the implemented at level x_t then $g_t(x_t)$ = units of the resource are used by activity t, and the benefit = $r_t(x_t)$ is obtained. The problem of obtaining the allocation of resources that maximises total benefit subject to the limited resource availability may be written as

$$\text{Max} \sum_{t=1}^{t=T} r_t(x_t)$$

$$\text{s.t.} \quad \sum_{t=1}^{t=T} g_t(x_t) \leq w \qquad (1)$$

Where x_t must be the member of {0, 1, 2,…}. To solve (1) by dynamic programming, define $f_t(d)$ =to be the maximum benefit that can be obtained from activities t, t+1, …, T if d units of the resource may be allocated to activities t, t+1, …, T. The recursions is then

$f_{T+1}(d) = 0$ for all d

$f_t(d) = \max\{r_t(x_t)) + f_{t+1}[d - g_t(x_t)]\}$

Where x_t must be a non-negative integer satisfying $g_t(x_t) \leq d$.

5.2.2 Maritime Surveillance System

The need for an "Integrated Maritime Picture" is based on the need to provide enhanced Situational Awareness with regard to all the areas of interest in the protection of the sovereignty of the RSA. The Integrated Maritime Picture focuses on the surveillance of our immediate area of maritime interest. This area, as a minimum should cover the sea areas of our RSA Exclusive Economic Zone (EEZ). It could, when conducting operations in areas outside our territorial waters, also include the tactical area of interest surrounding the proximity to RSA deployed forces, such as a Maritime Task Group (MTG) deployment or a Joint Task Force deployed in a coastal region in the African Littoral (also known as the expeditionary maritime picture).

The technological advancements made in sensors, vessel tracking technology, sensor fusion, networked Command and Control data, and the increase in the availability of relevant intelligence, information and data, are changing the traditional concept of a Common Operational Picture (COP) or a General Operation Picture (GOP). The increased understanding of this integrated picture is greatly enhancing situational awareness and in several texts this now increasingly being referred to 'Marine Domain Awareness' or MDA. This MDA of the surface, subsurface (and air) approaches to the RSA is imperative. Being able to control and influence what happens in its waters is fundamental to a state's sovereignty and security.

In any system of marine domain awareness (MDA), there is a requirement to perform three basic functions: surveillance, patrol and response.

- Surveillance requires the detection of the 'known knowns,' the 'known unknowns' and even the 'unknown unknowns' to a reasonable degree of confidence. Any MDA surveillance system will likely be a layered system of systems with each subsystem supporting the other. Once the various inputs have been assessed from the surveillance sensors, a 'recognized' picture is prepared and disseminated, highlighting any anomalies that require further investigation.

- Patrols are carried out to demonstrate ‘presence’ in areas of interest to national authorities. They can be random but are likely to be tied to areas in dispute, choke points or seasonal activity such as fishing.
- Response relates to the action carried out to counter a threat to national security or violations of sovereignty or regulations.

While considerable progress has been made in the approach to MDA by various sources, a vital element, which is missing, is a national plan for marine domain awareness. Such a plan would provide a doctrinal basis for MDA and outline the responsibilities of the various players. MDA touches a variety of national, provincial and municipal governments as well as private enterprise, but without an agreed national focus, MDA is a mission that belongs to everyone yet belongs to no one.

Ultimately, a national plan for marine domain awareness must address the following five questions:

- What information is required?
- In which geographic area will it focus?
- To what level of confidence will it operate?
- By whom will the information be acquired and assessed?
- To whom will the assessed information be provided?

Prior to examining solutions, it is important to determine who the potential stakeholders in aspects of the maritime domain awareness are. Maritime Domain Awareness crosses several government ministerial boundaries and the ultimate solution will require interagency and ministry cooperation. The most dominant agencies/organisations with an interest in maritime domain awareness, or aspects of the integrated maritime picture, are:

- Chief of Joint Operations (CJOPS) at the SANDF Level.
- The South African Navy (SAN).
- Defence Intelligence.
- The Regional Joint Task Forces.
- The South African Air Force (Maritime Systems and 35 Squadron).
- The Maritime Rescue Coordination Centre (MRCC).
- The Maritime Security Coordination Centre (MSCC).
- The South African Maritime Safety Authority (SAMSA).
- The Department of Environmental Affairs and Tourism (DEAT), Marine and Coastal Management (MCM).
- DEAT, Marine and Coastal Pollution Control.
- The South African Police Services (SAPS), in particular their Marine Border Protection sections.
- The Department of Trade and Industry (DTI).
- The Department of Transport (DOT),
- The South African Receiver of Revenue (SARS).
- National Ports Authority (Harbours).
- National Ports Authority (Aids to Navigation, Lighthouses).
- Offshore Resource Companies (De Beers Marine, MOSGAS, etc).

The broad requirements of marine domain awareness in the domestic role – i.e., Surveillance, patrol and response – apply equally to intelligence, surveillance and reconnaissance (ISR) operations in the expeditionary role. The principal difference, of course, is the increased possibility of hostile action.

As in MDA, fixed wing aircraft are best employed in the response and patrol roles. In this capacity, they are normally part of a coalition effort to perform ISR functions in the theatre of operations. Due to their autonomous nature and onboard sensors, fixed wing aircraft have the ability to work with a number of coalition partners in a variety of roles of differing complexity. Fixed wing aircraft, particularly long-range patrol aircraft, are, however, at a disadvantage in expeditionary ISR due to the requirement to carry capable self-defence equipment and the necessity, in some cases, to operate at suitable standoff ranges.

There are 2 main areas of Maritime Domain Awareness, which need to be addressed. These are:

- Regional Homeland based Maritime Domain Awareness
- Expeditionary Maritime Domain Awareness

The regional homeland based

MDA is associated with the homeland security of the RSA and has been the basis of most of the work conducted on this project. To establish maritime domain awareness, an Integrated Maritime Picture containing inputs from all available sensor and information sources needs to be compiled. The Integrated Maritime Picture effort has focussed on providing situational awareness of the RSA's Exclusive Economic Zone (Coastal). The question of MDA in remote areas of our EEZ, such as the area around the Prince Edward Islands, and areas which may be allocated to our EEZ due to continental shelf claims, are not addressed in detail in this report and could form the subject of a separate study. The remoteness of these locations could lend itself to a totally different approach in terms of sensors and surveillance. In the case of expeditionary maritime domain awareness (outside the regional zones), sensors of the expeditionary group would be the primary sources of real-time target data, and they would take precedence in compiling the Integrated Maritime Picture. This IMP could also include previously measured geophysical data and intelligence information, and it could be augmented by updated reports from remote sensors such as satellites. ISR resources deployed specifically with the goal of improving the situational awareness could also augment this picture. The same principles used to compile the Integrated Maritime Picture for regional homeland security, could apply. Many building blocks could be utilised in both and it is merely the availability of sensors providing inputs which changes. During this phase of this project, the focus has been on the regional homeland based Integrated Maritime Picture, and this section provides inputs to establishing the user requirements for this aspect. The primary area of concern is shown in the figure below.

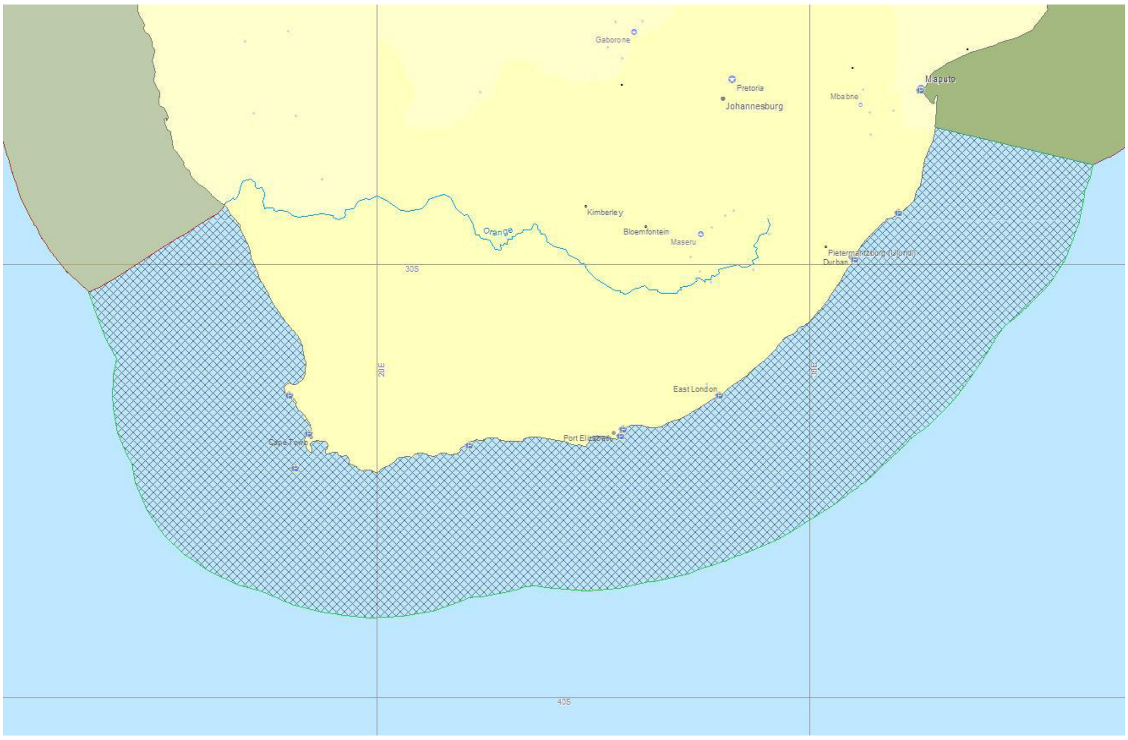

Figure 7: RSA coastal Exclusive Economic Zone

Ultimately, a national plan for marine domain awareness must address the following five questions:

- What information is required?
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Different layers of information from detection sensors, depending on operational detection zones, is required for the following zones:

- Harbour Surveillance
- Inner Zone Surveillance
- Coastal Zone Surveillance
- Outer Zone Surveillance
- Regional Surveillance

Harbour Surveillance

This is close-in surveillance of harbours and their entrances. At present this is the responsibility of the National Ports Authority and they have the necessary radar sensors and Vessel Traffic Systems (VTS) to conduct their functions. These include Port entry and exit control, as well as taking up anchorage facilities in the proximity to harbours.

Inner Zone Surveillance

The surveillance of high value areas such as the close vicinity of national key points (Refineries, Power Stations etc) or areas which are reserves, or have high resource values (False Bay, De Hoop). This type of surveillance should meet the following requirements:

- Detection and tracking of small surface targets under all weather and light conditions.
- Detecting and tracking targets in dense coastal environment (the target resolution should be better than 20m).
- The range required is a maximum of 25km.
- Surface Target speeds can vary between 0 to 50kts.
- It should be possible to view targets with electro-optic sensors and record and store images for subsequent analysis.
- The surveillance sensors must be capable of being permanently installed, or by means of vehicle transported to a specific location.

- Communications - The system shall automatically relay all tracked data in "real-time" to a central monitoring station via virtual private network using cell phone and Internet infrastructure.

<u>Coastal Zone Surveillance</u>

The coastal zone shall extend out to cover at least the territorial waters of the RSA. Territorial waters extend to 12nm (about 22km). In order to cover this continuously means that adjacent sensors have a detection range well in excess of the 22km range.

Typically in medium zone coastal surveillance, a single sensor should be capable of surveying a sector of at least 120º without overlap. The overlap will occur at the sector extremities and with the minimum range of 22 km offshore at this point, the minimum line-of-sight range of such a sensor can be calculated as 44km. From this geometry, the minimum height for the radar can be extrapolated to be (44/4,123)2 = approximately 100m. If the target has a maximum height of 25m, the detection range can be expected to be in the order of 60km.
This means the radars must be spaced at approximately 76km intervals. With a total coastline of approximately 3000km, this will require approximately 40 radar sites.

The general surveillance requirements for these radars would be:

- To detect targets (ships) with an RCS of greater than 20dBsm out to a maximum detection range of 44km at least from the radar site.
- Detect targets with a range resolution of <150m and an angular resolution of less than 1º.
- Surface target speeds can vary between 0 to 50kts.
- Detection of targets shall be possible under day and night conditions, fog and mist, in an absolute wind speed of up to 30 knots, and in rainfall of up to 10mm/hour.

- Provide an update of all tracked targets at < 5sec intervals on a continuous 24hrs/day basis.
- Provide local target tracking identity and position, course and speed updates on each target data update cycle.

The range performance would be dependent on specific radar site locations, and the above would reflect the minimum acceptable performance requirements. A study shall be conducted with regard to the availability and suitability of sites along the entire RSA coastline and radars shall be mounted at optimum locations where detection and tracking performance shall exceed the minimum requirements stated above. This will also allow the minimisation of the practical number of sites required to cover the coastline.

At each of these sites an Automatic Identification System (AIS) transceiver shall be installed to extract AIS information from targets fitted with these devices. These transceivers can provide a wealth of information rich data on targets which are in compliance with SOLAS regulations, as well as a growing number of smaller ship's being fitted with Class B AIS systems which are primarily used for collision avoidance and navigation. This data can be fused and correlated with sensor tracking data, and it helps clear the identification challenge.

<u>Outer Zone Surveillance</u>

Existing outer zone surveillance, consisting of land-based sensors mounted in high geographic locations, such as some of the existing COASTRAD sites (such as Constantiaberg 928m and Kapteinskop 1100m), which provide radar surveillance out to ranges in the region of 130km, should be retained and possibly be expanded on. Although these sites cannot be placed around the whole coastline (due to topography), they provide valuable information in important geographical regions.

These sites are "piggybacked" onto existing radar systems where the primary function is not maritime surveillance. They include weather station radars and Air Traffic Control (ATC) radars, but due to technological innovation, they can provide consistent performance against larger sea-based targets at long ranges and add to the richness of information displayed on an Integrated Maritime Picture.

These sites also include the AIS transceiver system, which allows for long range identification and tracking via VHF transceivers.

Regional Surveillance

Several efforts are underway to provide true regional surveillance capabilities and these typically include:

- The Research and Development program into radars mounted in aerostats, taking place at primarily DPSS (AWARENET), and
- Satellite surveillance efforts in terms of Low Earth Orbiting (LEO) satellites at SUNSAT in Stellenbosch.

Although these surveillance technologies are not necessarily mature, it is important that activities are supported and interfaced to, to the maximum extent. These could lead to breakthroughs in regional maritime domain awareness in the future and are sources of knowledge and technology for future technological developments.

The goal to provide persistent real time surveillance of our maritime domain of interest should not be lost, and these efforts could be expanded to provide expeditionary support, as well as regional (SADC) solutions.

Regional Ship Monitoring

The international efforts of the IMO and the SOLAS convention to establish a worldwide Long Range Identification and Tracking (LRIT) system and the national commitment to compliance by SAMSA should not be ignored in the establishment of the Integrated Maritime Picture. SAMSA (under the auspices of the Department of Transport (DOT)) is establishing a national LRIT Data Centre and this will provide identification and tracking data on all compliant vessels (all vessels over 300 tonnes and passenger carrying vessels).

The LRIT Data Centre shall provide the Integrated Maritime Picture with 6 hourly positional and identification updates of all compliant vessels within the RSA EEZ and up to a range of 1000nm of the RSA's borders.

Geospatial Information Required

Over and above the target tracking data, which shall be extracted by the sensors, the integrated maritime picture shall include the following information (provided from Geospatial Information Systems (GIS) and other databases):

- Geographical based nautical charts with the option to show sea depth contours and coastlines,
- Digital terrain data (DTED) information of land masses adjoining the coast up to a range of 100km from the coast.
- Latest satellite images of land area which shall be capable of being superimposed on the terrain data described in paragraph b. above,
- All navigation aids data, such as location of lighthouses, their heights and their illumination sequences for navigation purposes.
- All restricted zones and their areas, as well as the nature of the restrictions placed in the zone.
- Designated shipping lanes and approaches to harbours
- Other information, which may be of benefit to the operator in interpreting the movement of vessels in a specific area.

The combination of GIS data, intelligence data and sensor data can greatly enhance the interpretation of the maritime domain awareness picture, and it is believed that we are only beginning to understand the implications. In future weather and oceanographic information could also be integrated, and this will allow decision makers a wealth of options and information on which to base their decisions. It could be particularly useful in mission planning and Search and Rescue situations.

Key Capabilities of the Maritime Surveillance System

The maritime integrated picture should be compiled to show a geographically based common operating picture integrated with data sets, such as intelligence overlays, ocean data and fishing zones. The underlying technology should provide the maritime tracking solution through the following:

- The ability to assimilate and view multiple data and track sources from the various sensors in one common operation picture.
- The automated correlation and fusion of track IDs based on asset identification of tracks.
- The automated querying of track data for display within the Common Operational Picture (COP) through individual asset filtering capabilities.
- The analysis of look-ahead scenarios given current holding routes, while displaying asset sensor fields-of-view for possible detection.
- Incorporation of analysis capabilities such as line-of-sight reports, multi-asset coverage statistics (e.g. expected radar surveillance areas for specific radars), and determination of pre-planned conjunctions.
- Facilitate asset deployment for further inspection and investigation of hostile vessels.
- The system should allow viewing and analysis to be done in real time, or to be played back, or propagated forward.

5.2.2.1 Over-the-horizon (OTH) Radar-Sky wave

Basic Principles

OTH Sky wave Radar is an HF radar configuration that uses the electrically conducting bottom side of the earth's ionosphere to reflect (or bounce) HF radio waves and illuminate the earth's surface beyond the line-of-sight horizon. This configuration provides a high altitude vantage point that permits radar surveillance to a range of approximately 2000 nautical miles (nmi). A conceptual view of an OTHR is shown in the figure 8. This figure shows an OTHR in Maine, United States, and providing surveillance of the North Atlantic Ocean. The transmit antenna radiates a beam of HF radio waves toward the ionosphere at a low elevation angle. The waves reflect and then illuminate a sector of the ocean.

Illuminated targets in the transmit beam scatter the radio waves back to the radar via a similar propagation path, where they are detected by a receive antenna array. The receive array is of broad aperture, allowing the scattered signals to be resolved into fine azimuth cells. In addition, by timing the received signal, one can resolve the signal into range cells. The resulting range-azimuth resolution cell pattern is then treated as a search plane for targets, which would manifest themselves as local maxima of received signal power in a cell relative to the surrounding cells. The local maxima are declared as detections. Tracking the location of these detections over time provides target trajectories (or "tracks"), which can be correlated with other sources of information to confirm the identity of the tracked targets.

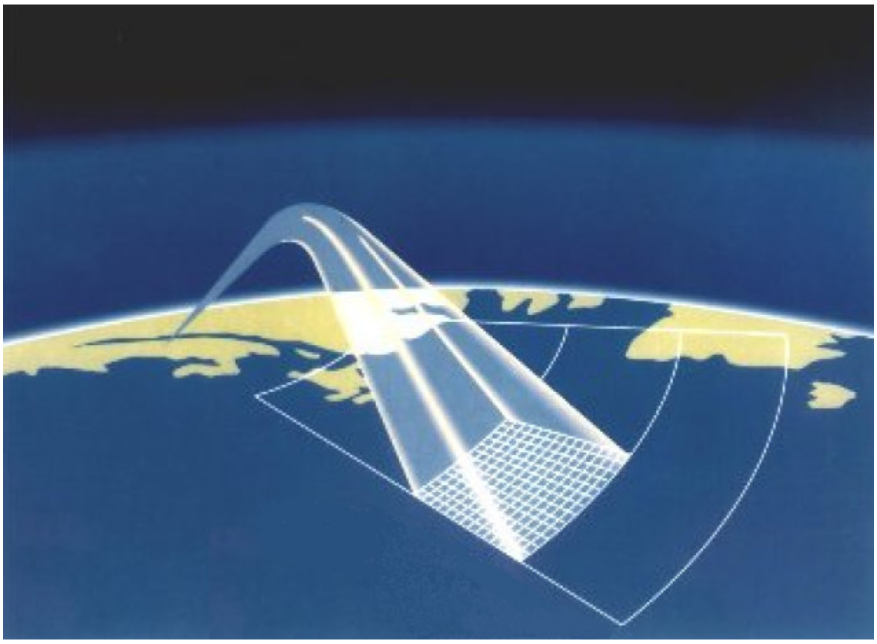

Figure 8: Conceptual view of OTHR

The proper functioning of an OTHR depends on an appreciation of the basic properties of the earth's ionosphere.

The Ionosphere

The ionosphere is a broad layer of ionized gas, called plasma, located in the region at 50–1000 km in altitude above the earth's surface. The ionosphere is classified into several sub-regions, including the D region (<90 km), the E region (90–160 km), and the F region (>160 km). The F region is the broadest and most strongly ionized layer, and is the most relevant for the OTHR application. In this layer, the ionized species are predominantly atomic oxygen and electrons. The peak plasma density is located at approximately 250 km, although there is a diurnal variation of about ±50 km. It must be noted that this peak density varies widely with location, time of day, season, and number of active sunspots, but it can be predicted to some degree using empirical data.

Refraction of Radio Waves in the Ionosphere

The refractive index, *n*, is a function of the density of the plasma, *N* (in free electrons per m^3), and the frequency of the radio wave, *f* (Hertz), given by:

$$n = \left(1 - 81N/f^2\right)^{\frac{1}{2}}$$

At ground level N is zero and n equals 1 (ie no refraction). As the altitude increases (and with it, *N*) the refractive index decreases. If it reduces to value of zero, the radio wave will be totally reflected.

From this equation it can be seen that low frequency waves will be reflected and high frequency waves will pass through the ionosphere. With $N_{max}=10^{12}m^{-3}$, waves above 9MHz will escape at vertical incidence, lower frequencies will be reflected back.

At oblique angles, the wave has to travel further through the ionosphere, so it effectively sees a reduced refractive index (and reflections will occur for higher frequencies). For the above example of plasma density, it can be shown that at an elevation angle of 20º, reflection will occur for frequencies below 26MHz. For a given elevation in the 20 to 90 degrees region, reflection will occur for wave frequencies up to a value of 9 to 26 MHz.

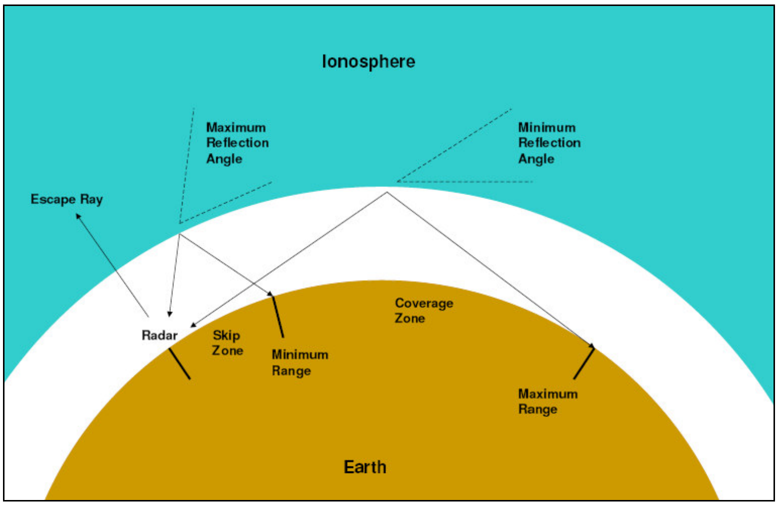

Figure 9: Geometry of Coverage using Ionospheric Reflection

This concept is shown in figure 9 and it can be seen that due to the geometry there are defined minimum and maximum ranges for different frequencies. The typical maximum range (taking the ionosphere and the earth's size into account) is 2000nmi (or 3800km).

For a given frequency, reflection is only possible up to a maximum elevation angle. This means that a certain minimum distance is uncovered and the first reflections will come from the skip range. The skip zone size is determined by frequency and other design considerations, but current OTH Radar systems have a minimum skip range of about 500nmi (~900km).

Practical Constraints

To achieve a low skip range, the lowest possible RF Frequency needs to be selected (see formula for refractive index). As indicated in the previous paragraph RF waves need to travel through the D-region of the ionosphere before being reflected in the F-region. The bulk of atmospheric propagation attenuation occurs in the D-region, and the attenuation varies with the inverse of the frequency (ie low frequency = high attenuation).

To achieve long range requires low elevation rays travelling long transit paths through the D- region. Low frequencies will be severely attenuated, and it will be necessary to select higher frequencies for long ranges. Several frequencies, with added complexity are required to achieve adequate coverage.

The second main constraint is that of the effective radiated power (ERP). Considerable Effective Radiated Power (ERP) is required to obtain adequate target illumination. Most OTHR systems run in the vicinity of 100 MW ERP. This ERP level is achieved using about 1 MW of transmitter power and about 20 dB of antenna gain. Higher ERPs start heating the atmosphere which in turn increases the attenuation. This becomes self-defeating and no more gain can be achieved.

Receive arrays for the JORN are in the region of 3.5km long. At 3 MHz with a wavelength of 100m we can expect a receive beam-width of approximately 100/3500=0. 0285rad=1.6º. Therefore at a range of 1000km, this translates into an angular cell width of 27.9km~30km. Because of the uncertainty of the reflection height, even using ionospheric sounders, a range resolution accuracy of better than 30km cannot be expected.

OTH Radar Practical Expectations

OTHR uses the earth's ionosphere to reflect radar signals and illuminate targets beyond the line-of-sight horizon. The density of plasma in the F region of the ionosphere (>160 km in altitude) imposes limits on the frequency range that can be used by the radar, and the variation in the plasma density over time means that the radar must be capable of adapting its carrier frequency in real time. This adds severe costs and complexity.

Radars can generally be designed that have sufficient flexibility to obtain coverage over 500–2000 nmi in good conditions, and 500–1200 nmi in conditions of strong low-lying plasma layers in the ionosphere E region (90–160 km). Large aircraft, such as commercial jets, can generally be observed 24 hours per day and located to within about 30 km of their actual position. Smaller airplanes and cruise missiles cannot be easily detected at night. In addition, the radar suffers vulnerability to outages due to disturbances in the ionosphere caused by adverse solar ("space weather") events. Furthermore, backscatter from fast-moving ionospheric irregularities in the region can cause spread-Doppler clutter that can prevent target detection.

Performance against surface targets such as ships and smaller vessels, is greatly reduced and under certain propagation conditions can be considered non-existent

Indicative Pricing

Preliminary discussions with regard to costs and feasibility were conducted with RLM of Australia. When the primary interest is in leveraging advanced system maturity to provide highly capable "current-generation" (JORN+) system(s), with as much cost take-out as technology allows, the cost was approximately R1000M per radar.

While a current-generation operations centre technology is largely acceptable, expansion of capability to reduce operator intervention is desirable. Straw man cost assuming significant JORN reuse and use of existing facility is in the region of R500M.

Overall expected system cost assuming 2 radars (each at least 180 degree coverage) and one centralised operations centre is 2.5 billion Rand. Local industry content would obviously be maximized to the extent practical.

5.2.2.2 High Frequency Surface Wave Radar (HFSWR)

High Frequency Surface Wave Radar (HFSWR) is being proposed as an effective and relatively low-cost means of providing over-the-horizon surveillance of surface vessels and low-flying aircraft in coastal regions. These radars have demonstrated the capability to detect and track surface vessels beyond 400 km range and small low-flying aircraft out to 120 km range, depending upon environmental conditions. Thus, theoretically these systems could be used to monitor activity within the full range of the exclusive economic zone.

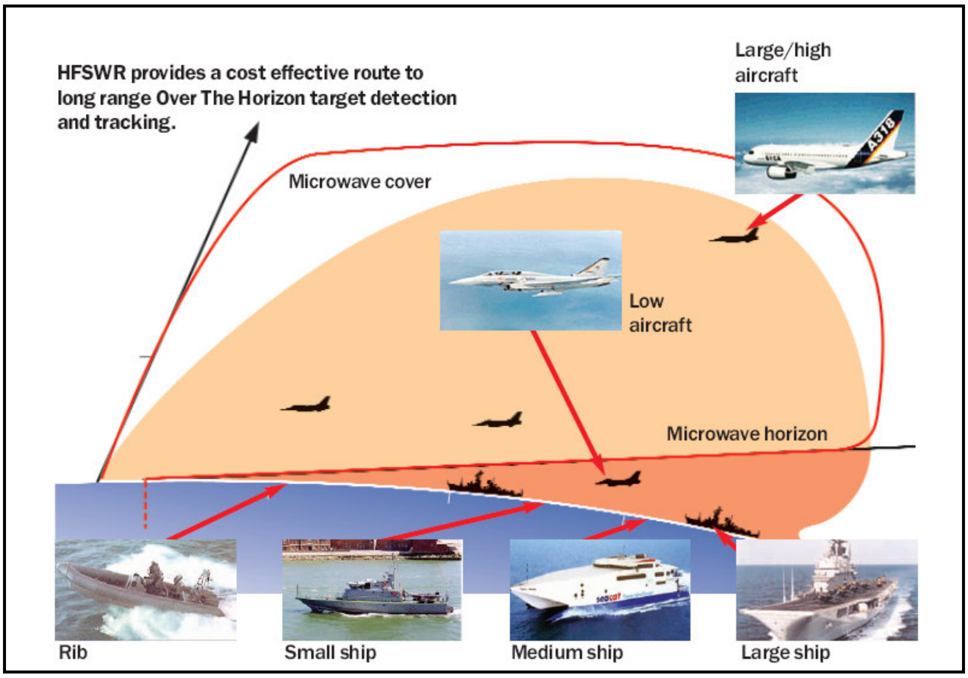

Figure 10: General Functional Illustration of HFSWR

Figure 10 shows the normal microwave coverage of normal radar and how detection of targets is limited to the microwave radar horizon. At lower frequencies in the HF Region (3-30MHz) the conductivity of the sea surface and variations in refractive index cause a tendency for waves to propagate around the surface and extend detection to beyond the microwave radar horizon. This is due to the difference in propagation speeds in the air and water and is known as diffraction.

Principle of Operation

HFSWR exploits High-Frequency (HF) signals' ability to propagate well beyond the visible horizon. This happens by diffraction over the curved conducting sea, independent of the atmosphere and ionosphere above it and is known as a Norton wave.

The single-pulse power received, Pr, by radar observing a point target is given by the well-known 2-way propagation radar formula:

$$P_r = \frac{P_t \lambda^2 G_t G_r \sigma_t F^4}{(4\pi)^3 R^4 L}$$

Where ***Pt is*** the transmitted power, λ is the wavelength, *Gt* is the gain of the transmit antenna system, ***G_r*** *is* the gain of the receive antenna system, σț is the radar cross-section of the target, ***R*** is the range to the target, ***L*** incorporates any losses such as system or atmospheric, and ***F*** is the pattern propagation factor.

This factor accounts for the effects of diffraction, refraction, reflection (multipath interference), absorption by atmospheric gases, surface roughness, and the gain pattern of the antenna. In addition, this factor includes the "ground-wave attenuation factor".

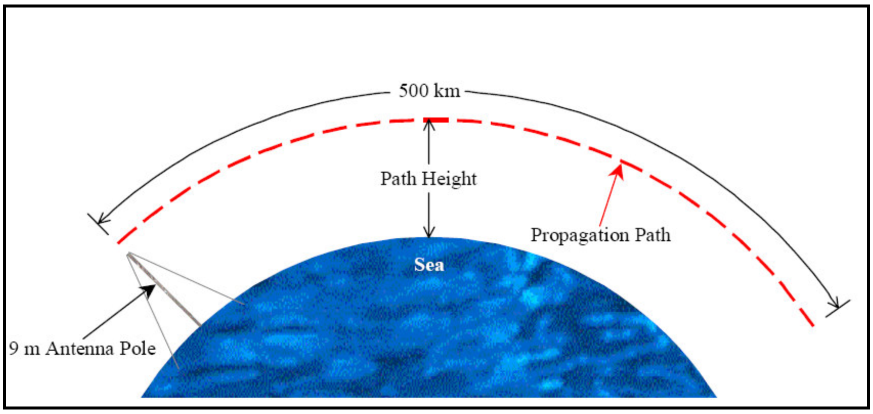

Figure 11: Geometry for the Propagation Calculations over the sea only

Claimed Performance

Raytheon Canada claims their "High Frequency Surface Wave Radar" can achieve the performance shown in the table below.

Target Size (Free Space RCS at 4MHz in dBsm)		Maximum Range		
		Sea State3	Sea State 5	Sea State 7
23dBsm (Typical 1000-3000 GRT or 12 to 50 m length vessels)	Day	Noise Limited 370km Sea Clutter Limited at 180km	Noise Limited 370km Sea Clutter Limited at 100km	Noise Limited 370km Sea Clutter Limited at 50km
	Night	Ionospheric Clutter limited at 240km	Ionospheric Clutter limited at 100km	Ionospheric Clutter limited at 50km
30dBsm (typical 2000-10000 GRT or 50 to 120m length)	Day	370km	370km	370km
	Night	Ionospheric Clutter limited at 240km	Ionospheric Clutter limited at 240km	Ionospheric Clutter limited at 240km
45dBsm (typical >10000 GRT or >120m length vessels)	Day	370km	370km	370km
	Night	Ionospheric Clutter limited at 240km	Ionospheric Clutter limited at 240km	Ionospheric Clutter limited at 240km

Table 3: Claimed Performance of Raytheon HFSWR

Expected Cost

During Summer 2003, initial request for information and proposals from the Canadian Government to DPSS suggested budgets of C$55M for purchase and installation of five HFSWR backscatter radars operating between 3-5 MHz with antennas that each require close to 1 km linear span of beach real estate.

In several articles with regard to Raytheon Canada providing Romania with 2 such systems, the costs were quoted at USD$16M for 2 systems. A Rough Order of Magnitude (ROM) cost for one such system could then be expected to be in the region of R80M to R100M.

5.2.2.3 Automatic Identification System (AIS)

The following is extracted from the US Coast Guard Navigation Centre Website:

“Picture a shipboard display system (e.g. radar, ECDIS, chart plotter, etc.) with overlaid electronic chart data that includes a mark for every significant ship within radio range; each as desired with a velocity vector (indicating speed and heading). Each ship "mark" could reflect the actual size of the ship, with position to GPS or differential GPS accuracy. By "clicking" on a ship mark, you could learn the ship name, course and speed, classification, call sign, registration number, and other information. Manoeuvring information, closest point of approach (CPA), time to closest point of approach (TCPA) and other navigation information, more accurate and timelier than information available from an automatic radar plotting aid, could also be available. Display information previously available only to modern Vessel Traffic Service operations centres could now be available to every AIS-equipped ship.

With this information, you could call any ship over VHF radiotelephone by name, rather than by "ship off my port bow" or some other imprecise means. Or you could dial it up directly using GMDSS equipment. Or you could send to the ship, or receive from it, short safety-related email messages”.

AIS are a system used by ships and Vessel Traffic Services (VTS) mainly for locating and identifying ships. It consists of a standardised VHF transceiver system coupled to an electronic navigation system, such as GPS or LORAN-C. It is also normally interfaced to other navigational equipment, such as the ship's log and gyrocompass. AIS provide a means for ship's to electronically exchange ship data, which includes identification, position, course and speed, with other nearby ships or VTS stations.

International Maritime Organisation (IMO).

The IMO International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted to all international voyaging ships with Gross Tonnage (GT) of 300 or more tons, and all passenger ships regardless of size (defined as Class A ships). According to Wikepedia (the free internet based encyclopedia) it is estimated that more than 40,000 ships currently carry AIS Class A equipment.

*AIS Functions***.**

The main functions of AIS are:

Collision Avoidance. AIS are used in navigation primarily for collision avoidance. When a ship is navigating at sea, the movement and identity of other ships in the vicinity is critical for navigators to make decisions to avoid collision with other ships and dangers (such as rocks and reefs). Due to the limitations of radio characteristics and because not all vessels are equipped with AIS, the system is primarily used in a "lookout" manner and to determine the risk of collision.

Vessel Traffic Services. In busy waters and harbours a Vessel Traffic Service (VTS) may exist to assist with the management of vessel traffic. In this case, the AIS serves as an additional input to provide ship and movement information which may not be available from other VTS sensors. It could also form part of a vessel traffic monitoring system, such as COASTRAD.

Aids to Navigation. AIS was developed to transmit positions and names of things other than vessels, namely, it can serve to transmit navigation aid data and marker positions. These aids can be located on shore, such as in a lighthouse, or on the water, on platforms or buoys.

Virtual or Artificial AIS. This also falls under the aids to navigation category, but in the case of Virtual AIS, it is used to transmit the position and details of a physical marker, but the transmitted signal originates from a transmitter location elsewhere. For example, an on-shore station based AIS could transmit the position of a number of channel markers, each of which is to small to carry its own transmitter. In the case of Artificial AIS, the transmitter could transmit positional data on a marker, which does not physically exist, or is a concern, which is not visible (eg submerged rocks).

Information Relay. Binary messages could be transmitted to provide information about other data such as canal water levels, lock orders and weather.

Principles of Operation

The AIS is a shipboard broadcast system that acts like a transponder, operating in the VHF maritime band that is capable of handling well over 4,500 reports per minute and updates as often as every two seconds. It uses Self-Organizing Time Division Multiple Access (SOTDMA) technology to meet this high broadcast rate and ensure reliable ship-to-ship operation.

Each AIS system consists of one VHF transmitter, two VHF TDMA receivers, one VHF Digital Selective Calling (DSC) receiver, and standard marine electronic communications links (IEC 61162/NMEA 0183) to shipboard display and sensor systems.

Position and timing information is normally derived from an integral or external global navigation satellite system (e.g. GPS) receiver, including a medium frequency differential GNSS receiver for precise position in coastal and inland waters. Other information broadcast by the AIS, if available, is electronically obtained from shipboard equipment through standard marine data connections.

All AIS-equipped ships would normally provide heading information and course and speed over ground. Other information, such as rate of turn, angle of heel, pitch and roll, and destination and ETA could also be provided.

The AIS transponder normally works in an autonomous and continuous mode, regardless of whether it is operating in the open seas or coastal or inland areas. Transmissions use 9.6 kb Gaussian Minimum Shift Keying (GMSK) modulation over 25 or 12.5 kHz channels using High-Level Data Link Control (HDLC) packet protocols. Although only one radio channel is necessary, each station transmits and receives over two radio channels to avoid interference problems, and to allow channels to be shifted without communications loss from other ships. The system provides for automatic contention resolution between itself and other stations, and communications integrity is maintained even in overload situations.

Each station determines its own transmission schedule (slot), based upon data link traffic history and knowledge of future actions by other stations. A position report from one AIS station fits into one of 2250 time slots established every 60 seconds. AIS stations continuously synchronize themselves to each other, to avoid overlap of slot transmissions. Slot selection by an AIS station is randomized within a defined interval, and tagged with a random timeout of between 0 and 8 frames. When a station changes its slot assignment, it pre-announces both the new location and the timeout for that location. In this way those vessels will always receive new stations, including those stations, which suddenly come within radio range close to other vessels. This is illustrated in the figure below.

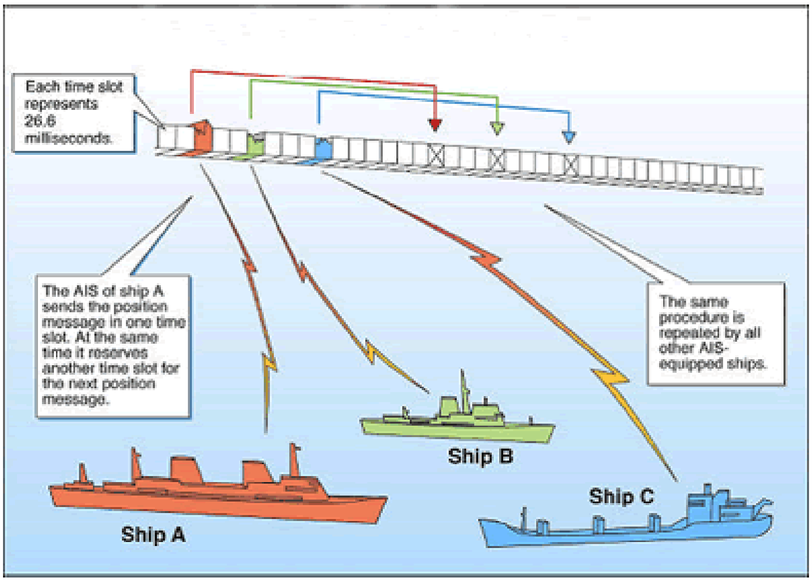

Figure 12: Illustration of Transmission Slot Arrangement - AIS

Broadcast Information

This detail is being provided only to illustrate to the reader how "rich" the information content from a simple device such as an AIS. A Class A AIS transceiver sends the following data every 2 to 10 seconds depending on the vessels speed when underway, and every 3 minutes while the vessel is at anchor. This data includes:

- The vessel's Maritime Mobile Service Identity (MMSI) – a unique 9-digit identification number
- Navigation Status – "at anchor", "underway using engine(s)", "not under command", etc
- Rate of turn – right or left in degrees per minute
- Speed over ground – 0.1-knot resolution from 0 to 102 knots
- Position Accuracy
- Longitude and Latitude – to 1/10000 minute
- Course over ground – relative to true north to 0.1 degree
- True heading – 0 to 359 degrees from gyrocompass

- Time stamp – UTC time accurate to the nearest second when this data was generated.

In addition, the following data is broadcast every 6 minutes:

- IMO ship identification number
- Radio Call Sign - international radio call sign, up to 7 characters, assigned to vessel by its country of registry
- Name – up to 20 characters
- Type of ship/cargo
- Dimensions of ship to nearest meter
- Location of positioning system (GPS) antenna onboard the vessel
- Type of positioning system - such as GPS, DGPS, LORAN etc
- Destination – max 20 characters
- Estimated Time of Arrival (ETA) at destination UTC month/date hour: minute

It can be seen from the above that a huge amount of possibly relevant information can be extracted from the main AIS messages. There are also other pre-defined messages.

Types of AIS Systems

ITU-R Recommendation M.1371-1 describes the following types of AIS:

Class A

Ship borne mobile equipment intended for vessels meeting the requirements of IMO AIS carriage requirement, and is described above.

Class B

Ship-borne mobile equipment provides facilities not necessarily in full accord with IMO AIS carriage requirements. The Class B is nearly identical to the Class A, except the Class B:

- Has a reporting rate less than a Class A (e.g. every 30 sec. when under 14 knots, as opposed to every 10 sec. for Class A)

- Does not transmit the vessel's IMO number or call sign
- Does not transmit ETA or destination
- Does not transmit navigational status
- Is only required to receive, not transmit, text safety messages
- Is only required to receive, not transmit, application identifiers (binary messages)
- Does not transmit rate of turn information
- Does not transmit maximum present static draught
- Search and Rescue Aircraft

Aircraft mobile equipment, normally reporting every ten seconds.

- Aids to Navigation

Shore-based station providing location of an aid to navigation. Normally reports every three minutes. This may eventually replace the racon.

AIS base station

- Is shore-based station providing text messages, time synchronization, meteorological or hydrological information, navigation information, or position of other vessels. Normally reports every ten seconds.

General Coverage Issues

The system coverage range is similar to other VHF applications, essentially depending on the height of the antenna. Its propagation is slightly better than that of radar, due to the longer wavelength, so it's possible to "see" around bends and behind islands if the landmasses are not too high. A typical value to be expected at sea is nominally 20 nautical miles. With the help of repeater stations, the coverage for both ship and VTS stations can be improved considerably.

IMT's experience with AIS sites mounted at heights of about 1000m, is that coverage for successful AIS data intercept of well in excess of 200km can be expected at most times.

IMO Regulations state that all SOLAS Chapter V vessels in the world be fitted with Class A AIS units (ie all passenger ships and ships over 300 tonnes, had to be fitted with AIS and be AIS compliant by 2007. All new-build vessels must be fitted prior to registration. It is estimated that 40,000 ships have been fitted and are compliant.

In addition the IMO have defined a Class B AIS unit which has lower power, and is a lower cost derivative for leisure and non-SOLAS markets. The benefits for collision avoidance and navigation assistance make the fitting of AIS to non-SOLAS vessels, such as recreational yachts and fishing vessels, a simple affordable and useful exercise. It can be expected that most reasonable seafarers would be pleased to have AIS installed, and it can be expected to become more of a norm in the future.

5.2.2.4 Coastal Radar Networks

There are already numerous coastal radar systems throughout the world. Some are autonomous and some networked, others are merely organised in groups to provide data to various users and authorities.

Single shore mounted radar can survey many hundreds of square kilometres of sea surface. A network of such radars can provide a composite wide area situational awareness picture. In order to automatically detect and identify threats, high quality target track data are needed from each radar sensor, along with sophisticated criteria to determine suspicious target behaviour. Practical solutions should also minimise operator interaction, as system cost includes the human labour needed to operate it.

Coastal Radar Network – Main Features

The coastal radar network consists of a number of coastal radars at various geographical locations, coupled via a communications network, to a central processing and display station. The main advantages of such a network are:

- By adding radars to the network, the coverage area can easily be increased
- Overlapping radar coverage can ensure the reduction of gaps in coverage
- Different types of radars could be coupled to detect specific types of targets at different ranges
- Can provide a very high probability of detection for targets, whether they are cooperative, or not, and
- Providing 24/7 real-time situational awareness to multiple remote users

The required network design elements that allow such a network to function with the above advantages are:

- Each radar node is to be connected to the network
- High performance signal processing to allow target detection and tracking is required at each node
- Real-time transmission of target data is required over a network to a central radar data server
- Compiling a maritime surveillance picture using data from each radar site and fusion with overlaps, or other sensors, by a master compiler
- Enabling user applications to connect to the server and access data as required/authorised
- Providing each user with “rich” display and post processing capability, and
- Providing for the recording and backup of all track data and information

System Design, Components and Features

Coastal radar network consists of a number of generic features/elements each covering certain aspects of compiling the surveillance picture. The most important of these aspects will briefly be discussed for each element.

Front End Radar Sensor/Transceiver.

In a coastal network, various radars could be coupled to provide sources of front-end data. Radars, which could be utilised, could be existing radars, such as Air Traffic Radars, Port Control Radars, Weather Station Radars, as well as dedicated maritime surveillance radars specifically installed for maritime surveillance purposes.

COASTRAD is an IMT designed system, which uses several existing radars, and this will be discussed later in the document. A number of different radar types could be utilised, depending on the primary area to be surveyed and the expected targets requiring detection. There are different requirements in different zones of our maritime area of interest. The main requirement is that it should be possible to interface for each and every radar and extract the required target detection and tracking signals required to conduct further processing.

The most common coastal radar networks found worldwide are based on relatively inexpensive Commercial-Off-The-Shelf (COTS) marine radars. In most cases the radars and their associated antennas are mounted on dedicated masts, or towers placed in advantageous viewing and coverage positions. These positions can be manned, or remote, and there are numerous factors influencing radar and site selection.

The most important aspects relating to type of radar and site selection are:

- Topography of the coastline
- Range and type of targets to detect and track,

- Access to facilities, such as power and communications,
- Security of installation site,
- Importance of a piece of coastline (national key points, ports or harbours, high value resources, safety at sea, etc).
- Cost of site establishment,
- Site supportability in terms of operators and logistics.

Digital Radar Processor

This is also commonly known as a plot extractor, but it could need more features and performance depending on requirements. A Digital Radar Processor (DRP) is a more generic term and will be used in this report.

The detail will be dependent on the type of radar to which it is interfacing, but typically the DRP would consist of a radar receiver video digitiser, an off-the-shelf computer (PC), specialised digital/signal processing, (possibly) display software and a network interface.

The DRP could have processing capabilities to include clutter-map generation, constant false alarm rate (CFAR) detection and various tracking and detection schemes and strategies. A stringent requirement would be the reliable detection and tracking of small, low RCS, manoeuvring targets in dense target and clutter environments. This would generally be required for inshore (less than 30km) surveillance in high traffic areas.

The DRP should send relevant target data via a network to a central Radar Data Server. Each node should be viewed as a high-quality surveillance system providing continuous target track information including geo-referenced location, speed, heading, ID, reference time and other available data.

If required, it may also be necessary to provide a remote radar control function which enables radar mode selection and scheduling, radar health monitoring, communication with an operator (if present) and perhaps even scheduling and configuring the radar to carry out specific requested surveillance tasks in real time.

Radar Network

A coastal surveillance network (which could have more than just radar data on it) is required to provide wide-area coverage by receiving sensor receive data, and also possibly providing information to remote users of remote sensors.

Each sensor node will require a modem or communications transceiver to couple it to some form of wide area communications system. In order to make a network affordable, the network could consist of COTS network technology and protocols (such as Cell phone Technology, TCP/IP, HTTP, Web Services, etc). Internet and wireless networks can be used for more affordability and flexibility.
The various nodes would then be linked to a central Sensor Data Server which collects the processed target data and information and distributes this to a number of remote users. Normally there would be a Central Monitoring Station (CMS) where information on the various targets and tracks from a number of radars/sensors are combined into a Common Operating Picture. This could also include addressing issues such as data fusion where data from multiple sensors overlap.

The received target data from the various radars will typically be stored efficiently on an industry standard Structured Query Language (SQL) database. This stored data can then be used to provide real-time or historical access to various users.
Security in such a network can also be addressed by using various forms of encryption and network architecture.

Expected Operating Envelopes

The operating envelopes are largely dictated by radar type and topographical installation data. Coverage limitations for any radar node would include range attenuation, line-of-sight horizon and shadowing caused by obstacles/land obstructions.

5.2.2.5 Existing RSA sensor system

COASTRAD

The COASTRAD system consists of a number of existing radars owned by various departments, which have undergone some modifications by IMT and networked into a central station at Silvermine. The original intention was to provide a coastal radar picture to Defence Intelligence (DI) utilising as much existing infrastructure as possible. The main radar sites are:

- An Air Traffic Control (ATC) Radar at East London (Civil Aviation)
- An ATC Radar in Port Elizabeth (Civil Aviation)
- The Weather Radar at Constantiaberg (SA Weather Bureau)
- The SAAF ATC Radar at Kapteinskop (SAAF)
- Limited radar data from port traffic control radars in Durban and Cape Town.

COASTRAD Network Structure

The operation of these various sites was achieved by means of a Digital Radar Processor (DRP), or Plot Extractors, developed by Messrs P. Botha and J. Theron of IMT. These processors extracted target (plot) data from the radar signal and stored the various tracks in digital format. These DRPs were originally coupled via modems to the TELKOM telephonic network to the central site at Silvermine.

Subsequently, the communications between plot extractors and the central site has been upgraded for near real-time data updates using an MTN hosted Virtual

Private Network (VPN) incorporating multilayer security over DSL/Diginet network.

COASTRAD Radar Coverage

Figure 13: COASTRAD Radar Coverage Areas shows an optimistic coverage diagram for the various radar systems currently coupled into the COASTRAD system. The reasons that this is optimistic are:

- The radars shown are not on 24 hours a day, seven days a week
- The coverage shows the range of each radar being fully operational, and this is often not the case.

There are a number of challenges/shortcomings with the existing radars being used by the COASTRAD system. These are:

- They belong to various parties who are not necessarily concerned with maritime surveillance (Weather Bureau, SAAF, Civil Aviation, etc).
- The coverage diagrams do not show shaded areas where detection of targets may be screened by obstructions such as hills or adjacent land masses (some of these radars do not have unobstructed lines of sight to all the sea areas – their primary function is detection of aircraft, not ships).
- The radars have different designs and waveforms, which are not necessarily optimised for surface target detection and tracking.
- They do not all have planned and coordinated support and maintenance schedules (often breakdown).

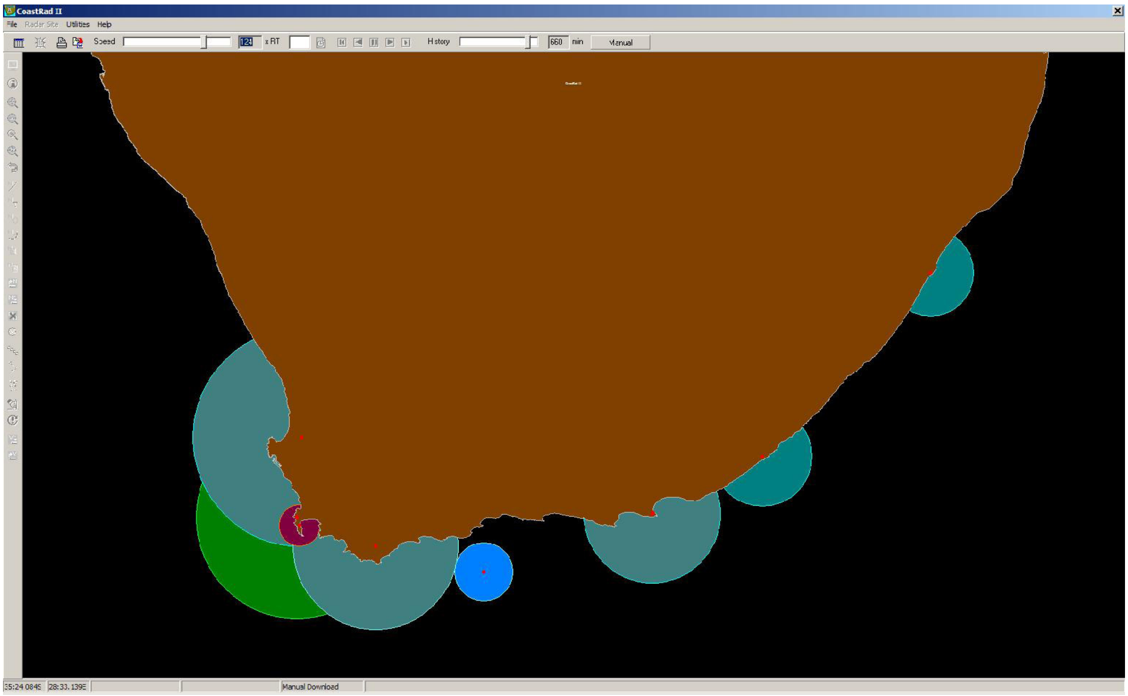

Figure 13: COASTRAD Radar coverage areas

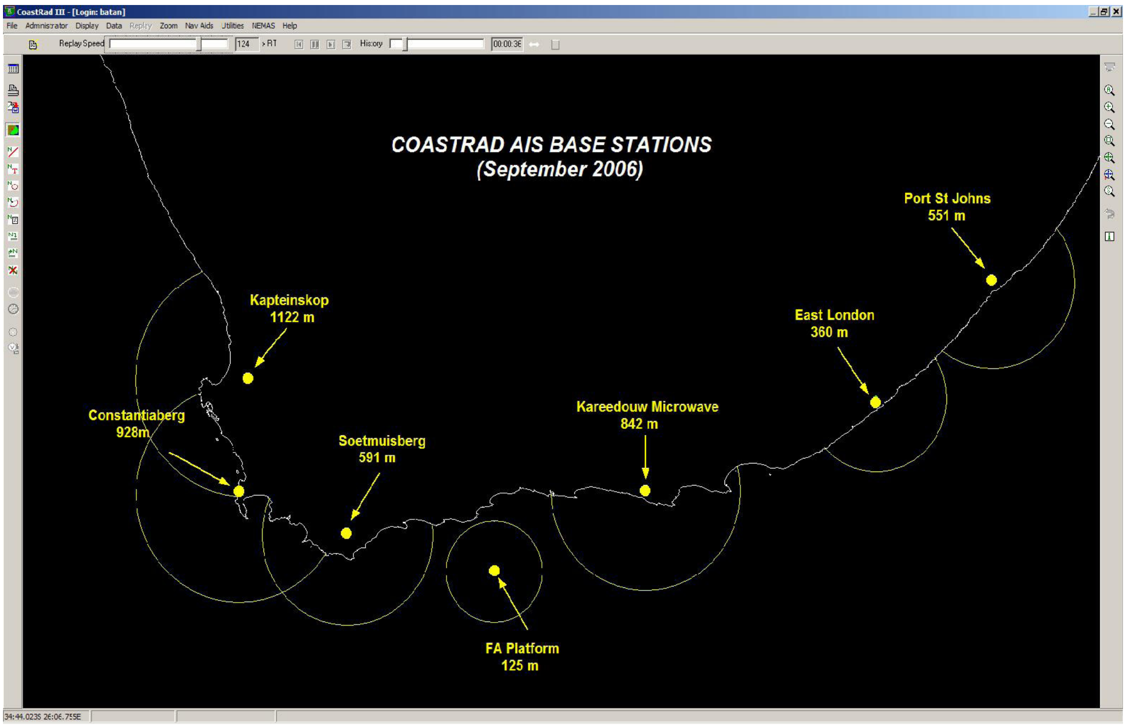

Figure 14: COASTRAD System AIS coverage as at October 2006

Maritime Patrol Aircraft

The SANDFs maritime patrol aircraft (MPA) have been reduced from a squadron of Shackleton and Albatross of dedicated MPAs to a single Dakota with a limited maritime surveillance capability.

With this situation, the lack of availability, potential coverage and poor persistence reduce the contribution that these aircraft can make to a broader integrated maritime picture to the point where their contribution may be considered to be neglible. Their primary use can now be considered mainly for dedicated Search and Rescue Operations and specific tasks investigation of smaller areas or targets, as requested. With the exception of carrying weapons and rapidly being able to respond to counter maritime threats, their surveillance functions can be addressed by many UAV systems available worldwide. Statements made for UAV sensors are generally applicable to MPAs as well.

Recently the SAAF has incorporated an AIS system in the Dakota, but this is still in testing phase and therefore has not been implemented completely.

SUPPORT TECHNOLOGIES

Geographical Information Systems (GIS)

Geographic Information System (GIS) is a system of computer software, hardware, methods, data and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. A GIS links locational (spatial) and database (tabular) information providing an entirely new perspective to data analysis that cannot be seen in a table or list format. GIS provides the ability to view, understand, question, interpret, and visualize data in many ways that reveal spatial relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS stores information about the world as a collection of thematic layers that can be linked together by geography/location. This simple but extremely powerful and versatile concept has proven to be invaluable for solving many spatial related problems.

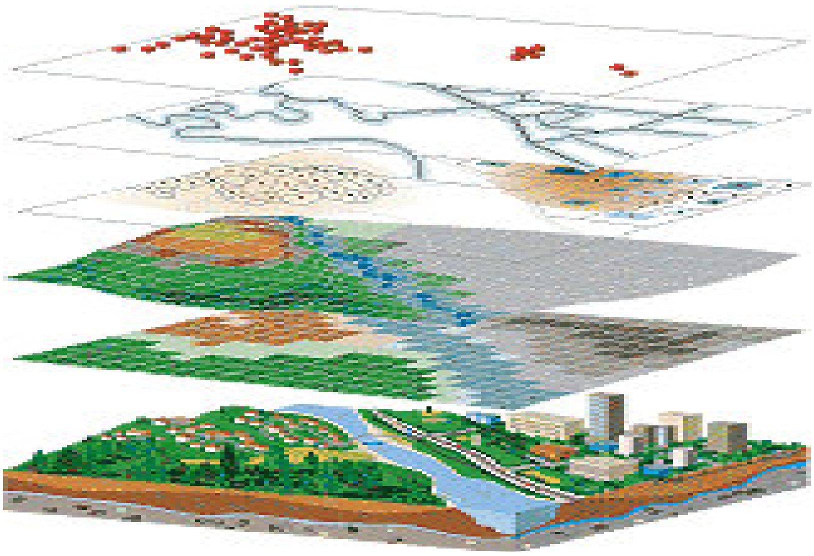

Figure 15: GIS Thematic Layer Concept

A GIS is most often associated with a map, however it is not the only way you can work with geographic data in a GIS. A GIS can provide a great deal more problem solving capabilities than using a simple mapping program or adding data to an online mapping tool.

The three perspective views of a GIS are as follows:

1. **The Database View:** A GIS is a unique kind of spatial database of the world a geographic database (geodatabase). It is an "Information System for Geography." The name combines *geo* (referring to spatial) with *database*—specifically, a relational database management system (RDBMS). The term promotes the idea of having all GIS data stored uniformly in a central location for easy access and management.

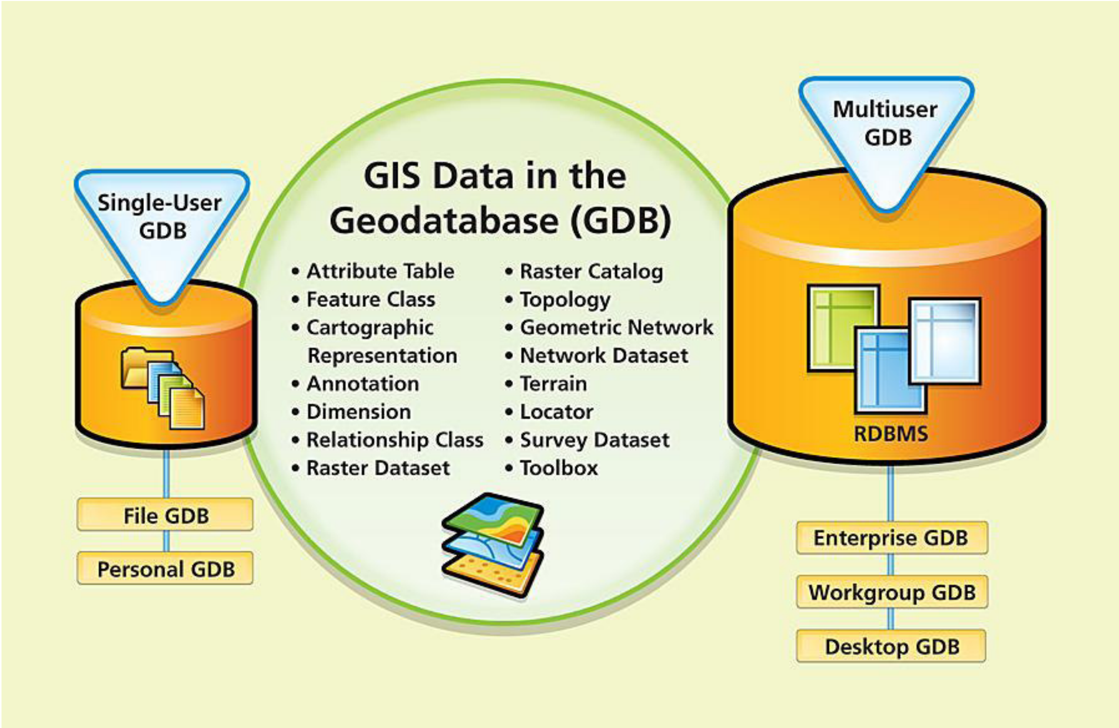

Figure 16: GIS Geodatabase View

The geodatabase is the primary data storage model for ArcGIS (ArcGIS is a proprietary software product used by IMT and many other agencies). It is a container of spatial and attributes data and enables the user to store many different types of GIS data within its structure. Its structure is implemented in an RDBMS or as a collection of files in a file system. With its comprehensive GIS data model, geospatial modeling capabilities, and scalable architecture, the geodatabase is the foundation that enables the assembling of intelligent geographic information systems that can be adapted for many different GIS applications.

2. **The Map View:** A GIS is a set of intelligent maps and other views that show features and feature relationships on the earth's surface. Maps of the underlying geographic information can be constructed and used as "windows into the database" to support queries, analysis, and editing of the information.

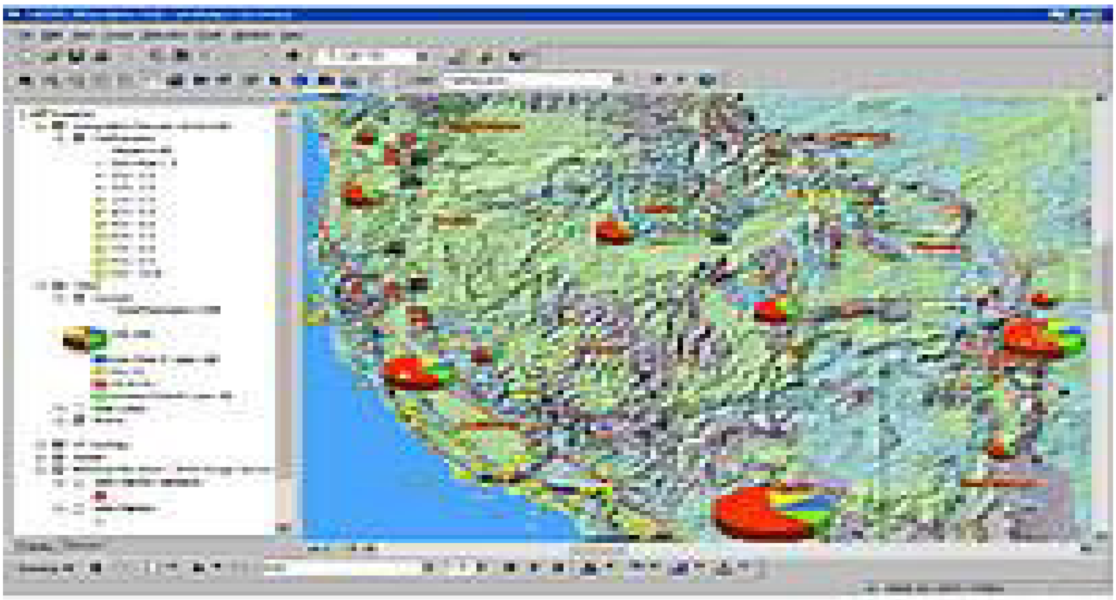

Figure 17: GIS Map View

3. **The Model View:** A GIS is a set of information transformation/ geoprocessing tools that derive new geographic datasets from existing datasets. These geoprocessing functions take information from existing datasets, apply analytic functions, and write results into new derived datasets.

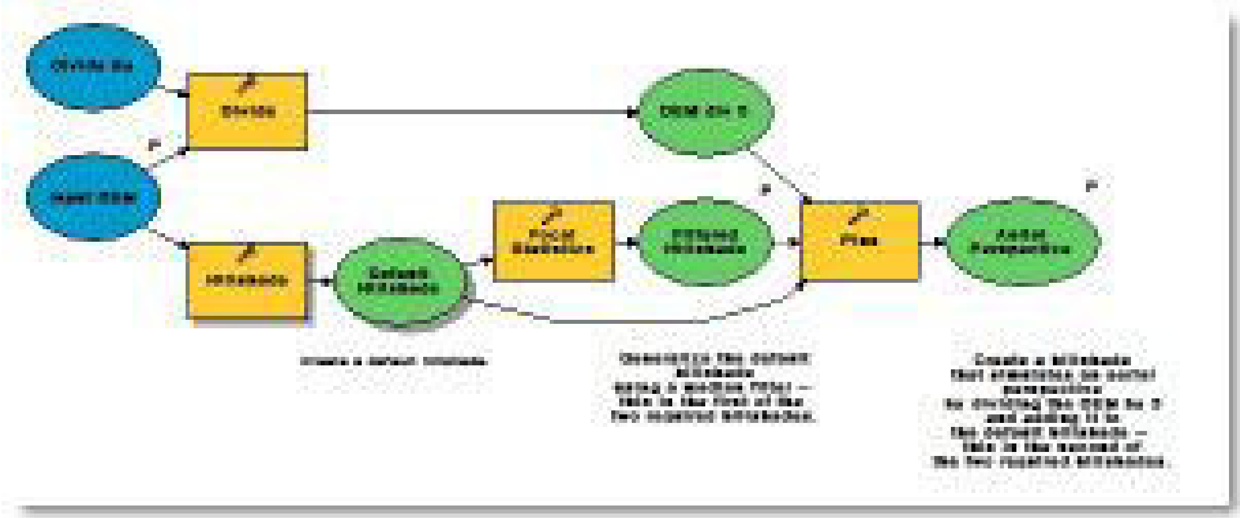

Figure 18: GIS Model View

SANDF Databases

Several databases exist in the SANDF which can augment and add value to information being displayed in the Integrated Maritime Picture. Examples of these are:

- Ship Information System (SIS) Defence Intelligence (DI), under the auspices of Directorate Electronic Collection (DEC) has a Subsection Shipping Information, Display and Analysis Section (SIDAS). The purpose of SIDAS is to gather information to be included into the already available comprehensive information on the Shipping Information System (SIS) with the real-time positional information provided by the AIS sensors along the RSA coast. This together with information gathered from the National Ports Authorities (NPA) Vessel Track Management System (VTS) and the Department of Environmental Affairs and Tourism's (DEAT) Marine and Coastal Management (MCM) Vessel Management System (VMS) would enable this Subsection to provide comprehensive inputs to the compilation of an Integrated Maritime Picture.
- Radar Library and Intercept Database. Databases exist for the recording of geographic locations of radar sites, together with ELINT parameters. This data could be interfaced and displayed as required when vessels are moving into areas where intelligence data is available.

5.2.3 Operational Control Centre

It appears from discussions with various parties that due to the local expertise and existing systems, Defence Intelligence (DI), Directorate Electronic Collection (DEC), Subsection Shipping Information, Display and Analysis Section (SIDAS) could be earmarked as the hub for maritime information for all government departments. The main reason for this is that this Subsection has the experience and most of the assets required to support the initiative. SIDAS group at Silvermine would be the logical location to form the centre for a national

Integrated Maritime Picture as they are already monitoring all available ship movements and the information associated with each identified ship Irrespective of who is given the ultimate responsibility for manning and running such a centre, it appears that there is a distinct need for a National Maritime Surveillance Centre (NMSC).

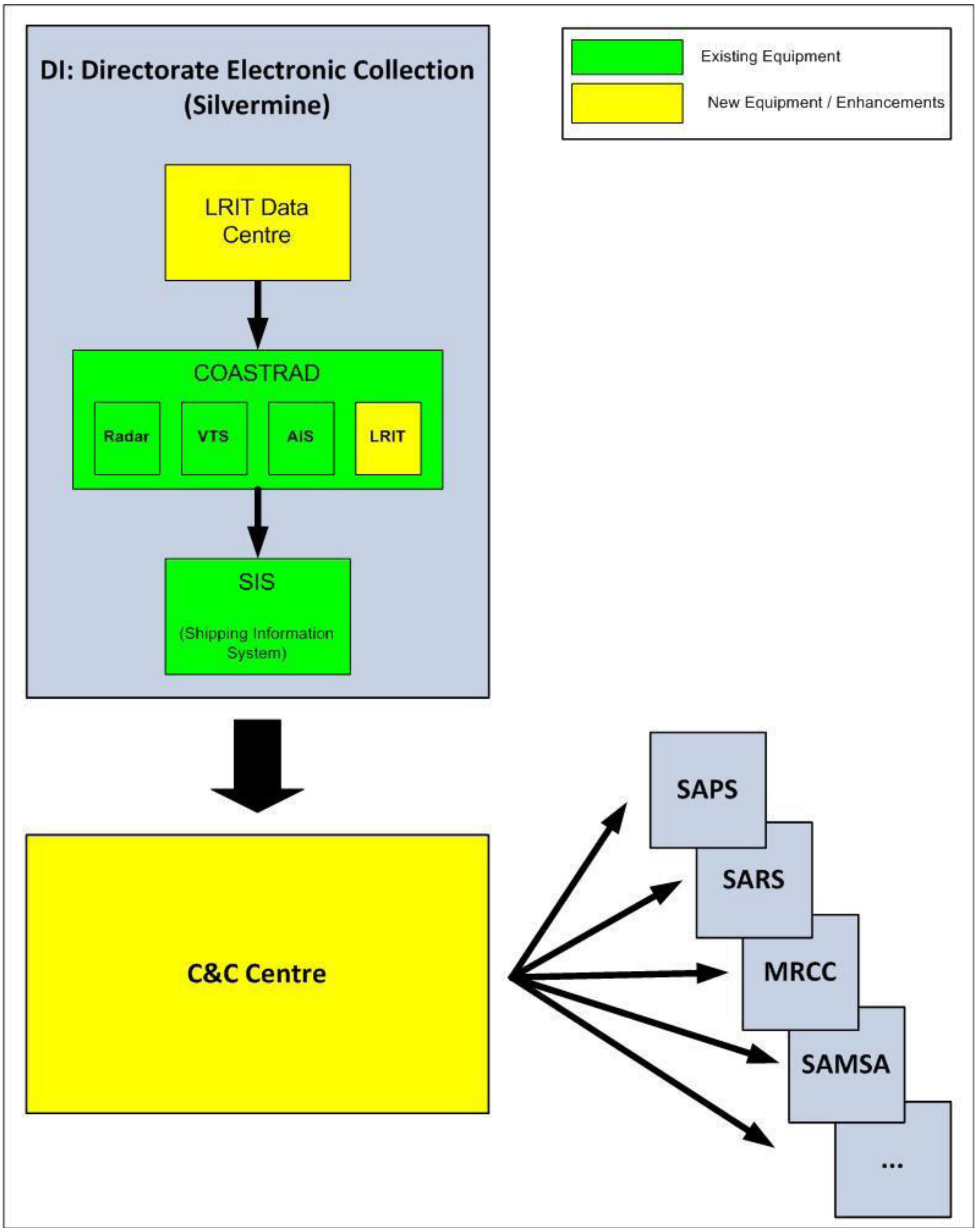

Figure 19: Propose National Surveillance Centre

Such an NMSC would require:

- The necessary communications networks with the remote sensor sites.
- An operations centre with the necessary displays and operator work stations.
- A computer network infrastructure with the necessary redundant backups and storage facilities to ensure reliability and integrity of data.
- A communications infrastructure for dissemination of data to the various identified users.
- Localised applications processors and displays at the various remote user sites.
- The human resources to provide continual monitoring and control of the data.
- The necessary support infrastructure to support both the NMSC and sensors.

If this centre is to also include and LRIT Data Centre, capable of tracking the South African Registered vessel(s) and conforming to all LRIT performance standards and regulations, this will have to meet the requirements set by the IMO.

Distribution of Information

Ultimately the SANDF is responsible to provide the sovereign protection to the people of the RSA and, as such, all data gathered and collated shall be available to the SANDF to carry out its duties. The distribution of the data gathered by this centre within the SANDF shall be determined solely by the SANDF and it is not within the scope of this study to address this issue.

The data and information required by the various government departments, or contributing agencies, needs to be addressed in a further study and a data distribution plan needs to be compiled.

Potential Interoperability, Scalability and Upgradeability

By adopting a layered and multisensory approach, as well as using multiple inputs for intelligence and geophysical information, the system must by its nature designed to take potential scalability and upgradeability into account. In this regard, latest advances in ICT in the SANDF environment shall direct the design of the architecture and computer hardware and software.

The standards and architectural requirements as defined by CJOPS and CMI shall be adopted and followed as far as is practical. In particular, for military communications with operational units Combat Network Interoperability Standard (CNIS) and LINKZA standards shall be adopted.

Use of Commercial Off The Shelf (COTS) Technologies

Homeland security applications for radar and sensors differ fundamentally from most military applications. The high price of military sensors is justified by the critical and urgent need for protection in combat zones or near high value assets. Homeland security, by contrast, deals with threats that materialise infrequently and can occur anywhere over vast areas. Surveillance to counter such threats must be deployed simultaneously across huge areas on a permanent 24/7 basis. Therefore, low cost is a fundamental requirement for sensors used in this application.

Typically, in the coastal surveillance zone, COTS marine radar with its antenna shall be used. Sensor to centre communications should also, as far as possible, make use of commercially available communications systems and infrastructure.

5.2.4 Cost Analysis – Feasibility Study

A cost analysis will be done to determine how well, or how poorly, the planned implementation will turn out. This analysis is based on financial terms, determining how viable the concepts and their implementation are, financially.

Since SANDF would be the primary user of the information of the Maritime Surveillance System they can incorporate these costs into their budget for the following financial year. The evaluation process of the feasibility of the project will be performed using After-Tax Economic Analysis. This method transforms before tax cash flow (BTCF) estimates into after tax cash flow (ATCF). This method considers the important effects of tax over the life of the project. (Blank and Tarquin, 2005). The (BTCF) and (ATCF) indicate the actual flow of money in and out of SANDF budget that will be yielded by the execution of the project.

The MARR is (Minimum Attractive Rate of Return). A Net Present Value (NPV) is representation of the monetary value of the entire project at a time deemed the present.

The analysis list the cash flow generated by the project, and then deducts depreciation of machinery and the tax incurred. The cash flows are then moved, considering the effects of time and rate of return, backwards throughout the project life into the present. The value generated is the Net Present Value (NPV). A positive net present value means the project is viable. Table 4 contains the data needed to successfully compute the NPV. The rest of the calculation is given below.

Element	Value
Before tax MARR	10%
Effective tax rate	40%
Tax life	10 years
Project life	20 years

Table 4: Calculation Data

After tax MARR = MARR (Before tax)*(1-Tax rate)

= 10%(1-0.4)

= 6%

If the MARR value after tax is < then the MARR value before tax means that this would most likely result in a positive NPV value. Net Present Value (NPV) >0, therefore the project is economically viable.

5.3 Conclusion

SANDF is under increasing pressure from a variety of sources to adopt better methods and approach to their maritime surveillance problem, particularly in the context of technical innovation. Whilst there is some data which confirms their efforts through their acquiring of systems used by IMT, there is also contradictory evidence.

The literature study shows that although the trend towards the use of technology and more efficient simulation models is recognized as important, it is not yet well-understood and is receiving comparatively little attention, particularly in the form of empirical research into more effective and economic maritime surveillance solutions.

The document contains all the necessary literature for the purpose of understanding the problem, innovative and at a later stage authentic ideas/concepts and a sound implementation plan. Looking at the Existing COASTRAD system run by IMT and the pitfalls they are experiencing could lead to remedial measures being put in place.

The project execution, through adhering to the scope and striving to deliver the deliverables could have the following advantages:

- Early warning to possible threats
- Quicker response time to possible threat and
- Optimization of limited resources.

The report reflects a summary of the understanding of existing surface. The deliverables outlined in the project proposal document were executed. The resource allocation mathematical formulation is generalized to simplify the problem making it possible to formulate and implement a resource allocation system. The system operation is driven by the model developed. The model serves as a tool used in the process of allocating resources where it is most needed. It is evident, through the cost analysis, that the project is feasible as the gain (return) is much larger than the loss (cost).

It is necessary to look at the aspects of the report when developing an Integrate Maritime Picture.

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