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International Association of Marine Aids to Navigation and Lighthouse Authorities

IALA

AISM Association Internationale de Signalisation Maritime

IALA Guideline No. 1111

on

Preparation of Operational and Technical Performance Requirements for VTS Systems

Edition 1

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
Edition 1 May 2015	Originated from IALA Recommendation V-128, edition 3.	Annex from former Recommendation changed to Guideline and revised to include additional considerations, new technologies and emerging technologies. Additionally consistency has been improved and duplications were removed.

Preamble

This guideline presents a common source of information to assist Competent Authorities and VTS Authorities in the preparation and establishment of operational and technical performance requirements of standards and specifications for VTS systems. Tailoring is required to capture the specific and relevant performance requirements from the generic information included within this document. The Guideline shall not be used as a specification without such tailoring.

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Abbreviations

º	Degree
±	Plus or minus
>	Greater than
≤	Less than or equal to
≥	Greater than or equal to
µs	microsecond
A R and M	availability, reliability and maintainability
AIS	Automatic Identification System
AREPS	Advanced Refractive Effects Prediction System
ASL	Above Sea Level
AtoN	Aid to Navigation
BITE	Built In Test Equipment
BoM	Bureau of Meteorology (Australia)
C	Celsius
CARPET	Computer Aided Radar Performance Evaluation Tool
CAT	Customer Acceptance Test
CE	Conformité Européenne
CHC	Canadian Hurricane Centre
CCTV	Closed-Circuit Television
COG	Course over Ground
COSPAS/SARSAT	Search and Rescue Satellite-Aided Tracking
CPA	Closest Point of Approach
CPHC	Central Pacific Hurricane Centre
CW	Continuous Wave
dB	deciBel
dBi	deciBel isotropic
dBm	deciBel milliWatt
DF	Direction Finder
DSF	Decision Support Function
DST	Decision Support Tool
D-GNSS	Differential GNSS
ECC	Electronic Communications Committee
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
EIA	Electronics Industry Association
ELT	Emergency Location Transmitter
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Electro-Optical
EOS	Electro-Optical Sensor
EPIRB	Emergency Position Indicating Radio Beacon
ERC	European Research Council
ETA	Estimated Time of Arrival
EU	European Union
F	Fahrenheit
FAT	Factory Acceptance Test
FATDMA	Fixed-Access Time-Division Multiple Access
FMCW	Frequency Modulated Continuous Wave
FMS	Fiji Meteorological Service
FoV	Field of View
GHz	GigaHertz
GIT	Georgia Institute of Technology
GLOSS	Global Sea Level Observing System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System

GOOS	Global Ocean Observing System
GPS	Global Positioning System
HDF	Hierarchical Data Format
HMI	Human / Machine Interface
hPa	hectoPascal
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ICAO	International Civil Aviation Organization
ID	Identification
IDC	International Data Centre (for LRIT)
IEC	International Electro-Technical Commission
IEEE	The Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IMD	Indian Meteorological Department
IMO	International Maritime Organization
INS	Information Service
IOC	Intergovernmental Oceanographic Commission
IP	Ingress Protection
IP	Internet Protocol
IT	Information Technology
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radiocommunication
JMS	Japan Meteorological Service
JTWC	Joint Typhoon Warning Center
Ka-band	26.4 – 40 GHz
kg	kilogram
kHz	kiloHertz
km/h	kilometre/hour
Ku-band	12.0 – 18.0 GHz
kW	kiloWatt
LAN	Local Area Network
LNFE	Low Noise Front End
LPS	Local Port Services
LRIT	Long Range Identification and Tracking
LVD	Low Voltage Directive
m	metre
m/s	metre/second
m^2	square metre
m^3	cubic metre
MDS	Minimum Detectable Signal
MFR	Météo France
MHz	MegaHertz
MKD	Minimum Keyboard and Display
mm/hr	millimetre per hour
MMSI	Maritime Mobile Service Identity
MOB	Man over board
MPA	Marine Protected Area
MPEG	Moving Pictures Expert Group
mph	miles per hour
MRCC	Maritime Rescue Co-ordination Centre
MSC	Maritime Safety Committee (of IMO)
MTBF	Mean Time Between Failure
MTI	Moving Target Indication
MTTR	Mean Time to Repair
NAS	Navigational Assistance Service
N/A	Not applicable

NHC	National Hurricane Centre
NIMA	National Imagery and Mapping Agency
NM	Nautical Mile
NMEA	National Marine Electronics Association
NTIA	National Telecommunications and Information Administration
OFTA	Office of the Telecommunications Authority
PC	Personal Computer
P_D	Probability of Detection
P_{FA}	Probability of False Alarm
POB	Persons on-board
PRF	Pulse Repetition Frequency
PSLR	Peak Side Lobe Ratio
PSS	Practical Salinity Scale
PTZ	Pan, Tilt, Zoom
PW	Pulse Width
R	Range (also ρ)
RADAR	Radio Detection and Ranging
RAID	Redundant Array of Independent Disks
RATDMA	Random Access Time-Division Multiple Access
RCS	Radar Cross Section
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical substances
RF	Radio Frequency
RDF	Radio Direction Finder
RH	Relative Humidity
RMP	Recognized Maritime Picture
RMS	Root Mean Squared
RoHS	Reduction of Hazardous Substances
R&TTE	Radio and Telecommunications Terminal Equipment
SAIS	Satellite AIS
SAR	Search and Rescue
SART	Search and Rescue Transponder
SAT	Site Acceptance Test
S-band	2.0 – 4.0 GHz (Note: military designation is F-band)
SLA	Service-Level Agreement
SOG	Speed over Ground
SOLAS	Safety of Life at Sea
SOTDMA	Self-Organising Time-Division Multiple Access
SPA	Special Protected Area
SS	Sea State
STC	Sensitivity-Time Control
TBA	To Be Advised
TCPA	Time to Closest Point of Approach
TDMA	Time-Division Multiple Access
TOS	Traffic Organization Service
UCAR	University Corporation for Atmospheric Research
UPS	Uninterruptable Power Supply
US	United States (of America)
UTC	Universal Time Co-ordinated
UTM	Universal Transverse Mercator
VDL	VHF Data Link
VHF	Very High Frequency
VoIP	Voice over Internet Protocol
VTMIS	Vessel Traffic Management and Information System
VTS	Vessel Traffic Services
VTSO	Vessel Traffic Services Operator

W	Watt
WMO	World Meteorological Organization
X-band	8.0 – 12.0 GHz (Note: military designation is I-band)
XML	Extensible Mark-up Language

1 CORE OPERATIONAL AND TECHNICAL REQUIREMENTS

1.1 Introduction

The main purpose of this document is to assist the VTS Authority in preparing the definition, specification, establishment, operation and upgrades of a VTS system. The document addresses the relationship between the Operational Requirements and VTS system performance (Technical) requirements and how these reflect into system design and sub system requirements.

The document presents system design, sensors, communications, processing and acceptance, without inferring priority:

- Core Operational and Technical requirements;
- Radar;
- Automatic Identification System (AIS);
- Environmental Monitoring;
- Electro-Optical equipment;
- Radio Direction Finders;
- Long Range sensors;
- Radio Communications;
- Data Processing;
- Human / Machine Interface (HMI);
- Decision Support;
- External Information Exchange;
- Verification and Validation.

1.2 Definitions and References

1.2.1 Definitions

VTS Equipment – within this document, VTS Equipment refers to the individual items of hardware and software which make up the VTS System.

VTS System – within this document, the VTS System is considered to be the hardware software and their behavior as a coherent entity. This excludes personnel and procedures.

Within this document, reference is made to three different levels of equipment capabilities; Basic, Standard and Advanced. In the specification of VTS, the Authority should determine the required performance for situational awareness, and associate this to the level of capabilities described in this document. This process should also consider the relationship between capabilities and system cost. The required performance is likely to vary in different parts of the VTS area.

1.2.2 References

[1] Convention on Safety of Life At Sea (SOLAS 1974) (as amended).

[2] IMO Resolution A.857(20) - Guidelines for Vessel Traffic Services (1997).

[3] IALA Vessel Traffic Services Manual.

[4] IALA Recommendation V-103 - On Standards for Training and Certification of VTS Personnel.

[5] IALA Recommendation V-119 – The Implementation of Vessel Traffic Services

[6] MIL-STD-810G - Environmental Engineering Considerations and Laboratory Tests.

1.3 Establishing the Requirements for a VTS System

The Operational requirements should form the basis for the entire system lifecycle, its definition and its verification and validation following implementation.

The Operational requirements are defined in accordance with V119 [5] (Implementation of Vessel Traffic Services) and these are used to derive the technical requirements.

1.3.1 Operational Requirements

The operational requirements needed to derive the system concept and technical requirements should consider:

- Delineating the VTS area and, if appropriate, VTS sub-areas or sectors;
- Type of services to be provided (INS, TOS, NAS);
- Types and sizes of vessels which are required or expected to participate in the VTS;
- Navigational Hazards and traffic patterns;
- Human factors including health and safety issues;
- Tasks to be performed by System users;
- Operational procedures, staffing level and operating hours of the VTS;
- Co-operation with external stakeholders;
- Physical security of the VTS Centre and remote sites;
- Business continuity, availability, reliability and disaster recovery;
- Legal framework.

1.3.2 Deriving the System Level Technical Requirements

The technical requirements should be derived from the operational requirements. This may be an iterative process, which can be aligned with the phases of IALA Recommendation V119 'On the Implementation of Vessel Traffic Services' as illustrated by Figure 1.

In order to define technical requirements the operational requirements may be grouped into:

- Communications;
- Situational awareness;
- Recording and playback;
- Reliability and Availability;

The grouping of operational requirements facilitates the creation of technical requirements, for example divided into:

- Voice and data communication;
- The VTS centre, sites, sensors and processing;
- Recording and replay incl. Post Situational Analysis;
- Redundancy and Resilience;

The provisional system concept and the associated technical requirements are input to the provisional risk assessment and cost assessment. Depending on the outcome the system concept and requirements may need to be reassessed prior to the Formal Risk Assessment and Cost Benefit Analysis phases.

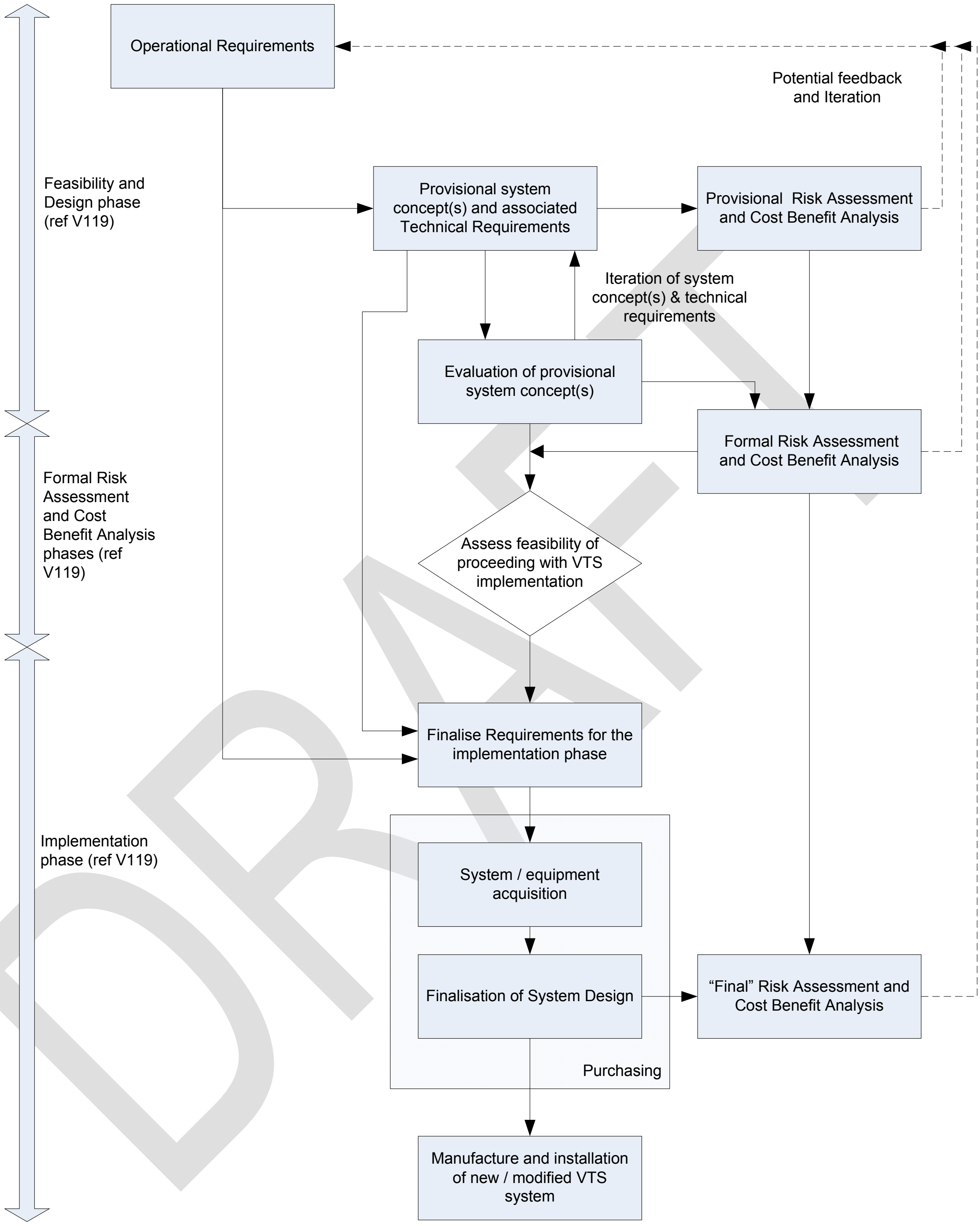

Figure 1 Deriving implementation from operational requirements

Deriving system concepts may involve various mathematical, functional and simulation models to visualise different characteristics of the system. Models to consider might include:

- Radio communications coverage;
- Sensor coverage;
- Communications network infrastructure;
- Data architecture and interfaces;
- Reliability and Availability including any redundancy options;
- Lifecycle costs;

The models could assist in establishing the relationship between the system concepts, associated technical requirements and the operational requirements. Feasibility studies (site surveys, equipment trials etc.) may also be appropriate to reduce technical risks which may otherwise not be apparent until implementation.

Additional technical requirements may come from:

- Environmental considerations;
- Legal obligations;
- Ergonomic issues
- Safety (other than navigational safety);
- Security requirements;

After completion of the system concept and associated technical requirements, the result should be input to the Formal Risk Assessment and Cost Benefit Analysis.

Completion of the Cost Benefit Analysis leads to the decision to proceed with implementation.

The first activity in the implementation phase is finalising the requirements. This involves combining the relevant operational requirements with the technical requirements, without unintentionally restricting flexibility in the implementation.

It is important to write well-structured, individual requirement statements within the published requirements documentation.

Note that, for the implementation, several possible technical solutions may be identified to achieve the operational requirements and each of these solutions may have different strengths and weaknesses. Scoring systems to address the most critical aspects of the operational requirements may be appropriate.

1.4 Technical Implementation considerations

Implementation of a VTS system requires consideration of:

- VTS Centre location(s);
- Available land and suitability of sensor sites;
- Sensor and radio coverage;
- Overlapping coverage and equipment redundancy;
- Existing infrastructure such as power and data lines;
- Communications routes;
- Environmental constraints and impact;
- Operating conditions such as wind, influence from sea, precipitation and possibly ice;
- Electromagnetic issues (EMI/EMC),
- Applicable regulations and required licenses (transmission, building etc.);
- Selection of installation sites with due respect to neighbours.

- Security and site access;

Any VTS system should, as a minimum, be equipped with a means to build a traffic image as well as providing reliable communications.

The system architecture should carefully consider issues such as:

- Bandwidth requirements;
- Redundant data paths;
- Data integrity;
- Data link security;
- Voice communication and associated latency;
- Reporting and maintenance facilities.

In addition, the architecture should have built in flexibility for future upgrades and have the capability to be maintained without impacting routine VTS operations.

During the development of the system architecture, comprehensive site surveys could be performed, including but not limited to the above considerations. Involvement of relevant stakeholders in the site survey early in the process adds value and ensures awareness of design and performance issues.

1.4.1 Availability and Reliability

Availability and Reliability figures for the overall system should be defined by the VTS authority based on the Risk assessment results, from which individual equipment reliability may be derived. Relations between downtime and availability figures are given by Table 1.

Table 1 Relation between downtime and availability

Availability			
Annual downtime	24 hours	8 hours	4 hours
Corresponding Availability	99.7%	99.9%	99.95%

Note that multiple means of communications and multiple sources of sensor information may result in reduced requirements for the availability of each item of equipment individually.

Availability figures apply to systems and individual equipment, including both hardware and software. Scheduled maintenance activities are also included in the availability figures.

Also note that if required spare parts are not readily available, the extended time to repair will decrease the availability figures. Therefore, VTS authorities should plan for sufficient spare parts and service arrangements in order to meet the availability criteria.

The system availability can be improved by the following redundancy measures:

- By duplicating equipment at individual sensor sites and in the communication with sensors. In such cases, parameter hand-over from active to stand-by equipment should be considered;
- Between sensors, where overlap can provide redundancy, possibly with reduced performance;
- Between various types of sensors, where overlap can provide redundancy, possibly with reduced performance.
- By adding graceful degradation capabilities to individual equipment

1.4.2 Recording, Archiving and Replay

Within legal limitations, provision should be made for the storage, security, retrieval and presentation of VTS data.

The data type, resolution and period of time for which data gathered by a VTS is required to be stored should be derived from operational procedures. The time period should allow for the full retrieval of data post-incident/accident, in compliance with national requirements and those of the incident/accident investigation procedures of the VTS Authority and other authorised parties.

A minimum of 30 days storage capacity is recommended. Archiving of older data may be considered.

Stored and archived data should include:

- Communications;
- Sensor and track information;
- Shipping information;
- Meteorological and hydrological information;
- Information from other sources if relevant;

The data should be recorded automatically and be capable of replay without impact to on-going VTS operations. Synchronisation of information is recommended for replay

1.4.3 Design, Installation and Maintenance Considerations

1.4.3.1 Climatic Categories for outdoor installations

The VTS authority should specify conditions for outdoor installations. Part three of MIL-STD-810G - Environmental Engineering Considerations and Laboratory Tests [6] provides appropriate planning guidance for realistic consideration of climatic conditions.

“Basic”, “Hot”, “Cold” and “Severe Cold” categories are defined and guidance on e.g. Coastal/Ocean, hot dry and hot humid considerations can be found. The document is very detailed and includes a description of daily cycles etc.

1.4.3.2 Wind Considerations

Wind specifications will have a considerable impact on the cost of equipment and civil works. It is recommended to specify operational requirements with a safety margin, recognising the possibility to cease VTS operations in extreme conditions. Equipment survivability may have to be achieved by shutdown, associated protective measures and relaxation of operational requirements under those conditions.

For specification purposes, indicative data, including those for extreme situations, are normally available from local meteorological services. Note that this data may not capture short-term extremes of wind due to measurement averaging and may also not reflect the exact site conditions.

An additional complication may be that VTS equipment is located where wind loads are asymmetrical with respect to both horizontal and vertical components, is subject to turbulence, wind gradients and Venturi effects. The influence of air density (temperature), obstructions and tropical cyclones may also need consideration. Increased wind speed, due to such effects, especially vertical wind components can be hazardous to equipment, in particular, rotating antennas.

Rotating antennas are sensitive to excessive turbulence. Therefore, the positioning of an antenna in relation to the type of tower can be critical. For example, open lattice towers cause less turbulence around an antenna than closed towers. Note that, in general, antenna specifications only provide maximum wind limits in the horizontal plane.

1.4.3.2.1 The Beaufort Scale

The Beaufort scale is a common standard for wind force and relates sea condition to the specific wind condition as given by table 2. Wave heights in the scale are for conditions at the open ocean, and should not generally be applied in littoral waters. Sea bed characteristics and sounding topology also affect the sea condition, so wind speed cannot be directly related to the sea condition in most VTS areas.

Table 2 The Beaufort scale

Beaufort Number	Wind Description	Wind Speed	Land Conditions	Sea Conditions	Significant Wave Height, fully developed sea at open ocean
0	Calm	< 0.3 m/s	Calm. Smoke rises vertically.	Flat.	0 m
1	Light air	0.3–1.5 m/s	Smoke drift indicates wind direction and wind vanes cease moving.	Ripples without crests.	0–0.2 m
2	Light breeze	1.6–3.4 m/s	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.	Small wavelets. Crests of glassy appearance, not breaking.	0.2–0.5 m
3	Gentle breeze	3.4–5.4 m/s	Leaves and small twigs constantly moving, light flags extended.	Large wavelets. Crests begin to break; scattered whitecaps.	0.5–1 m
4	Moderate breeze	5.5–7.9 m/s	Dust and loose paper raised. Small branches begin to move.	Small waves with breaking crests. Fairly frequent whitecaps.	1–2 m
5	Fresh breeze	8.0–10.7 m/s	Branches of a moderate size move. Small trees in leaf begin to sway	Moderate waves of some length. Many whitecaps. Small amounts of spray.	2–3 m
6	Strong breeze	10.8–13.8 m/s	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	3–4 m
7	Near gale	13.9–17.1 m/s	Whole trees in motion. Effort needed to walk against the wind.	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	4–5.5 m
8	Gale	17.2–20.7 m/s	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	5.5–7.5 m
9	Severe gale	20.8–24.4 m/s	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	7–10 m
10	Storm	24.5–28.4 m/s	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	9–12.5 m
11	Violent storm	28.5–32.6 m/s	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	11.5–16 m
12	Hurricane	≥32.7 m/s	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	≥ 14 m

1.4.3.2.2 Tropical Cyclones

Tropical systems are officially ranked on one of several tropical cyclone scales according to their maximum sustained winds and in what oceanic basin they are located as per table 3.

Table 3 Classification of Tropical Cyclones

<table>
<tr><th colspan="9">Tropical Cyclone Classifications (all winds are 10-minute averages)</th></tr>
<tr><th>Beaufort scale</th><th>10-minute sustained winds [km/hr]</th><th>N Indian Ocean (IMD)</th><th>SW Indian Ocean (MFR)</th><th>Australia (BoM)</th><th>SW Pacific (FMS)</th><th>NW Pacific (JMA)</th><th>NW Pacific (JTWC)</th><th>NE Pacific, N Atlantic (NHC, CHC & CPHC)</th></tr>
<tr><td>0–6</td><td><52</td><td>Depression</td><td>Tropical Disturbance</td><td rowspan="3">Tropical Low</td><td rowspan="3">Tropical Depression</td><td rowspan="3">Tropical Depression</td><td rowspan="3">Tropical Depression</td><td rowspan="3">Tropical Depression</td></tr>
<tr><td rowspan="2">7</td><td>52-56</td><td rowspan="2">Deep Depression</td><td rowspan="2">Tropical Depression</td></tr>
<tr><td>56-63</td></tr>
<tr><td>8–9</td><td>63-89</td><td>Cyclonic Storm</td><td>Moderate Tropical Storm</td><td>Tropical Cyclone (1)</td><td>Tropical Cyclone (1)</td><td>Tropical Storm</td><td rowspan="3">Tropical Storm</td><td rowspan="3">Tropical Storm</td></tr>
<tr><td>10</td><td>89-104</td><td rowspan="2">Severe Cyclonic Storm</td><td rowspan="2">Severe Tropical Storm</td><td rowspan="2">Tropical Cyclone (2)</td><td rowspan="2">Tropical Cyclone (2)</td><td rowspan="2">Severe Tropical Storm</td></tr>
<tr><td>11</td><td>104-119</td></tr>
<tr><td>12</td><td>119-135</td><td rowspan="7">Very Severe Cyclonic Storm</td><td rowspan="3">Tropical Cyclone</td><td rowspan="2">Severe Tropical Cyclone (3)</td><td rowspan="2">Severe Tropical Cyclone (3)</td><td rowspan="8">Typhoon</td><td rowspan="6">Typhoon</td><td>Hurricane (1)</td></tr>
<tr><td>13</td><td>135-159</td><td>Hurricane (2)</td></tr>
<tr><td>14</td><td>159-167</td><td rowspan="3">Severe Tropical Cyclone (4)</td><td rowspan="3">Severe Tropical Cyclone (4)</td><td rowspan="2">Major Hurricane (3)</td></tr>
<tr><td>15</td><td>167-185</td><td rowspan="3">Intense Tropical Cyclone</td></tr>
<tr><td>16</td><td>185-198</td><td rowspan="3">Major Hurricane (4)</td></tr>
<tr><td rowspan="3">17</td><td>198-213</td><td rowspan="3">Severe Tropical Cyclone (5)</td><td rowspan="3">Severe Tropical Cyclone (5)</td></tr>
<tr><td>213-222</td><td rowspan="2">Very Intense Tropical Cyclone</td><td rowspan="2">Super Typhoon</td></tr>
<tr><td>>222</td><td>Super Cyclonic Storm</td><td>Major Hurricane (5)</td></tr>
</table>

1.4.3.2.3 Air Density

The wind load on outdoor structures varies with air density which, in turn, varies with air temperature as indicated in table 4. This effect should be taken into consideration when specifying VTS equipment for extreme conditions.

Table 4 Air Density versus Air Temperature

Temperature [°C]	Air Density [kg/m^3]	Normalized Density 20°C = 1.0
35	1.15	0.95
30	1.16	0.97
25	1.18	0.98
20	1.20	1.00
15	1.23	1.02
10	1.25	1.04
5	1.27	1.05
0	1.29	1.07

Temperature [°C]	Air Density [kg/m^3]	Normalized Density 20°C = 1.0
-5	1.32	1.09
-10	1.34	1.11
-15	1.37	1.14
-20	1.39	1.16
-25	1.42	1.18

1.4.3.2.4 Gradient Wind Effect

Meteorological services normally measure wind at 10 metre above ground level. Site conditions may differ substantially from the nearest Met station measurements. One of the reasons for this is gradient wind effects.

The Gradient wind effect is caused by the fact that wind speed reduces near the earth or sea surface due to friction or drag. More uneven earth (or sea) surfaces increase the friction and wind speed can therefore vary considerably with both terrain (or sea condition) and height above the surface as illustrated by figure 2.

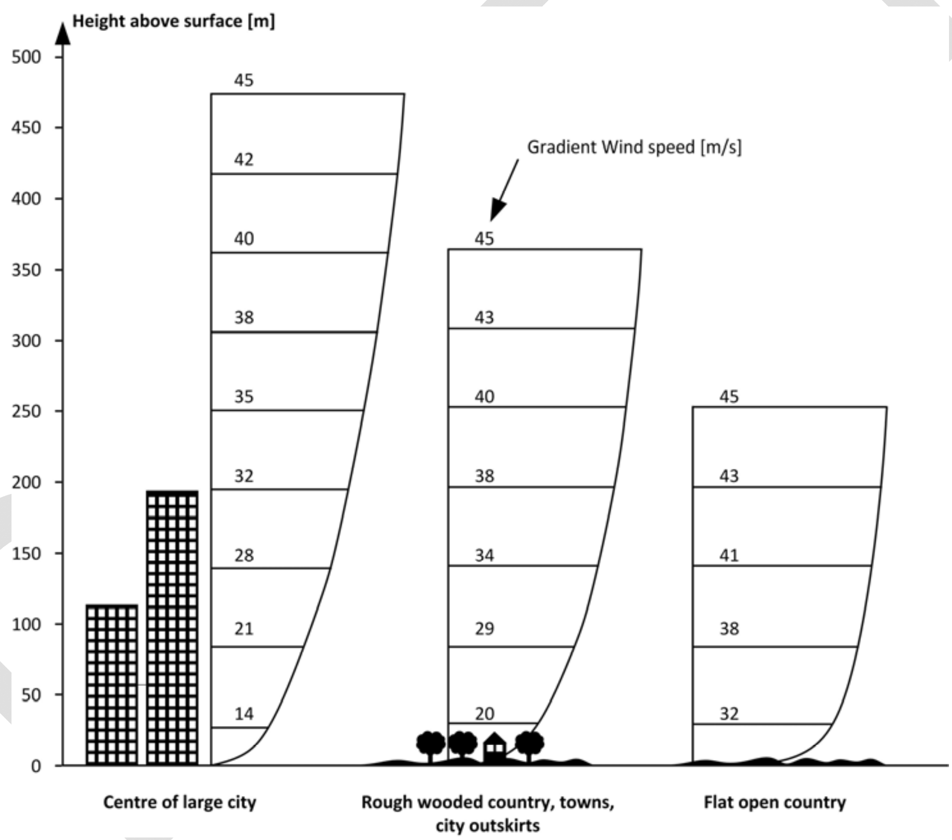

Figure 2 Average wind speed profiles over terrain with three different roughness characteristics for 45 m/s in higher altitude

1.4.3.2.5 The Venturi Effect

If wind passes upwardly on a slope or around a building as illustrated by figure 3 and figure 4, it generates a Venturi effect and causes a strong increase in the wind velocity at a given height above the surface. The height can be determined by local measurement, but may vary with wind speed and direction. It is not recommended to install, for instance, radar antennas directly in the Venturi.

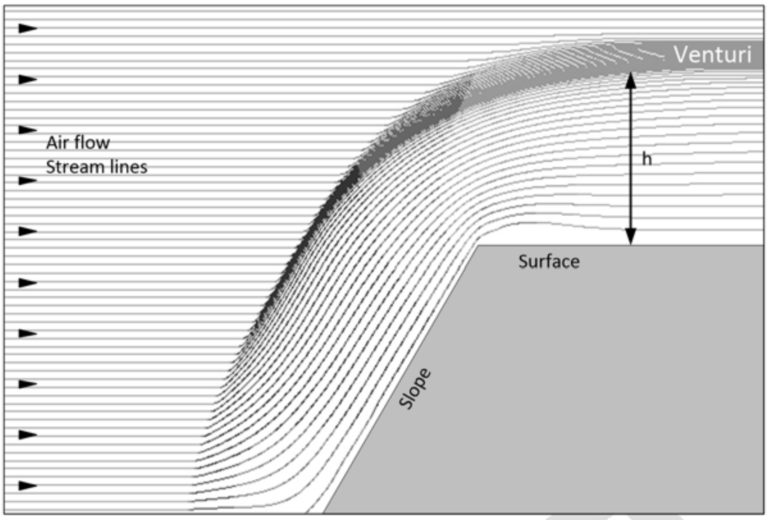

Figure 3 Simplified illustration of the Venturi effect on a slope

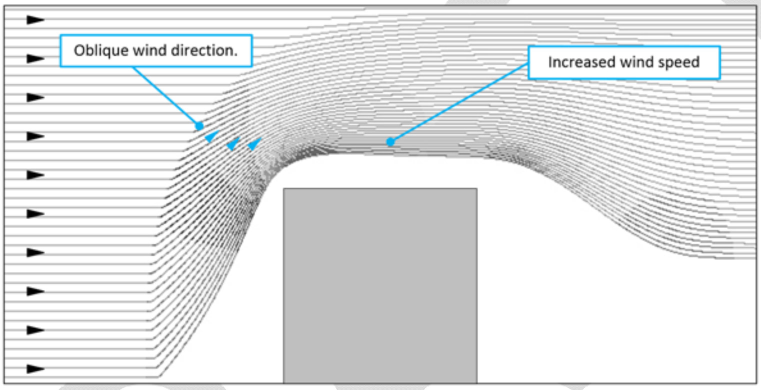

Figure 4 Simplified illustration of the Venturi effect around a building

1.4.3.2.6 Turbulence

Turbulence is a phenomenon that occurs when an interruption or impediment is introduced into the air (or liquid) flow as shown in figure 5.

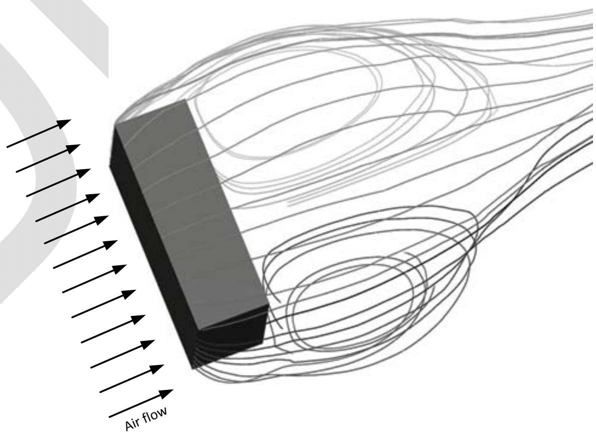

Figure 5 Turbulence around a building

Turbulence is characterized by apparently random and chaotic three-dimensional vortices, and the agitated, irregular motion usually involves movement at various rates of speed.

Turbulence can be very difficult to predict and it is recommended to avoid installation of sensitive equipment in turbulent areas.

1.4.3.2.7 Lee Side Mountain Wind

Mountain ranges can modify strong winds aloft to create waves and large eddies on the lee side of the mountains. Winds dip down due to the difference in pressure on the lee side, thus initiating wave actions in strong winds. Lens-shaped clouds (altocumulus lenticularus) may develop in the tops of these waves.

The clouds are usually high, and the resulting winds may not be felt at the surface. However, occasionally these strong winds aloft may dip to the surface, or eddy winds may reverse the direction of usual winds. Depending on your location, surface winds can be significantly modified by this process.

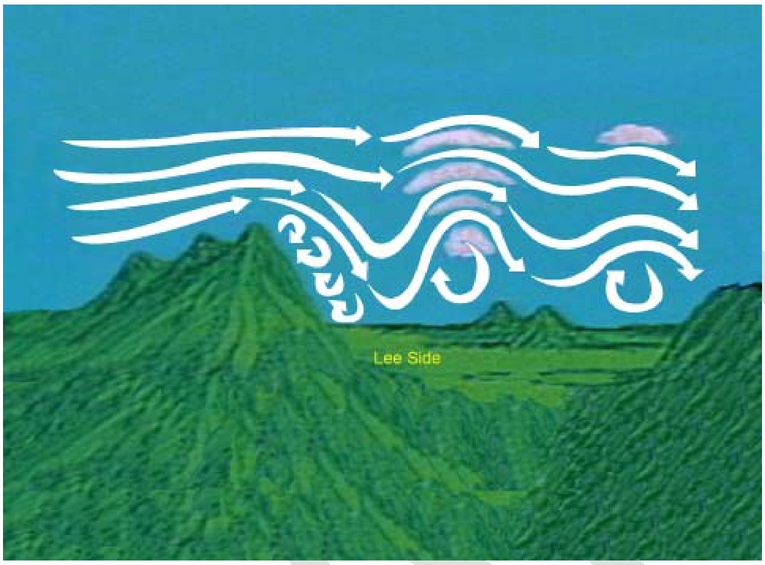

Figure 6 Lee side mountain winds

An example of the lee side phenomenon is the changeable Bora gust wind that exists over the Adriatic east coast. It blows in gusts and is most common during the winter. In severe Bora cases, mean hourly wind speeds rarely exceed 17 m/s, but during gusts, wind may reach speeds of up to 69 m/s!

1.4.3.3 Special Considerations

1.4.3.3.1 Storage and Transportation.

Environmental conditions for storage and transportation may be more severe than those of operation, due to the possibility of induced/combined environments (e.g. heat, humidity, shock, vibration, pressure etc.), higher levels of some parameters (e.g. high temperature in temporary open storage) or greater exposure times.

1.4.3.3.2 Design of Sheltered Equipment.

The shelter can provide a protective environment with characteristics that depend on the location and design of the shelter. In situations where contained equipment is reliant on the environment created by the shelter, the shelter facilities (e.g. cooling or heating) may become critical to the achieved availability of the equipment.

1.4.3.4 Installation Considerations

1.4.3.4.1 Lightning Protection

Lightning protection is often subject to national or local legislation taking into account local conditions, severity, earth conductivity, power grid constraints etc. The guidance from country to country differs depending on lightning strike frequency and severity. As a consequence, requirements for the number and type of lightning arrestors, the number of earthing points and the minimum cross section of lightning conductors vary to suit local conditions.

The general principles include:

- Lightning arresters should be higher than other equipment and be designed to protect the entire installation. They should have separate down conductor(s) on the exterior of buildings and the down conductors should not be connected to metal parts of buildings such as steel reinforcements, handrails and antenna masts;
- Safety grounding of equipment should be kept separate from lightning protection;
- Potential equalisation should be achieved in earth and never at the top of the equipment.

1.4.3.4.2 Warning Lights

High structures may require warning lights for air traffic, such as radar towers. It is recommended to consult local aviation authorities for specific requirements.

1.4.3.4.3 Site and Equipment Access

As part of the design of VTS or VTS equipment locations, the VTS Authority should analyse the need for site access for installation and maintenance. Fencing and other protective means against illegal intrusion will also be needed in many cases.

1.4.3.4.4 Electrical Power

VTS equipment is often installed in harsh and/or remote environments and lack of reliable power may require back-up facilities including generators and/or Uninterruptable Power Supplies (UPSs).

The VTS Authority should assess the installation requirements and ensure that the availability of electrical power is included in the overall availability considerations.

1.4.3.4.5 Safety and Security Precautions

For each location, the VTS Authority should determine safety and security requirements.

Safety requirements should, at least, consider:

- Safety switches to isolate equipment and to stop rotating antennas;
- Precautions regarding electromagnetic radiation, rotating machinery and electrical shock, railings on masts etc.;
- Safety procedures, such as instructions to personnel performing maintenance;
- Lone working on remote sites should be avoided.
- Protection of the general public.

Security requirements should, at least, consider:

- Access restrictions;
- Alarm systems;
- Protection of data.

1.4.3.4.6 Equipment Preservation and Monitoring

In addition to personnel safety and security-related features manned and unmanned site-designs should consider:

- Authorised and unauthorised access (e.g. CCTV) and associated alarms;
- Fire detection and (remote) alarms;
- The need for automated fire extinguishers;
- Remote monitoring of site status (power, fuel, temperature, meteo data etc.);
- Remote monitoring of equipment status.

1.4.3.4.7 Marking and Identification

Equipment should be marked with manufacturer name, type and serial number. In addition, build state records for equipment, including software, should be included with delivered equipment.

Legislation may require additional marking or identification, signposts etc.

Privacy regulations may require the posting of signs to notify the public that they are under surveillance.

1.4.3.4.8 Precautionary Measures to Extreme Events

VTS Authorities, responsible for VTS in areas subject to extreme events such as earthquake and tsunami, should specify requirements to construction accordingly.

This will typically include special requirements to equipment shock resistance, alignment capabilities, civil works and power supply.

1.4.3.5 Design and Installation Documentation

The VTS Authority should specify deliverable documentation to accompany the VTS equipment. As a minimum, documentation should include:

- Operating instructions;
- Maintenance instructions (preventive and corrective) inclusive of procedures and spare parts catalogue;
- Safety information (e.g. regarding radiation, electrical safety and rotating machinery);
- Certificates and permissions as required by law (e.g. CE marking, permission to radiate, permit to build and acoustic noise certificate);
- Test procedures, test certificates, "As built" documentation, etc.

1.4.3.6 Design Standards Applicable to VTS Equipment

VTS equipment is subject to a variety of local, regional and international standards. The VTS Authority should ensure compliance with the applicable standards as part of the acquisition process.

The following tables include examples of typical specification levels and the corresponding standards.

Table 5 International standards applicable for in- and outdoor equipment

Subject	Description	Corresponding Test Standard
EMC immunity	Immunity for industrial environments	IEC 61000-6-2
EMC emission	Emission standard for residential environments	IEC 61000-6-3

Table 6 International standards and specification levels for indoor equipment

Subject	Environment		Corresponding Test Standard
	Equipment Rooms	Operator Rooms	
Temperature	0°C to 45°C	10°C to 35°C	IEC 60068-2-2
Humidity	< 95% RH at 45ºC		IEC 60068-2-3
IP protection class	IP 52 (Dust and dripping water 15°)	IP 20	IEC 60529
Acoustic noise		*< 45 dB(A) at 1 m*	IEC 11201

Table 7 International standards and specification levels for outdoor equipment

<table>
<tr><th rowspan="2">Subject</th><th colspan="3">Environment</th><th rowspan="2">Corresponding Test Standard</th></tr>
<tr><th>Cold and Basic</th><th>Hot</th><th>Severe Cold</th></tr>
<tr><td>Temperature</td><td>-30°C to 45°C</td><td>-10°C to 55°C</td><td rowspan="9">To individual site conditions</td><td>IEC 60068-2-2</td></tr>
<tr><td>Sun radiation</td><td colspan="2">≤ 1120 W/m^2</td><td>IEC 60068-2-9, test A</td></tr>
<tr><td>UV radiation</td><td colspan="2">Method 505.4</td><td>IEC 60945
MIL-STD-810F</td></tr>
<tr><td>IP protection class</td><td colspan="2">IP 54 (Dust and water splash)</td><td>IEC 60529</td></tr>
<tr><td>Corrosion category</td><td colspan="2">C5-M (Aggressive marine atmosphere)</td><td>ISO 12944</td></tr>
<tr><td>Salt mist</td><td colspan="2">Severity (1) - Salt 5% by weight</td><td>IEC 60068-2-52</td></tr>
<tr><td>Hail</td><td colspan="2">≤ 10 mm hail @ 18 m/s wind</td><td></td></tr>
<tr><td>Ice load</td><td colspan="2">≤ 12.7 kg/m^2</td><td></td></tr>
<tr><td>Wind</td><td colspan="2">To individual site conditions</td><td></td></tr>
</table>

In addition to international standards, regional (e.g. EU) or national standards are often mandatory.

1.4.3.7 Equipment Approvals

Legal requirements for equipment approval (or statements of conformity) vary from country to country; they are in continuous development and it is the responsibility of the VTS Authority to ensure and maintain compliance.

National requirements imposed upon the VTS Authority should, of course, be met. There is a tendency, however, to adopt international and regional standards and the following sections reflect the most commonly used legislation and methods to ensure compliance.

On some aspects, applicable law may require conformance testing by accredited institutions; on other aspects, the VTS Authority is free to decide on the test procedure.

Although the given examples are predominantly European, the equivalent applicable local legislative documents should be used. At the time of editing of this document (2015), the following examples indicate legal requirements for equipment conformance:

1.4.3.7.1 Electrical Safety

- European Low Voltage Directive (LVD) 2014/35/EU and the related design standard, IEC60950-1, 2nd edition.
  - Published in OJ L96 29 March 2014, mandatory from May 2016
  - Replaces Low Voltage Directive 2006/95/EC

1.4.3.7.2 Mechanical Safety

- European Machinery Directive 2006/42/EC.

1.4.3.7.3 Radiation Safety (Radio and Radar)

- For non-ionising radiation, the European standard for human exposure to RF electromagnetic fields is the International Commission on Non-Ionizing Radiation Protection (ICNIRP) ;
- EMF Directive 2013/35/EU.

Compliance is required in order to obtain CE marking (mandatory within EU) and can be achieved and documented in accordance with ICNIRP guidelines. Note: two thresholds for radiation safety are specified relating to occupational exposure and exposure to the general public.

Also note that, for pulsed energy, measurement of power densities requires sophisticated test equipment and it is commonly accepted to verify worst case radiation levels and determine corresponding safe distances through an engineering report on power densities around the antenna, utilizing the guidelines laid down by the International Commission on Non-Ionizing Radiation Protection.

1.4.3.7.4 Electromagnetic Compatibility

- European EMC Directive 2014/30/EU.
  - Published in OJ L96 29 March 2014, mandatory from May 2016
  - Replaces EMC Directive 2004/108/EC

  Generic European EMC standards used:

  - Immunity as industrial equipment according to IEC 61000-6-2;
  - Emission as residential equipment according to IEC 61000-6-3;
  - Compliance is required in order to obtain CE marking (mandatory within EU).

1.4.3.7.5 Radio Spectrum Requirements

EU Requirements:

- European Radio Equipment Directive 2014/53/EU.
  - Published in OJ L153 22 May 2014, mandatory from May 2016
  - Replaces Radio & Telecommunication Terminal Equipment Directive (R&TTE) 1999/5/EC

  ETSI EN 303 135 defines the required parameters for VTS/CS radars:

  - ECC/Recommendation (02)05 (2012): 'Unwanted emissions';
  - ERC/Recommendation 74-01 (2011): 'Unwanted emissions in the spurious domain'.

ITU Recommendations:

- ITU-R Recommendation SM.1541-5 (2013): 'Unwanted emissions in the out-of-band domain';
- ITU-R Recommendation SM.329-12 (2012): 'Unwanted emissions in the spurious domain".

US Federal Requirements:

- NTIA - Manual of Regulations and Procedures for Federal Radio Frequency Management.

Chinese Radio Transmission Type Approval:

- Chinese Authorities require dedicated Chinese Type Approval, Compliant to ITU recommendations;
- Special rules apply for Hong Kong, where OFTA approval is required.

1.4.3.7.6 Reduction of Hazardous Substances

- VTS equipment in the European Union should be designed to comply with the Reduction of Hazardous Substances (RoHS) directive 2011/65/EU (RoHS II) by July 22, 2017;
- China RoHS is also becoming a national requirement, but currently this does not affect radar transceivers, although additional marking and documentation is required.

1.4.3.7.7 Chemical Substances

- VTS equipment in the European Union should comply with the REACH Directive (Regulation (EC) No 1907/2006).

2 RADAR

2.1 Introduction

The purpose of this section is to support Competent and VTS authorities in the understanding of radar performance, supporting the design of radar service and its contribution to the VTS traffic image (situational awareness).

The VTS Authority should specify the Operational and associated Validation Requirements, (e.g. coverage, targets to be detected and target separation) rather than Technical Specifications, (e.g. Transmitted power, pulse characteristics and antenna data) of radar sensor(s). Weather, sea conditions and geographical constraints pose challenges to the detection capability of radar sensors in VTS. The use of multi-sensor integration, including radar, AIS and other sensors also needs to be taken into account.

Specific security requirements may introduce particular challenges to the radar sensor where there could be a need to detect small targets in heavy clutter conditions or where small versus large target discrimination is essential.

2.2 Definitions and References

2.2.1 Definitions

For general terms used throughout this section refer to:

IEEE Std 686-1997 IEEE Standard Radar Definitions;

Specific terms are defined as follows:

Azimuth (Antenna) Side Lobes - antenna responses (in azimuth) outside the intended radiation beam. Weighting of the illumination function allows a significant reduction of these lobes, but some response outside the intended direction is unavoidable, normally presenting an irregular pattern with "peaks" and "nulls". The side lobes may produce responses from targets in unwanted directions, allowing disturbing signals (intentional or not) to enter the receiver, and in addition makes the radar detectable by receivers, which are not illuminated by the main beam;

Availability - is the probability that a system will perform its specified function when required;

Blind Spots – typically resulting from either blind range (the Range corresponding to an echo delay of one or more pulse repetition intervals: the echo then arrives at the receiver while the radar is transmitting a new pulse and the receiver is blanked) or Blind speed (target speeds which produce Doppler shift which are integer multiples of the radar pulse repetition frequency (PRF), which are therefore aliased to zero Doppler and cancelled by the clutter rejection filtering). Blind spots can also arise behind significant obstructions in the field of view (buildings, land masses, oil tankers);

Chirp - frequency modulation of the carrier frequency applied within the radar pulse to increase its bandwidth and therefore the range resolution (see also pulse compression);

Coherence - capability of a system to keep a stable phase reference during the target illumination time in order to properly exploit the received phase information for moving target indication (MTI), pulse Doppler processing or other purposes;

Doppler Shift - shift in frequency of a wave due to the relative motion between the transmitter and the receiver. Frequency shift is relative target velocity/wavelength. Radar echoes are shifted twice this value because this shift must be accounted for in both the forward and the return path;

Doppler Side Lobes - when using Doppler processing (or MTI) the integrated ideal pulse always presents a response outside the integration peak (across all Doppler filters) known as Doppler side lobes. Their main effect is to limit the capability to discriminate weak returns in proximity of strong returns (with side lobes of the same order of magnitude as the primary response of the weak return);

FMCW - Frequency Modulation - Continuous Wave - A type of radar where a continuous wave instead of pulse is transmitted. The range information is derived by frequency modulating the carrier with a saw tooth waveform and comparing the echo FM modulation envelope with the reference;

Ghost Targets (Ghost Echoes) – undesirable radar echoes resulting from a number of sources. For example multipath related wave reflections caused by large structures or surface reflections, time sidelobes, antenna azimuth sidelobes, and Doppler sidelobes;

Interference Rejection - this function is included to seek to reduce or eliminate interference received from transmitters utilising the same or nearby frequencies. One common technique is to compare adjacent range cells in the present "live" video signal with the video signal from the previous sweep. The output video signal to the display device is inhibited should the comparison indicate the presence of interference;

Normal Weather and Propagation Conditions - are the conditions not exceeded 99% to 99.9 % of the time as defined by the individual VTS Authority. The rest of the time is considered having adverse weather and propagation conditions;

Plot Extraction – the process of determining the likely target related radar returns from the radar video signal. This typically consists of comparing the video level with a threshold which can be (dynamically) adapted to local background noise and clutter conditions;

Polarisation - of a radar signal is determined by the orientation of the electrical field. In the case of **circular polarisation** the field rotates left or right;

Pulse – typically a pulse (which is modulated in the case of pulse compression radar) of RF energy transmitted from the radar;

Pulse Compression – A technique used to achieve a wide pulse bandwidth (and, therefore, enhanced range resolution) using long pulse (for high pulse energy with limited peak power) by introducing an intra-pulse modulation (e.g., chirp frequency modulation or Barker discrete phase modulation) and performing a correlation on the received echo;

Radar Cross Section (RCS) - an assessment of the cross sectional area presented by a reflector (typically a target or unwanted “clutter”) to the transmitted radar energy. The RCS can vary with frequency and target attitude;

Radar Information - a generic term potentially referring to the radar picture/video, target data, clutter data, topographical data, aids to navigation SARTs etc.;

Radar P_D - is the probability of target detection at the output of a radar, subsequent to plot extraction, but prior to tracking, and presentation. Note, in some systems the boundary of the radar and its achieved P_D complicate this definition – clarification may be required to avoid misunderstanding arising from, for example, data compression or video processing;

Radar P_{FA} - is the probability of false alarm at the output of a radar, subsequent to plot extraction, but prior to tracking, and presentation. In this context, the P_{FA} is defined as relating to the number of false target declarations per radar cell (range cell x azimuth cells), arising from a noise plus clutter environment (only). Note, in some systems the boundary of the radar and its achieved P_{FA} complicate this definition – clarification may be required to avoid misunderstanding arising from, for example, noise related threshold crossings vs. unwanted radar energy reflections (unwanted targets, ghost targets etc.);

Radar Plot - is the generic term to describe the report resulting from a radar sensor observation. Each report contains positional information, possibly supplemented by other data;

Radar Target - an object about which information is sought with radar equipment

Radar Video - a time-varying signal, proportional to the sum of the radio frequency (RF) signals being received and the RF noise inherent in the receiver itself. Traditionally, radar video is an analogue signal with associated azimuth reference information. Recently, radar systems have become available which provide equivalent data in digital format;

Radar Sensor - the transmitting, receiving and signal handling apparatus, delivering radar information to the tracking and presentation features of VTS.

Radar Service - a service that delivers all radar-derived data, such as radar image, radar plots, radar tracks.

Radar Tracks - A target report resulting from the correlation, by a special algorithm (tracking) of a succession of radar-reported positions (radar plots) for one object. The report normally contains filtered position, speed vector information, identity, (e.g. track number). Additional information may include, for example, track uncertainties, the associated plot, timestamp, track quality;

Range Ambiguous Returns – the measured range of a target typically assumes that the target true range is less than the first range ambiguity (the Range corresponding to an echo delay of one pulse repetition interval) whereas large targets beyond this range can be detected but typically with (incorrect) ambiguous range measurement. Techniques exist for the resolution of range ambiguity if required. See also blind spots above;

Range Side Lobes – see Time Side Lobes (below);

Receiver Dynamic Range – essentially the range of signal levels over which a receiver can operate. The low end of the range is governed by its sensitivity whilst, at the high end, it is governed by its overload or strong signal handling performance;

Reliability - the probability that a system, when it is available performs a specified function without failure under given conditions for a given period of time;

Sea Characteristics – often described by sea state but additional parameters can also be of interest. Sea characteristics include wave/swell height, direction and speed of waves/swell, distance between waves/swell, salinity etc.;

Standard Atmospheric Condition - The International Commission of Air Navigation uses a definition for a standard atmosphere, defining temperature and pressure relative to the height. In the troposphere (0 metres to 11,000 metres), the temperature is defined to be 15 °C at the surface and changing -6.5 °C/km;

Squint - the potential angular difference between antenna broadside and the antenna beam pointing direction. This angular difference may change with transmission frequency. The effect can be fully compensated;

Swerling Cases – a series of mathematical models representing RCS fluctuations to characterise the statistical behaviour of reflected radar signals from a target (see also target fluctuations);

Target Fluctuations – (also known as Glint or Swerling characteristic) - Fluctuation of a target radar cross section (RCS) (and, therefore, of the received echo amplitude) due to changes in the target attitude and illuminating frequency. For complex targets (consisting of a number of reflecting surfaces), RCS is normally strongly dependent on the angle of observation;

Target Separation – (also known as Target resolution) – the ability to successfully identify two discrete detectable, similarly sized targets when closely spaced in either range or azimuth;

Track Swapping – the (usually unwanted) transfer of a track identity (track label) to another track. This can break the intended association between a track and a physical object;

Time Side Lobes - when using pulse compression the correlated pulse always presents responses outside the correlation peak (before and after it) known as time (or range) side lobes. Their main effect is to limit the capability to discriminate weak returns in proximity of strong returns (with side lobes of the same order of magnitude as the primary response of the weak return).

2.2.2 Definition of IALA Target Types for Range Coverage Modelling

For calculation purposes, the IALA simplified target types are defined in table 8.

Typical targets of interest are modelled as point targets with conservative estimate of Radar Cross Section and height. This is normally sufficient for estimation of detection range for consideration in VTS radar sensor coverage. However, further considerations are required for the overall design of radar systems as discussed later in this section.

Radar performance estimation, including concerns regarding fluctuations, is discussed later in this section.

Table 8 IALA Target Types

IALA Point Target Types					
Target Type	**Typically Representing**	**Radar Cross Section**		**Height (ASL)**	**Fluctuation**
		S-Band	**X-Band**		
1	AtoN without radar reflector. Small open boats, fibreglass, wood or rubber with outboard motor and, at least, 4 metres long. Small speedboats, small fishing vessels, and small sailing boats.	<<1 m^2	1 m^2	1 m	Rapid, depending on sea state and target movement
2	In-shore fishing vessels, sailing boats and speedboats.	<1 m^2	3 m^2	2 m	
3	Aids to Navigation with radar reflector.	4 m^2	10 m^2	3 m	
4	Small metal ships, fishing vessels and patrol vessels.	40 m^2	100 m^2	5 m	Moderate
5	Small coasters and large fishing trawlers.	400 m^2	1,000 m^2	8 m	
6	Large coasters, bulk carriers and cargo ships.	4,000 m^2	10,000 m^2	12 m	Negligible
7	Container carriers and tankers.	40,000 m^2	100,000 m^2	18 m	

Note: RCS values are average values for the distribution of single pulse radar echoes. The indicated values include allowance for the RCS-limiting effect of the cell size in the case of radars with high-resolution (see also table 9).

2.2.3 References

[1] IEEE Std 686-1997 - IEEE Standard Radar Definitions

[2] Merrill I. Skolnik - Introduction to Radar Systems, McGraw-Hill Higher Education, ISBN 0-07-290980-3

[3] P.D.L. Williams, H.D, Cramp and Kay Curtis - Experimental study of the radar cross section of maritime targets, ELECTRONIC CIRCUITS AND SYSTEMS, July 1978. Vol. 2. No 4

[4] Ingo Harre - RCS in Radar Range Calculations for Maritime Targets (http://www.mar-it.de/Radar/RCS/RCS_18.pdf)

[5] International Maritime Organisation (IMO) - Performance Standards for radar reflectors

[6] ITU-R SM.1541 - Unwanted emissions in the out-of-band domain

[7] ITU-R SM.329-9 - Spurious emissions

[8] ISO 8729 Ships and marine technology – Marine radar reflectors

[9] International Commission for Air Navigation - Definition of the Standard Atmosphere

[10] CARPET[1]: Computer Aided Radar Performance Tool TNO (Netherlands Organisation for Applied Scientific Research) Physics and Electronics Laboratory, P.O. Box 96864, 2509 JG The Hague, Netherlands, http://www.tno.nl

[11] AREPS[1]: Advanced Refractive Effects Prediction System, Space and Naval Warfare Systems Center, San Diego, http://sunspot.spawar.navy.mil

[1] Note that the use of off-the-shelf performance tools for assessment of the latest radar sensors, employing complex multiple pulse waveforms, may require specialist assistance to obtain appropriate and valid performance predictions.

2.3 Radar System Solutions

2.3.1 General

The radar coverage required for a VTS may consist of multiple radar sensors either co-located or distributed to optimise availability, radar data integrity, security constraints and equipment access considerations. With this in mind, there are a number of design decisions regarding the cost, complexity, location and detailed design of the radar sensors within a VTS.

In addition, there are design decisions and trade-offs to be considered for each radar sensor. These might include magnetron vs. solid state, transmission power, antenna size, receiver technology, signal processing and waveform design, all of which need to be considered together in the specifications of each radar sensor within the VTS network.

Therefore, the VTS Authority should keep options open, avoiding detailed technical specifications, and requiring that VTS vendors propose solutions to meet the specified operational and functional requirements based on the guidelines in this document.

The remaining text in section 2.3 is descriptive and intended to introduce the reader to common radar topics. Guidance for specifying VTS radar follows in subsequent sections.

2.3.2 Radar Types

VTS radars could be of the following types:

- Pulse Radar (usually Magnetron based);
- Pulse Compression radar (usually Solid State);
- Frequency Modulated Continuous Wave, FMCW (usually Solid State).

A general explanation of each radar type will follow.

2.3.2.1 Pulse Radar

A pulse radar typically transmits high peak power RF pulses (10 to 50 kiloWatt) of very short duration (50 to 1000 nanoseconds). The transmission is made with a pulse repetition frequency (PRF) of typically 1000 to 4000 pulses per second. Upon reception, the returned signal is amplified, demodulated and processed.

Main characteristics include:

- It is a well-known and proven technology;
- It has fixed pulse lengths;
- Increased pulse duration translates into longer-range detection, but reduced range resolution and reduced ability to penetrate precipitation due to increased backscatter;
- Normally with a fixed transmission frequency (or frequencies);
- Requires wide frequency band allocation for compatibility with adjacent equipment.

Additional challenges (as of 2015) include:

- The need to reduce out-of-band transmissions. Note that ITU requirements for shipborne radar are less stringent than for land-based radar.

2.3.2.2 Pulse Compression Radar

A pulse compression radar transmits low peak power modulated chirps (typically up to 200 Watt and eventually higher) with a typical pulse duration of up to 100 micro seconds. The transmission is made with a chirp repetition frequency of typically 1000 to 20000 chirps per second. Upon reception, the returned signal is amplified, pulse-compressed and processed

The energy in the chirp of a pulse compression radar is comparable to the energy emitted in a pulse from a magnetron radar. The longer chirps are converted into short pulses upon reception by the process of pulse compression; therefore improved range resolution can be achieved at all ranges within a single radar mode.

Main characteristics include:

- It is based on well-known and proven principles, but at time of writing (2015), the high power at high frequency solid state amplifier technology relies on recent transistor developments;
- No need for magnetron replacement due to solid-state power amplifier, reducing the need for periodic maintenance;
- Increased ability to penetrate adverse weather conditions facilitating smaller target detection;
- Transmission frequencies can be programmed;
- Cleaner spectrum than magnetron radars, with reduced emissions outside the allocated frequency band(s).

Additional challenges (as of 2015) include:

- The need for sophisticated interference rejection due to the longer chirps transmitted;
- The need for simultaneous short and long range detection increases complexity;
- High power solid state amplifiers operate with large currents therefore requiring careful design to obtain high reliability;
- By nature the pulse compression radar creates so-called time side lobes. Avoiding such side lobes, requires sophisticated techniques, alternatively side lobes suppression may imply a reduced detection of small targets in the vicinity of larger targets.

Note: There may be legal restrictions (dual use, catch-all etc.) limiting the compression ratio and other parameters when importing (pulse compression) radars to certain countries. This may limit the availability of this technology to some VTS Authorities.

2.3.2.3 Frequency Modulated Continuous Wave

Frequency modulated continuous wave radar transmits low peak power continuous wave forms (typically up to 50 Watt). The waveforms are repeated with a typical rate of 500 to 2000 per second. Upon reception, the returned signal is amplified, compressed and processed.

The energy in a frequency modulated continuous wave radar is comparable to the energy emitted in a pulse from a magnetron radar. The waveforms are converted into pulses upon reception, therefore high range resolution can be maintained at all ranges.

Main characteristics include:

- Well-known and proven principles;
- No need for magnetron replacement due to solid-state power amplifier, reducing the need for periodic maintenance;
- The ability to detect from very short range;
- Transmission frequencies can be programmed;
- Cleaner spectrum than magnetron radars, with reduced emissions outside the allocated frequency band(s).

Additional challenges (as of 2015) include:

- Dynamic limitations restrict the ability to handle small and large targets simultaneously and also affects long range detection;
- Target revisit rate is low compared to typical VTS target kinematics;
- The need for sophisticated interference rejection, even more than for pulse compression radars;
- By nature FMCW creates so-called time side lobes;

  Suppressing the side lobes may imply reduced detection of small targets in the vicinity of larger targets.
- More complicated antenna system, 2 antennas or complicated antenna feed.
- The inability to detect RACONS and SART transponders

2.3.3 Antennas

The selection of antenna parameters (height, gain, side lobes, rotation rate, polarisation etc.) for a given installation, is integral to the resulting radar performance and VTS authorities are advised to avoid specifying detailed antenna parameters in favour of identifying operational needs such as coverage area requirements (based on risk assessments), track update rates (based on tracker design and typical target manoeuvres in high density areas), range performance, overlapping and redundant coverage. The identified operational needs will allow the radar expert some flexibility to achieve the best solution within the constraints of cost and location options.

2.3.3.1 Antenna Principles

Typically, the VTS radar design includes an antenna, which provides a narrow beam in azimuth and a wide beam in elevation. Thus, the VTS antenna is not designed to measure the target elevation (from which target height might be determined) or to separate targets on the basis of elevation angle difference.

The installed antenna height is determined based on avoidance of physical obstructions, and the compromise between the need for close range visibility vs. long-range performance.

The radar designer, in his selection of antenna characteristics, needs to optimise the compromise between antenna size (and cost), track update rate, integration time on target (related to rotation rate and azimuth beamwidth and contributing to target detection range) and azimuth target separation and accuracy. In addition, the choice of transmission frequency influences the size vs. beamwidth compromise.

Flat face electronic scanning antennas (phased array) may have advantages in terms of no rotating parts, flexible beam management, and the possibility to focus attention in some key directions. Note this antenna technology may also have disadvantages in terms of technical complexity and cost. Performance (e.g. variation in gain, blind coverage directions, beamwidth and update rates) at all applicable scan angles should be considered when assessing radar antenna performance.

2.3.3.2 Antenna Side Lobes

The antenna designer uses an amplitude weighting function to control the azimuth side lobe levels to a level which recognises the requirements for close in (< 10° from the main lobe peak) azimuth side lobes and the requirements for side lobes beyond this region. Side lobes are specified as a ratio (in dB) relative to the antenna beam peak.

The antenna gain defined from a specific point in the radar system is specified as a ratio above ‘isotropic’ (dB or dBi) and can be increased by increasing the physical size of the antenna. This will also reduce the beamwidth (azimuth, elevation or both).

Elevation side lobes are unlikely to be a major contributor to the performance of the VTS radar system.

Azimuth grating lobes can also be a factor and these should be included in consideration and measurement of side lobe levels.

2.4 Characteristics of Radar Targets

VTS radar targets are defined by their height above sea level, their speed and manoeuvrability, their polarisation characteristics, their radar cross section (RCS) and the fluctuations in RCS.

2.4.1 Radar Cross Section

A target may be observed when transmitted RF energy is reflected back from the target to the receiver. The amount of energy reflected is directly proportional to the radar cross section of the target.

The RCS is defined as the ratio between the power (in W) scattered by the target back towards the radar receiver and the power density (in W/m^2) hitting the target. Thus RCS is measured in m^2 and has the dimensions of area.

Note: There is no simple relationship between the physical size of the target and the RCS. The reflected energy depends on several factors, such as the radar operating frequency or frequencies, the angle of incidence of the radio waves, target speed, material and geometry.

The RCS of a target will fluctuate as a result of target movements, frequency and environmental effects with consequences on the detection and presentation of the target.

2.4.2 Polarisation

Radio waves are polarised and objects (target and clutter) will often reflect differently for the polarisation used. This can be utilised by radar system designers, where rules of thumb are that:

- Target returns from linear polarisation, (horizontal or vertical) in general will be stronger than returns from circular polarisation;
- Non-metallic and natural objects, such as human beings will return linear polarised radio waves much better than circular polarised radio waves;
- Most radar reflectors will be poor reflectors for circular polarised radio waves;
- Distant ships with vertical masts tend to give the strongest return for vertical polarisation, whereas the opposite tends to be the case for modern ship designs without tall masts;

In addition, target detection in clutter can be affected by the polarisation. For instance:

- Linear polarisation (horizontal or vertical) will result in higher rain clutter returns than circular polarisation;
- Vertical or circular polarisation will result in higher sea clutter returns than horizontal polarisation, especially for lower sea states;

In summary complex designs are possible in which VTSOs may select the polarisation. However, this adds to equipment costs and adds to the VTSO workload.

In general the best cost/performance combined with ease of operation is achieved by horizontal polarisation. Circular or switchable may however be appropriate to achieve acceptable performance for operation in areas with extreme (tropical) rainfall.

Note that, in the case of a radar station also being used for oil spill detection, the preferred polarization is vertical.

2.4.3 Complex Target Models

The point target characteristics in table 8 will normally be sufficient for range calculation of specific targets of interest in VTS.

However, the design of a radar system should consider the overall characteristics of all objects within coverage range of the individual radar and table 9 provides an overview of such characterises for targets, typically of interest to VTS radar. Data is primarily based on references [3] and [4], supplemented by data obtained from the experiences of IALA VTS committee members.

Table 9 Typical Target Characteristics

<table>
<tr><th rowspan="2">Target</th><th colspan="3">Typical characteristics at X-band</th></tr>
<tr><th>RCS</th><th>Height</th><th>Fluctuations etc.</th></tr>
<tr><td>Aids to Navigation without radar reflector.</td><td>Up to 1 m^2</td><td rowspan="2">1 to 4 m ASL</td><td>Rapidly fluctuating, highly dependent on sea characteristics. Polarisation characteristics will often vary depending on wind.</td></tr>
<tr><td>Aids to Navigation with radar reflector.</td><td>10 – 100 m^2</td><td>Rapidly fluctuating, wind and currents may tilt to blind angles and lobing may cause reflectors to be in blind spots. Most radar reflectors will be poor radar targets in case of circular polarisation</td></tr>
</table>

Target	Typical characteristics at X-band		
	RCS	**Height**	**Fluctuations etc.**
Small open boat, fibreglass, wood or rubber with outboard motor and at least 2 persons on board, small speedboat, small fishing vessels or small sailing boats.	0.5 – 5 m^2	0.5 to 1 m ASL	Rapidly fluctuating may be hidden behind waves up to 50 % of the time. Slow moving targets tend to lie lower in the water than fast moving ones and therefore RCS visible to the radar tends to increase with speed. Humans and non-metallic targets will give poor radar return in case of circular polarisation
Inshore fishing vessels, sailing boats and speedboats, equipped with radar reflector of good quality.	3 – 10 m^2	1 to 2 m ASL	Rapidly fluctuating.
Small metal ships, fishing vessels, patrol vessels and other similar vessels.	10 – 100 m^2	2 to 4 m ASL	Moderately fluctuating.
Coasters and other similar vessels.	100 – 1000 m^2	6 to 10 m ASL	RCS is highly dependent on aspect angle of the individual vessel. Rate of fluctuations is typically moderate.
Large coasters, Bulk carriers, cargo ships and other similar vessels.	1000 – 10,000 m^2	10 to 25 m ASL	
Container carriers, tankers and other similar vessels.	10,000 – 2,000,000 m^2	15 to 40 m ASL	
Buildings, cranes. Stacks of containers and other large structures.	Up to 1,000,000 m^2	Depends on site	Insignificant.
Floating items, oil drums and other similar items.	Up to 1 m^2	0 to 0.5 m ASL	Rapidly fluctuating, highly dependent on sea characteristics and target movements.
Birds, floating or flying.		Sea level and up	
Flocks of birds.	Up to 3 m^2	Sea level and up	Rapidly fluctuating, flight paths tend to be characteristic of given species in given areas of interest.
Jet Skis and other personal water craft	Up to 0.5 m^2	0 to 1 m ASL	Rapidly fluctuating but virtually independent of aspect angle
Wind turbines (onshore and offshore)	Up to 1,000,000 m^2		Fluctuations for towers are insignificant. Rotating parts give a wide spectrum of Doppler shifts with RCS up to hundreds of m^2

Note: Modern warship design seeks to minimise RCS and, as a result, the above figures cannot be related to such vessels.

In case the physical size of the target exceeds the size of the resolution cell of the radar, the target gets extended into other resolution cells. In such a case, the RCS values, as mentioned above, may be incorrect (as the target reflection is now distributed across more than one resolution cell). Additionally, the extension of the target poses extra challenges on detection and tracking performance. Extension of targets and the consequences thereof should especially be considered in situations where the radar is positioned close to the targets to be detected and tracked and/or in case of high-resolution radars.

RCS on targets using S-band is typically 40% of the RCS in X-band except for small non-metallic targets where the RCS difference between the 2 bands can be much higher.

To determine RCS on targets using other radar bands, such as Ka and Ku, the standard radar textbooks should be consulted to scale from the X-band figures in table 8 and table 9.

2.4.4 Target RCS Fluctuations

For VTS target types, statistical RCS fluctuations can adversely affect target detection. To predict range performance more realistically, such fluctuations can be mathematically modelled using the different Swerling cases. The radar design can to some extent compensate for the consequences of target RCS fluctuations.

2.4.5 Target Speed and Manoeuvrability

When assessing the requirements for both the tracking function and the radar sensor, the VTS Integrator needs to understand the range of target speeds and manoeuvres that might reasonably be expected and, where appropriate, any particular coverage areas in the VTS where extreme manoeuvres are most likely to occur. The VTS Authority should ensure that the range of target speeds and manoeuvres is specified as part of the operational needs.

2.5 Operational Requirements

It is recommended that the VTS Authority should specify the Operational and associated Validation Requirements rather than Technical Specifications of radar sensor(s).

The operational requirements may be determined by:

- Definition of the radar coverage of the VTS area;
- Definition of targets to be detected;
- Determination of environmental capabilities and constraints;
- Determination of other influencing factors, radar location(s), obstructions;
- Definition of targets detection requirements in weather and propagation conditions normal for the VTS area;
- Target separation and positional accuracy
- Update rate
- Definition of radar dynamic capabilities and constraints.

This might be an interactive task involving iterations including evaluation of achievable performance versus overall system cost. It might, for example, be better to start with simpler solutions, meeting the available budget, than to be left without any radar coverage.

2.5.1 Definition of Radar Coverage

The recommended method for determination of radar coverage and range performance is a combination of site inspections and radar system performance predictions.

The evaluation should include:

- Calculation of range detection performance, focused on the smallest targets of interest in poor weather conditions;

  All applicable losses should be included in calculations.
- Evaluation of the effects from propagation conditions and obstructions;
- An evaluation of dynamic requirements.

The calculations may be supplemented by comparison and/or validation test.

It will typically not be possible to encounter all combinations of variables, and calculations are therefore made on the basis of a simplified model of the targets and the environment based on statistical information with associated limitations and tolerances.

To provide coverage over large areas and/or to mitigate shadow effects of other vessels, multiple radar sensors may be utilised. Combined processing of images from 2 or more radars may also be utilised for elimination of false (ghost) echoes and to improve target discrimination.

The selected location of radar sensors and their height should ensure that the desired coverage and target separation requirements are met.

The figures below illustrate how the height of the antenna above the water surface affects the maximum and minimum detection range performance.

Careful consideration should be given to optimise radar location(s) and antenna height(s) to ensure appropriate radar coverage and radar target separation.

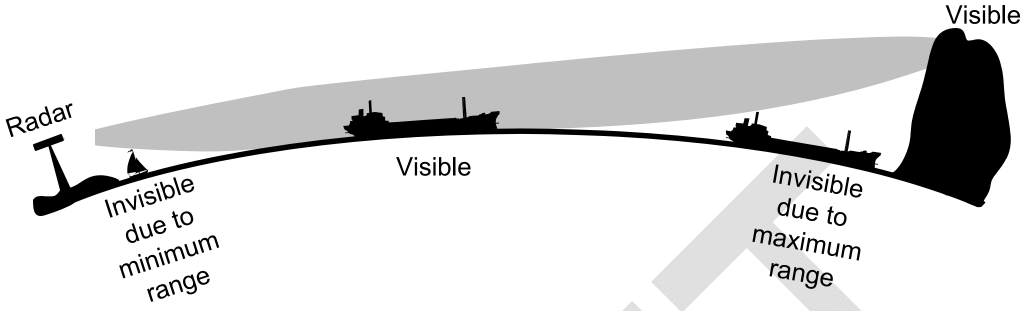

Figure 7 Target range and visibility

2.5.2 Targets to be detected

The radar detection performance should be sufficient to meet the VTS operational requirement in the individual VTS areas. This includes detection and tracking all types of surface objects defined by the VTS Authority in weather conditions typical for the individual site. Special local conditions such as heavy rainfall should also be considered. Additional factors affecting the detection performance of radar systems include noise, interference, clutter and propagation.

Table 10 lists the IALA target types to be detected for different levels of capability. Refer to table 8 for IALA target definitions. Obviously, smaller targets at close range are detectable by radars in any of the categories, but table 10 indicates the minimum applicable for VTS.

Table 10 Targets to be Detected

IALA Target Type	Typically Representing	Capability		
		Basic	Standard	Advanced
1	Aids to Navigation without radar reflector. Small open boats, fibreglass, wood or rubber with outboard motor and, at least, 4 metres long. Small speedboats, small fishing vessels, small sailing boats and the like.			X
2	In-shore fishing vessels, sailing boats, speedboats and the like.		X	X
3	Aids to Navigation with radar reflector.	X	X	X
4	Small metal ships, fishing vessels, patrol vessels and the like.	X	X	X
5	Coasters and the like.	X	X	X
6	Large coasters, bulk carriers, cargo ships and the like.	X	X	X
7	Container carriers, tankers etc.	X	X	X

In addition, any special objects of interest should be specified separately.

2.5.3 Determination of Environmental Capabilities and Constraints

The environmental conditions of the VTS area should be described, including the annual cycle. This should include conditions to be expected as normal over a 12-month period as well as extreme events.

Restrictions with respect to operation and access to site(s) due to weather should also be included.

There is a strong and complicated relationship between radar performance, geographical constraints and environmental conditions and it is highly recommended that individual assessments, involving radar and meteorological experts, are made for each VTS site separately. The sections below indicate typical conditions covering the majority of VTS installations.

2.5.3.1 Precipitation

Information about precipitation over the VTS areas should be obtained from meteorological services, and the VTS Authority should define the required radar performance requirements in clear conditions as well as for normal precipitation conditions.

Note that rising coastline tends to increase precipitation over land at some locations, and normal as well as extreme precipitation over sea may therefore differ substantially from precipitation statistics determined for land-based meteorological stations.

Additionally, high rainfall rates tend to be highly localised. A general formula valid for rainfall rates up to 57 mm/hr, for the diameter (extent) of a rainstorm is given by:

$$D = 41.595 - 23.608 \log(R)$$

Where D is the rainstorm extent (km) and R is the rainfall rate (in mm/hr).

Note that rainfall is rare in dry/hot regions, maybe only once or twice per year and the VTS Authority should consider if rain should be specified at all.

Also note that designing a system to perform in tropical rain showers will typically call for S-band radars. However, the worst rain conditions may only be present for a few hours per year, and reduction in performance on other parameters, may not justify the additional investment.

2.5.3.2 Sea Clutter

Numerous Sea clutter models exist. The CARPET models adopted for this guideline derive the mean sea clutter reflectivity from the clutter model developed by the Georgia Institute of Technology (GIT). The average wave height is derived from the hydrographic sea state so that fully developed sea conditions are assumed. The hydrographic sea state scale with the corresponding wind speeds and average wave heights are shown below.

Table 11 Douglas (GIT) Sea State Table

Sea State	Descriptive Term	Wave Height [m]	
		Average (CARPET)	Significant
0	Calm	0.0	0.0
1	Smooth	0.1	0.2
2	Slight	0.3	0.5
3	Moderate	0.7	1.2
4	Rough	1.3	2.2
5	Very Rough	2.0	3.3
6	High	2.9	4.8
7	Very High	3.9	6.5
8	Precipitous	5.1	8.5

This has also been adapted for this recommendation, providing values of the clutter reflectivity under standard propagation conditions for calculation purposes. Note: this mean sea clutter reflectivity is used for performance assessments within the CARPET modelling. Real world experience at a given site may not align with this simplified model. In particular, for high-resolution radars, the validity of the sea-clutter models is known to be problematic.

The models are also not representative in case of currents in combination with large variations in water depth (for example caused by sand banks and or other obstructions below the waterline). Specific combinations of the relative directions of currents and wind relative to the locations of depth variations can cause localized clutter phenomena that cannot be accurately predicted by generic clutter models. In a practical situation, testing may be required to ensure adequate system performance.

Table 12 provides recommended sea state requirements, used in VTS radar specifications.

Table 12 Sea State Specification Levels (Douglas Scale)

<table>
<tr><th rowspan="2">IALA Target Type</th><th colspan="2">Basic</th><th colspan="2">Standard</th><th colspan="2">Advanced</th></tr>
<tr><th>General</th><th>Ports and Inland Waterways</th><th>General</th><th>Ports and Inland Waterways</th><th>General</th><th>Ports and Inland Waterways</th></tr>
<tr><td>1</td><td colspan="2" rowspan="2">Nil</td><td colspan="2">Nil</td><td>SS 4</td><td rowspan="5">SS 3</td></tr>
<tr><td>2</td><td>SS 3</td><td rowspan="4">SS 3</td><td>SS 5</td></tr>
<tr><td>3</td><td>SS 3</td><td rowspan="3">SS 2</td><td>SS 4</td><td>SS 6</td></tr>
<tr><td>4</td><td>SS 4</td><td>SS 5</td><td>SS 7</td></tr>
<tr><td>5</td><td>SS 5</td><td>SS 6</td><td>SS 8</td></tr>
</table>

2.5.3.3 Other Influencing Factors, Obstructions and Interference

Obstructions, e.g. topography, buildings and other man-made structures may block or reflect radar signals. Other radars and sources of electromagnetic radiation may cause interference.

Inland and harbour VTS will often require special considerations as the number of structures, their density and their close ranges can create very complex distortions. Additional care should be taken to assess and mitigate effects caused by natural and man-made structures such as bridges, buildings, river banks, sheet metal pilings, and steep bends.

2.5.3.3.1 Shadowing Effects

Radar detection may be blocked by shadowing effects that, to the extent possible, should be avoided. Such effects include:

- Targets being hidden by larger targets or other obstructions;
- Masking of small targets by the effects of range and time side lobes.

These effects can be minimised by the appropriate siting of radars and selection of equipment with low side lobes.

2.5.3.3.2 Multipath Effects

The classical radar multipath behaviour associated with air targets and sea surface reflections has limited application and relevance to a system designed for the detection of surface targets. This effect is included within CARPET and, for VTS scenarios, results in shorter detection ranges than might be expected from free-space calculations.

However, multipath conditions resulting from reflections from large buildings and large vessels can still impact on VTS radar performance resulting in the possibility of target signal cancellation or enhancement. This effect is hard to predict and it is unreasonable to expect to model multipath affected performance unless a (potentially expensive) site-specific radar model is developed.

In addition, ghost targets can exist. These derive from undesirable radar echoes resulting from multipath related wave reflections caused by large structures, buildings or vessels.

2.5.3.4 Interference

Interference can be split into susceptibility (received interference) and compatibility (transmitted interference).

To minimise interference, separation between wanted and unwanted transmissions has to be optimised – this can be achieved by a combination of frequency separation, physical separation of transmission sites, antenna directionality, sector blanking, separation by time and also by ensuring that all the systems competing for the same or adjacent spectrum do not transmit excessive and unnecessary transmit power levels or transmit time periods. The radar receiver design will typically be very sensitive (to achieve the required performance), although gain control techniques (swept gain or STC) offer further resistance. Waveform designs incorporating staggered PRFs and processing schemes designed to reject known interference patterns can also aid the radar receiver to suppress unwanted returns.

2.5.3.4.1 Radar Susceptibility

In the case of any radar installation, (e.g. a permanent VTS installation of a radar or of each radar in a VTS network), the performance of that radar can be detrimentally affected by received emissions from other radiating sources (physically adjacent VTS radars, maritime shipborne radars, and other users (legitimate or otherwise) of the electromagnetic spectrum. Typically, local legislative regulations and restrictions will control and minimise unwanted received signals but elimination of such signals is likely to be impossible. National spectrum allocation authorities should always be approached by a VTS integrator when considering any changes to a VTS network (radar, microwave link, communications etc.) to enable a holistic view of the changes and how they might affect all users.

The radar design can assist in minimising the susceptibility to unwanted received interference, e.g. by utilising low antenna side lobes, avoiding large reflecting surfaces, minimising receiver front end bandwidth etc.

Note that FMCW and pulse compression radars may typically require larger front end receiver bandwidths than conventional magnetron systems. The multi-pulse waveforms transmitted (and consequently received) by pulse compression radars have to achieve a compromise between pulse chirp bandwidth (related to range cell size and hence range resolution), use of frequency diversity (to optimise performance in clutter), unwanted pulse to pulse interaction and so on versus spectrum usage and hence unwanted susceptibility with other transmitting spectrum users. FMCW radars transmit and receive (at low levels) for 100% of the time across a swept bandwidth.

2.5.3.4.2 Radar Compatibility with Other Users

In the case of any radar installation (e.g. a permanent VTS installation of a radar or of each radar in a VTS network), the performance of adjacent systems can be detrimentally affected by transmitted emissions from the radar in question (physically adjacent VTS radars, maritime shipborne radars, and other users (legitimate or otherwise) of the electromagnetic spectrum). Typically local legislative regulations and restrictions will control and minimise unwanted transmitted signals but elimination of the influence of such signals is likely to be impossible. As with susceptibility above, National spectrum allocation authorities should always be approached by a VTS integrator when considering any changes to the RF sub- systems within a VTS network.

The radar design can assist in minimising the impact of transmitted signals, for example by utilising low antenna side lobes, avoiding large reflecting surfaces, minimising transmit power, consideration of peak and mean power levels, sector blanking, physical location of the radar etc.

Note that conventional magnetron radars require larger peak power levels than pulse compression and FMCW radar systems. The magnetron technology can result in unnecessary wideband spectral emissions unless steps are taken to include frequency band pass filtering (which has an inherent loss to the wanted signal). However, pulse compression radars and FMCW radars, although utilising lower peak powers, use techniques, which may include frequency modulation, pulse-to-pulse frequency variation, frequency diversity etc. all of which increase the use of the spectrum and increase the chances of unwanted degradation of adjacent systems.

2.5.3.4.3 Influence from Wind Farms

Wind turbines produce large static target-like returns which, from a VTSO’s perspective, are normally easy to distinguish from vessel traffic.

The complex return from a wind turbine is made up of two key elements:

- The tower and generator housing offering a large static zero-Doppler RCS, in some cases up to 1 million square metres.
- The rotating blades of the turbine offering a complex spread of non-zero-Doppler RCS, typically up to 100 square metres, which will vary with wind direction and speed.

This composite return will be seen as a large static target by a conventional pulse radar, whereas FMCW and coherent radars using Doppler processing will see a complex target spread across the Doppler domain.

The influence, independent of the applied radar technology, will be reflections causing unwanted ghost echoes and suppression of nearby targets. The large RCS may also result in antenna side lobe returns, resulting in reduced detectability. The symmetrical layout of wind farms may add further to the disturbances.

2.5.3.5 Calculation of Radar Detection Performance

The achievable target detection range is highly dependent on several factors including antenna height, target characteristics, weather and atmospheric propagation conditions. In the design of radar systems it is furthermore very important not only to focus on maximum detection range but also on radar quality at all ranges, the ability to handle clutter, the ability to suppress interferences and the ability to simultaneous handling of defined (small and large) targets in the VTS area covered by radar.

Calculation for magnetron radars can be performed by the CARPET program (refer to [10]).

> **Warning:** The cumulative detection stated by CARPET can be very misleading if used for determination of VTS detection performance.

CARPET may not be sufficient for determination of performance for pulse compression radars, where it may be necessary to rely on vendor furnished information, possibly supported by performance tests.

The tables below include typical examples of detection and tracking ranges for X-band and S-band radar systems, in standard atmospheric propagation conditions.

These tables use different rainfall rates to align with the likely choice of radar band in high rainfall areas.

Table 13 Typical Range Performance Predictions for X-band Radar

Antenna Elevation	**IALA Target Type**	**Basic**		**Standard**		**Advanced**	
		Clear	**Rain 2 mm/hr**	**Clear**	**Rain 4 mm/hr**	**Clear**	**Rain 10 mm/hr**
20 m ASL	1	Nil		Nil		0.02-5 NM SS 0-4	Nil
	2			0.02-7 NM SS 0-3	0.02-4NM SS 0-3	0.02-7 NM SS 0-5	0.02-6 NM SS 0-5
	3	0.02-7 NM SS 0-3	0.02-4NM SS 0-3	0.02-8 NM SS 0-4	0.02-5NM SS 0-4	0.02-9 NM SS 0-6	0.02-7 NM SS 0-6
	4	0.02-9 NM SS 0-4	0.02-8 NM SS 0-4	0.02-11 NM SS 0-5	0.02-9NM SS 0-5	0.02-12 NM SS 0-7	0.02-10 NM SS 0-7
	5	0.02-12 NM SS 0-5	0.02-10 NM SS 0-5	0.02-13 NM SS 0-6	0.02-11 NM SS 0-6	0.02-14 NM SS 0-8	0.02-13 NM SS 0-8
50 m ASL	1	Nil		Nil		0.05-10 NM SS 0-4	Nil
	2			0.05-10 NM SS 0-3	0.05-7 NM SS 0-3	0.05-12 NM SS 0-5	0.05-9 NM SS 0-5
	3	0.05-10 NM SS 0-3	0.05-6 NM SS 0-3	0.05-12 NM SS 0-4	0.05-8 NM SS 0-4	0.05-14 NM SS 0-6	0.05-12 NM SS 0-6
	4	0.05-13 NM SS 0-4	0.05-12 NM SS 0-4	0.05-15 NM SS 0-5	0.05-13 NM SS 0-5	0.05-17 NM SS 0-7	0.05-15 NM SS 0-7
	5	0.05-16 NM SS 0-5	0.05-15 NM SS 0-5	0.05-18 NM SS 0-6	0.05-17NM SS 0-6	0.05-20 NM SS 0-8	0.05-18 NM SS 0-8
100 m ASL	1	N/A		Nil		0.1-12 NM SS 0-4	Nil
	2			0.1-13 NM SS 0-3	0.1-5 NM SS 0-3	0.1-16 NM SS 0-5	0.1-10 NM SS 0-5
	3			0.1-17 NM SS 0-4	0.1-10 NM SS 0-4	0.1-18 NM SS 0-6	0.1-16 NM SS 0-6
	4			0.1-20 NM SS 0-5	0.1-19 NM SS 0-5	0.1-22 NM SS 0-7	0.1-20 NM SS 0-7
	5			0.1-23 NM SS 0-6	0.1-22 NM SS 0-6	0.1-25 NM SS 0-8	0.1-23 NM SS 0-8

Table 14 Typical Range Performance Predictions for S-Band Radar

Antenna Elevation	IALA Target Type	Standard	
		Clear	**Rain 16 mm/hr**
20 m ASL	3	0.03-4 NM SS 0-4	0.03–3 NM SS 0-4
	4	0.03-7 NM SS 0-5	0.03-5 NM SS 0-5
	5	0.03-10 NM SS 0-6	0.03-8 NM SS 0-6
50 m ASL	3	0.05-7 NM SS 0-4	0.05–4 NM SS 0-4
	4	0.05-11 NM SS 0-5	0.05-8 NM SS 0-5
	5	0.05-14 SS 0-6	0.05-13 SS 0-6
100 m ASL	3	0.1-10 SS 0-4	Nil
	4	0.1-14 SS 0-5	0.1-12 SS 0-5
	5	0.1-18 SS 0-6	0.1-15 SS 0-6

It is normally sufficient to calculate detection range for small and medium size targets, therefore IALA targets type 6 and 7 are not included in these tables.
The minimum ranges stated in the tables are those typically achievable from a pulsed radar with a fan beam antenna. Geographical conditions may set other requirements and other values may offer benefits to the overall design.

Note the influence from sea clutter increases substantially with antenna height with consequential reduction in target detectability.

It should also be noted that radar performance predictions are indications and not guarantees of real world performance. There are many variables within a CARPET-based prediction that can only be considered to be approximations of target, radar and environment behaviour.

> **Warning:** The use of radar prediction models requires full understanding of their validity and limitations. Their use as a comparative tool should be performed by radar experts and any predictions may not represent achievable real world performance. It is recommended that performance validation against expectations includes live testing.

Ku and Ka band performance indications are not provided due to the limited use of them for VTS. Supplier information may be used for comparative purposes.

2.5.3.5.1 Probability of Detection and False Alarm Rate

The probability of detection and the false alarm rates, used for calculations, should comply with those required to meet the operational performance. Please note the definitions of radar P_D and radar P_{FA} (refer to section 2.2.1).

It should also be noted that improved system performance may be obtained by allowing a higher radar P_{FA} in combination with subsequent, enhanced plot extraction and tracking.

At specified maximum coverage ranges, the single-scan probability of detection values for VTS will typically lie in the range from 0.7 to 0.9.

It is normally desirable not to have noise and clutter spikes presented to the VTSO in each scan. Classically, optimal false alarm rates for VTS applications normally lie in the range from 10^{-4} to 10^{-5} for the radar video display. Different values may apply for the tracking, on the condition that tracking requirements are met, however, with modern high resolution technology there is a tendency to allow higher false alarm rates and let the extraction and tracking discriminate between noise and targets of interest.

The false alarms, taken into account in the calculations, should include unwanted information from noise and clutter, as presented to the VTSO or to the tracker (after signal processing), but not signals from other unwanted objects.

2.5.3.6 Influence from Propagation

The performance of surface based radar systems is strongly influenced by the electromagnetic properties of the atmosphere and the surface of the Earth. In free space, electromagnetic waves propagate in straight lines from the antenna toward the targets and back. However, radars located near the Earth's surface should deal with, and adjust to the diffraction and refraction of the propagating wave.

Performance should, in all cases, be evaluated assuming Standard Atmospheric Conditions, combined with precipitation and sea state information for the individual location. Evaluation of the effects from adverse propagation should in addition be included for hot, dry areas of the world, e.g. the Arab Gulf.

2.5.3.6.1 Propagation in the Standard Atmosphere

An electromagnetic wave observed at a target consists of a summation of an infinite number of contributions from different paths to the target leading to constructive and destructive contributions at the target. The return path suffers from similar effects. For small low targets this results in shorter detection ranges, than the distance calculated by simple line of sight calculations.

In addition, the barometric pressure and water vapour content of the standard atmosphere decreases rapidly with height, and the temperature decreases slowly with height. This causes the electromagnetic waves to bend a little towards the Earth's curvature.

Radar parameters, losses in transmission lines (not only waveguide), processing losses, clutter and precipitation add to the complexity and, even for the Standard Atmosphere, it is necessary to combine this with propagation factors by radar calculation tools in order to determine the predicted performance for a VTS radar sensor. This is typically modelled by increasing the radius of the Earth by a multiplier (typically 1.33) and assuming straight-line propagation.

2.5.3.6.2 Sub-refraction and Super-refraction

Sub-refraction, bending the electromagnetic waves up, and super-refraction, bending the electromagnetic waves down, exists when the atmosphere deviates from the standard.

Sub-refraction can be caused by fast reduction of temperature and slower reduction of water vapour content with height, bending the electromagnetic waves towards space. However, this phenomenon occurs rarely in nature.

Super-refraction can be caused by temperature increase with height (generally by temperature inversion) and/or rapid decrease of water vapour with height, decreasing N. Decreasing the refractivity gradient will eventually cause it to reach the critical gradient, at which point an electromagnetic wave will travel parallel to the Earth's curvature.

2.5.3.6.3 Ducts and Trapping Layers

Super-refraction will develop into trapping layers, if the refractivity gradient decreases beyond the critical gradient, at which point the electromagnetic wave will be trapped and follow the Earth's curvature.

Ducts act like waveguides for propagating waves bordered by trapping layers or the Earth's surface. In order to couple into a duct and remain in a duct, the angle of incidence must be small, typically less than 1°.

Ducting can be categorized into three main types:

- Evaporation duct:
  - Weak, caused by evaporation from the sea surface, and only at low levels (maximum of 40 metres ASL);
  - Generally increasing the radar horizon, especially for low mounted antennas.
- Surface-based duct:
  - Surface ducts caused by low level inversion (increase of temperature /decrease of humidity with height), up to 500 metres ASL;
  - Increase of radar range, depending on duct and antenna height.
- Elevated duct:
  - 0.2-2 km above the surface;
  - Typical no effect on surface-based antennas.

The effects are typically increased range but also increased amounts of noise and 2^{nd} / multiple time around returns which may appear as false radar returns.

Notice that the electromagnetic waves are refracted (bent) and not reflected by the trapping layers.

2.5.3.6.4 Evaporation Ducts

Evaporation ducts exist over the ocean to some degree, almost all the time. A change in the moisture distribution without an accompanying temperature change will lead to a trapping refractivity gradient. The air in contact with the ocean surface is saturated with water vapour, creating a pressure that is decreasing to some value above the surface.

This will cause a steep refractivity gradient (trapping) near the surface, but will gradually equalise towards normal refractivity gradient at a certain height, which is defined as the evaporation duct height.

Evaporation ducts are generally increasing the radar detection range and the antenna can be located above the duct and still have extended propagation strength. The effect of evaporation ducts is usually more noticeable for higher frequency radars. This means that the radar range extension caused by an evaporation duct will in general be more noticeable for a X-band radar than for a S-band radar.

For typical coastal radar installations, evaporation duct heights of 6 – 15 metres lead to the longest detection ranges. Evaporation duct heights of more than 10 metres will also introduce an increased amount of clutter, setting additional demands to clutter processing and noise reduction capabilities.

For example, investigations of weather data from the Arab Gulf area show that evaporation ducts exist all the time with typical duct heights of 5 to 25 metres, resulting in increased radar range in 80% of the time and increased clutter in 50% of the time.

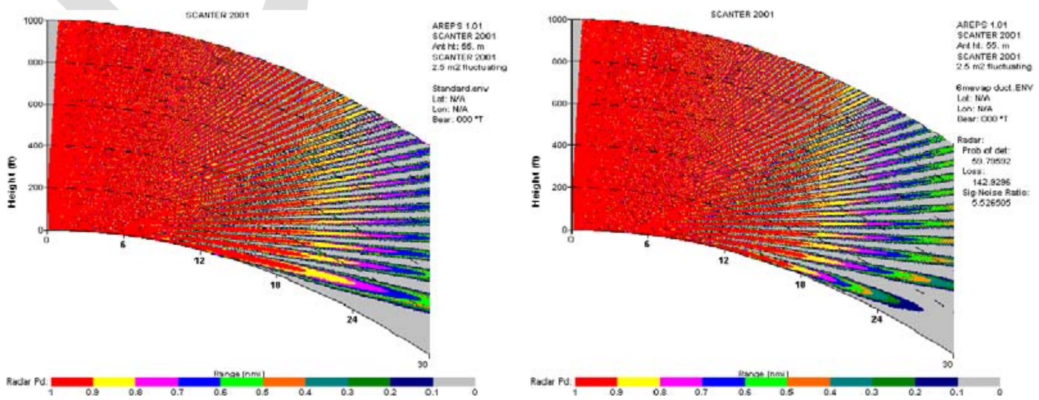

Figure 8 Coverage diagram, in normal atmosphere (left) and including an evaporation duct (right).

2.5.3.6.5 Surface-based Duct

Surface based ducts can be much stronger than evaporation ducts. They occur when the air aloft is hot (and dry) compared to the air at the Earth's surface. Over the ocean and near land masses, dry continental air may be advected over the cooler water surface; either directly from leeward side of continental land masses or by circulation associated with sea-breeze.

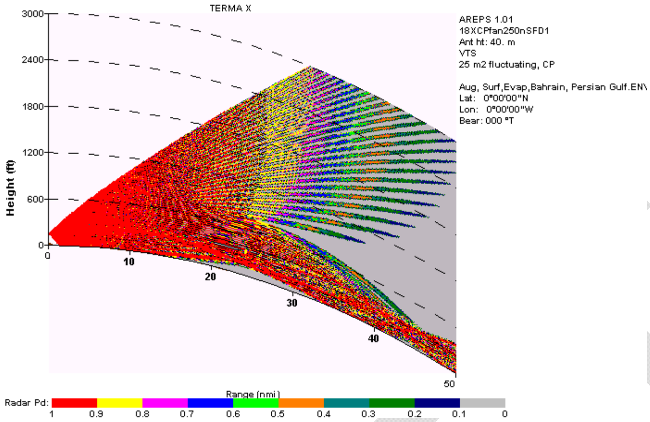

Figure 9 Example of simulated radar coverage in surface based + evaporation ducting conditions.

In addition to the temperature inversion, moisture is added to the cool marine air by evaporation, increasing the trapping gradient. In coastal areas, this leads to surface trapping ducts. However, away from land, this trapping layer may well rise from the surface thereby creating an elevated duct.

The electromagnetic wave will be refracted towards the surface of the Earth and be trapped in the duct like in a waveguide. This kind of trapping condition greatly increases the surface detection range - and the amount of noise received. Note that surface detection may occur far beyond the radar horizon with a "dead zone" in between.

Surface based ducts are often combined with evaporation ducts and examples of radar performance in such conditions, as illustrated by figure 9.

2.5.3.6.6 Elevated Duct

Generally, elevated ducts occur from descending, compressed and thereby heated air, from anticyclones, approaching the marine boundary layer and causing ducts. Elevated ducts may also occur from elevating surface-based ducts.

Surface detection might also occur in this case far beyond the radar horizon with a "dead zone" in between, adding noise to the radar image.

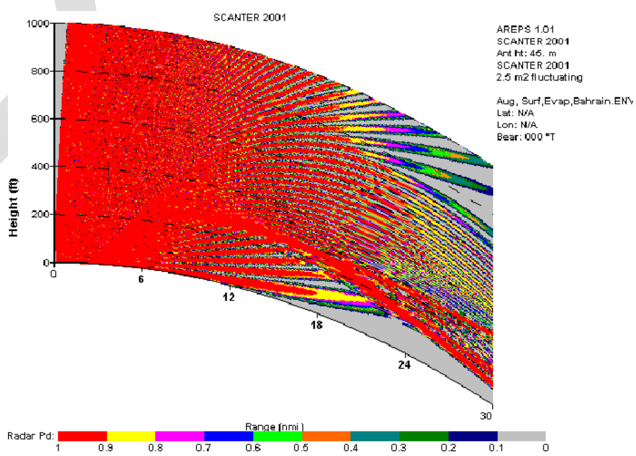

Figure 10 Coverage diagram, elevated duct

2.5.3.6.7 Severe Ducting at Coastlines Adjacent to Hot Flat Deserts

The large temperature variation between night and day in desert areas and the associated pressure differences between land and sea tend to cause very strong temperature inversion during night-time and result in strong sea breeze in the afternoons. This can result in very severe ducts. This type of duct can be very low, as little as 15 metres has been experienced

Range performance is very different for an antenna positioned inside or above these ducts, and radar systems with an antenna positioned within such a duct will have substantial increase in the detection range for surface targets. If the antenna is positioned above the trapping layer (outside the duct), the electromagnetic wave will be refracted and the detection range for surface targets will be substantially reduced.

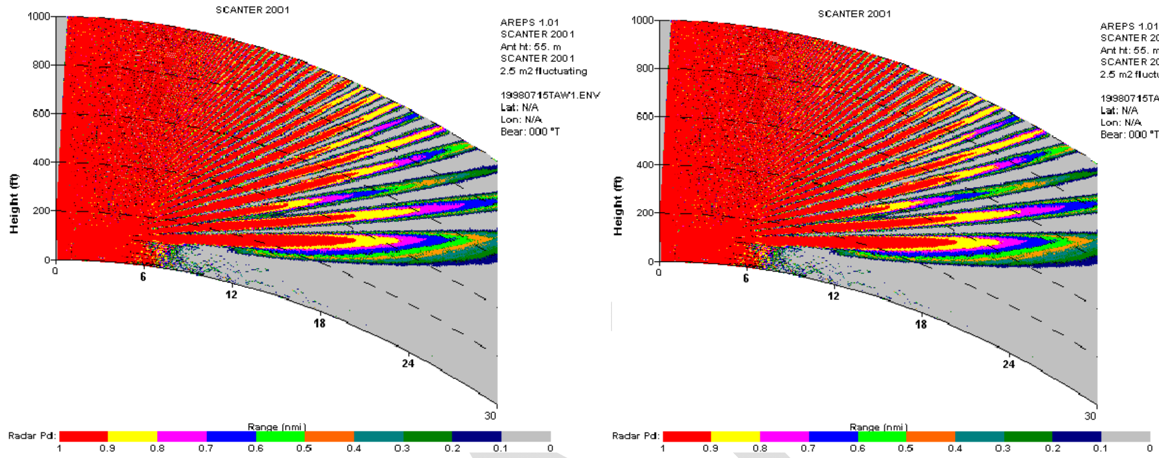

Figure 11 Coverage diagram based on a measured condition at a coastline adjacent to hot flat deserts.

Note. The radar detection using antennas positioned inside the duct (left) and above the duct (right) corresponded to the simulated coverage diagram.

The sea breeze also causes eddies over the sea, forming distinctive sea clutter patterns. The eddy results in a “snake” like pattern moving forth and back for a few hours in the afternoon on hot days with strong sea breezes (see figure 12). Of course, this may disturb display and tracking.

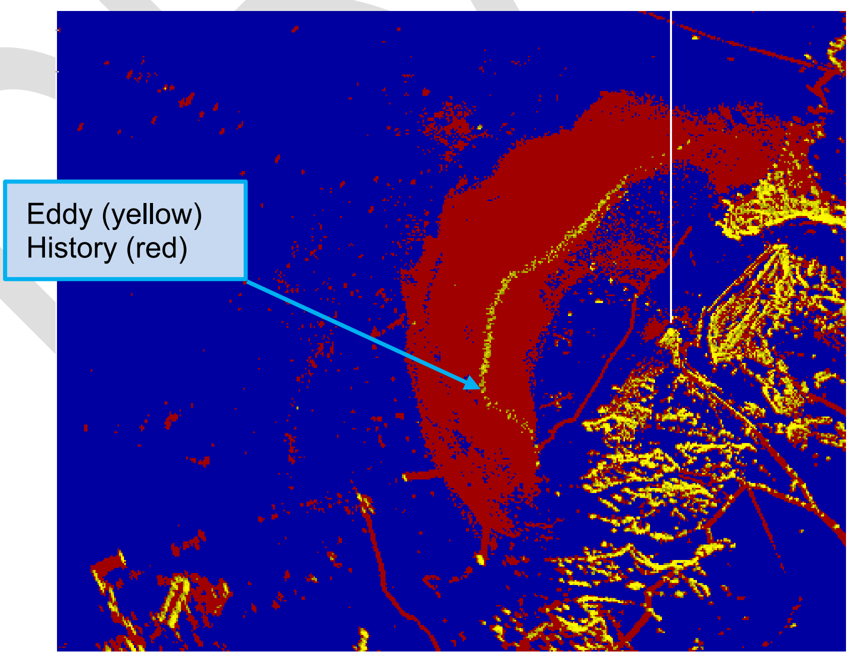

Figure 12 One hour of recordings with trials (snail tracks) shown in red.

Note. The yellow ‘snake’ at sea is an eddy moving back and forth with a speed of approximately 4 knots.

2.5.4 Target Separation and Target Accuracy

Target separation (sometimes referred to as discrimination) requirements and target accuracy requirements should be considered separately.

2.5.4.1 Target Separation

In normal weather and propagation conditions, surface objects within the VTS area should be separated in presentation, and individually tracked without track swap, at any applicable target speed when they are positioned apart and with distances as defined by the individual VTS Authority.

The system should be designed in such a way that the required radar separations based on risk assessments can be achieved in the identified area(s) covered by the VTS service. At long range, the impact of the height and type of antenna on the resolution performance should be taken into account. The system should also be capable of displaying and tracking all detectable targets of interest simultaneously in normal conditions, preferably without the need for manual adjustments by the VTSO.

The recommended definition of target separation is to specify the point of intersect between the two returns of point source and similarly sized targets, as being -6dB relative to the peak signal of the smaller target. A VTSO will normally be able to distinguish between 2 targets on a radar display using this definition.

For the extraction and tracking process more separation is needed, typically double spacing of that achieved at the -6dB points.

Warning: Measurement of separation using small floating targets can be unreliable due to target fluctuations. Instead it is recommended to use small radar reflectors placed in a clutter free land area, e.g. a paved area or a beach. It is normally sufficient to measure at one or two points in distance, typically with reflectors placed in the far field beyond 1 nautical mile from the radar. For short range applications, a similar test at the range(s) of interest may be more appropriate.

Typically, target separation is achieved by a combination of range and azimuth (and Doppler, when available). The following sections assume separation is achieved individually in each of these dimensions.

2.5.4.1.1 Range Separation for Small Point Targets

The range separation is, for traditional magnetron radars, linked to the transmitted pulse length, see table 15. Substantially better range separation may be achieved by pulse compression radars[2].

Table 15 Typical Range Separation

Typical Range Separation of Small Point Targets [m]				
		Basic	**Standard**	**Advanced**
		-6 dB points		
Minimum Range Separation	Less than 5 NM instrumented range	25	20	15
	5-20 NM instrumented range	75	60	50
	More than 20 NM instrumented range	N/A	100	80

2.5.4.1.2 Azimuth Separation for Small Point Targets

[2] Pulse compression may be subject to export restrictions for some countries.

Guidelines for separation requirements for similar sized, point targets are given by table 16.

Table 16 Typical Azimuth Separation

Typical Azimuth Separation of Small Point Targets					
	X-Band Radar			S-Band Radar	
	Basic	Standard	Advanced	Standard	Advanced
	-6 dB points				
Azimuth separation in angle (in °)	1.0	0.6	0.5	2.4	1.5
Or distance, whichever is the greater [m]	25	20	15	20	15

Note that the definition of azimuth separation has been further refined compared to previous editions of this guideline; however, expectations to radar performance remain unchanged.

2.5.4.1.3 Separation of Larger Targets

Beyond the separation of point targets, the VTS Authority is recommended to express target separation requirements in operational terms rather than radar subsystem parameters.

For larger (non-point) targets and for separation of dissimilar sized targets, the definition of separation is highly dependent on physical size, aspect angles, relative return amplitude, pulse stretch, and other radar characteristics. System capability should be assessed by live testing of predefined scenarios, as modelled or predicted performance can give misleading results.

Note: In the special case of offshore installations with low traffic density combined with severe consequences of accident, it is recommended that target separation equivalent to Basic capabilities are considered, whereas other operational requirements should be Advanced.

2.5.4.1.4 Doppler Separation

The use of Doppler separation (based on target radial velocity) to achieve successful target separation, can improve performance, however, single targets can create multiple, complex Doppler returns which can lead to confusion when associating track updates with existing tracks. Therefore, it is generally suggested that there should be a separation of at least one Doppler resolution cell when relying on Doppler separation.

Radars incorporating Doppler or MTI processing are subject to Doppler side lobes which in addition can limit Doppler separation of smaller fast moving targets from large targets at the same range.

2.5.4.2 Target Position Accuracy

The system should be designed in such a way that the defined radar target accuracy is aligned to the core operational requirements.

Several elements of a VTS system contribute to the track accuracy and these should be appropriately budgeted for before deriving the radar sensor accuracy requirements. The target tracking requirements contained in Section 9 should be used in combination with knowledge of the design of the target tracking function to derive the individual radar sensor measurement accuracy requirements. Typical target position accuracy is provided in table 17. This includes the effects of quantisation noise (related to radar cell size), plot extraction, calibration and installation inaccuracies.

The impact of the antenna height on the measuring accuracy (slant range vs. plan range) is additional to the figures.

Table 17 Typical Target Position Accuracies

Typical Target Position Accuracies (RMS) for Small Point Targets						
		Basic	**Standard**		**Advanced**	
		X-band	**S-band**	**X-band**	**S-band**	**X-band**
Range (Slant range from radar to trailing edge of return)	Maximum fraction of instrumented range	0.50%	0.20%		0.10%	
	Or absolute value, whichever is the greater [m]	15	10		5	
Azimuth	Maximum angular error (in °)	0.50	1.00	0.35	0.50	0.25
	Or absolute value, whichever is the greater [m]	15	20	10	10	5

Warning: Measurement of accuracy using small floating targets can be unreliable due to target fluctuations. Instead it is recommended to use small radar reflectors placed in a clutter free land area, e.g. a paved area or a beach. If a suitable land area is not available, the measurement of accuracy should be carried out in a calm sea area.

It is normally sufficient to measure at one or two points in the distance, typically with reflectors placed in the far field beyond 1 nautical mile from the radar. For short range applications a similar test at the range(s) of interest may be more appropriate.

2.5.5 Update rate

The required radar update rate is determined by the behaviour of the expected target types. Typical update rates for VTS lie between 2 and 4 seconds, however, values outside this range may offer alternative benefits to the overall design.

For short range applications with requirements to follow fast manoeuvring targets, update rates of 1-2 seconds may be beneficial. Up to 10 seconds may be preferable for very long range applications.

Note that tracking performance, especially the continuity of tracks, can be highly dependent on the radar update rate and there is a trade-off between radar sensitivity, accuracy and the ability to follow fast manoeuvring targets.

2.5.6 Radar Dynamic Capabilities and Constraints

2.5.6.1 Dynamic Requirements

The dynamic range of the radar should, in normal weather and propagation conditions, detect and process the surface objects specified by the VTS Authority. This should be achieved without significant side lobes, degradation of target appearance, degradation of detection or degradation of separation capability.

The dynamic range is determined by:

- The ratio between the largest nearby objects expected and the smallest distant objects to be detected;
- Target return signal fluctuations including multipath.

Requirements for the radar(s) can be determined from the characteristics of the objects in the coverage area of the individual radar. The characteristics of objects typically considered and the corresponding dynamic range, as a function of RCS and detection range, can be determined from figure 13.

The figure represents targets in free space. This is normally sufficient for the determination of VTS radar requirements when combined with 10 dB allowance for target fluctuations.

> **Notes**: If more accurate determination than that from the graph in figure 13 is deemed necessary, this can be performed using performance evaluation tools, combined with evaluations of near range effects.
>
> Technology limitations may restrict compliance with the extreme dynamic range that could be derived from figure 13. The numbers suggested in the notes in figure 13 are achievable at the time of compilation of this document (2015).

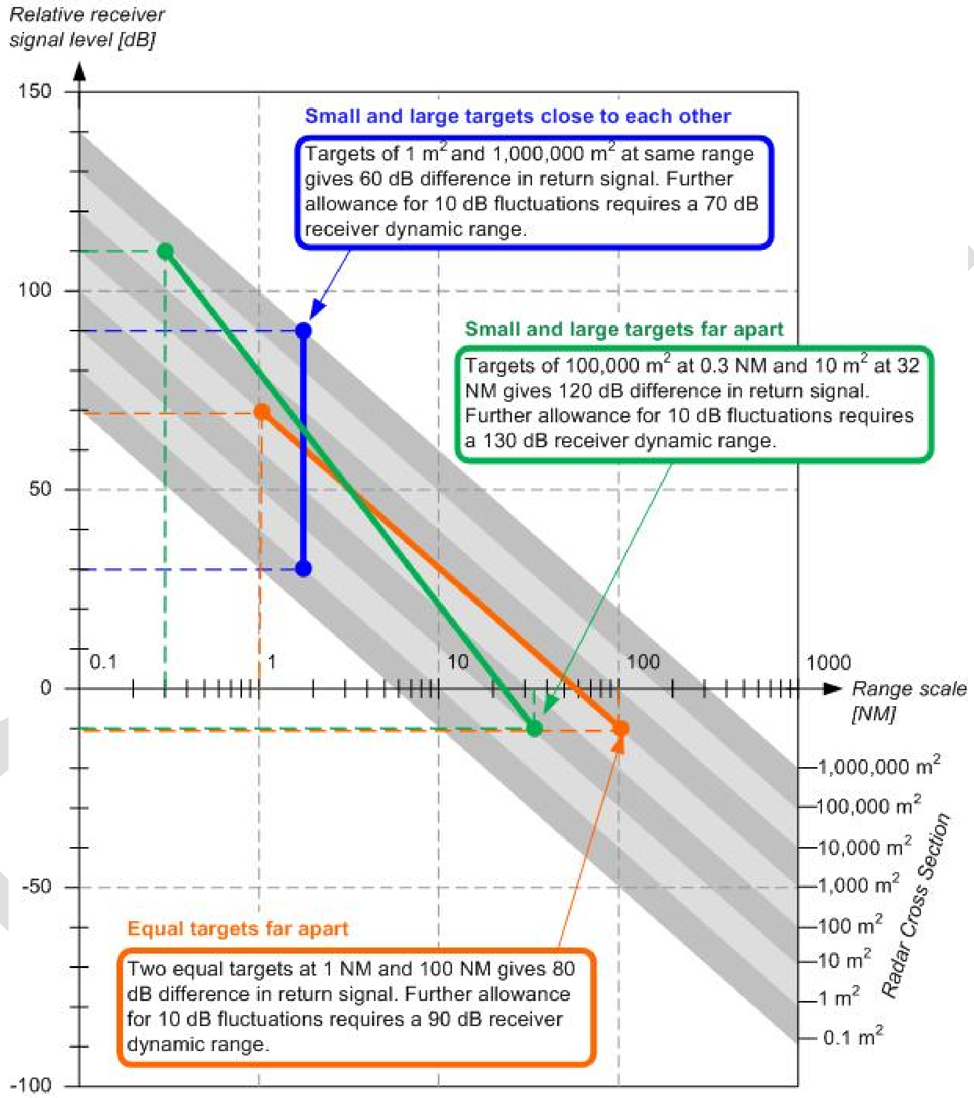

Figure 13 Dynamic characteristics of signal received versus target RCS and target range (in NM) for point targets in free space

2.5.6.2 Sidelobes

Side lobes (see figure 14) are unwanted, as they will limit the size of a small Radar Cross Section (RCS) target that can be detected next to a large RCS target. The ratio between the peak level of the target and the highest side lobe is called the Peak Side Lobe Ratio (PSLR).

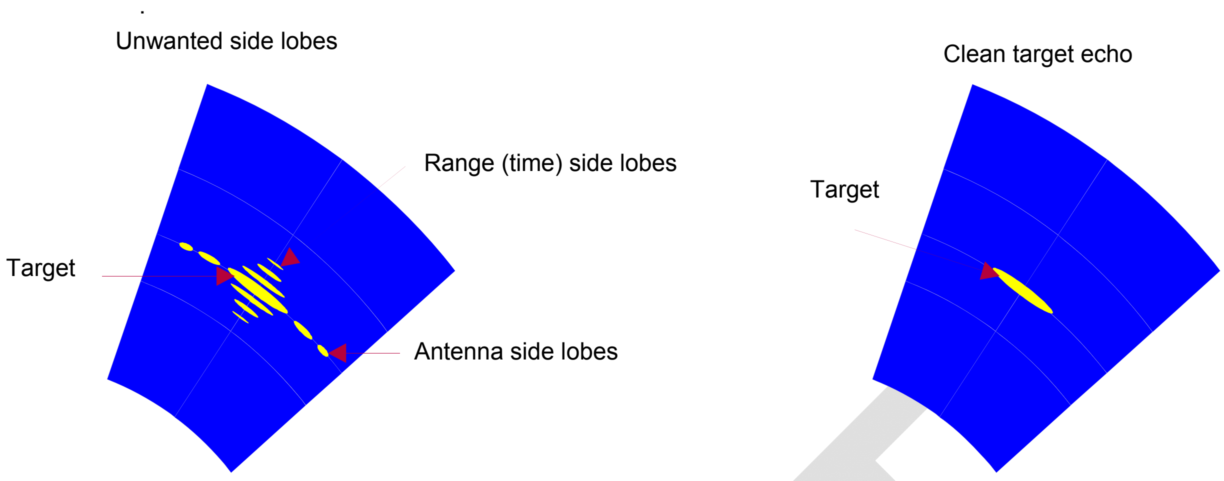

Figure 14 Side lobe effects

Typically, azimuth (antenna) side lobes are the only contributor in traditional magnetron pulse radars. FMCW and pulse compression radars are subject to range as well as azimuth side lobes.

Table 18 Maximum Side Lobe Level Relative to Non-saturating Target Signals

	Level		
	Basic	**Standard**	**Advanced**
Maximum near side lobe level (within +/- 10° in azimuth and +/- 250 metres in range from any target)	- 52 dB (-26 dB one way)	- 54 dB (-27 dB one way)	- 56 dB (-28 dB one way)
Maximum far side lobe level (outside +/- 10° in azimuth and +/- 250 metres in range from any target)	- 66 dB (-33 dB one way)	- 68 dB (-34 dB one way)	- 70 dB (-35 dB one way)

Side lobes should be sufficiently low to avoid masking of smaller targets in the proximity of large returns from targets or clutter. In addition, low side lobes minimise the probability of false targets arising from other large returns. Table 18 recommends the maximum allowed signal presented to the display and plot extractor, originating from antenna and range (or time) side lobes.

The figures account for two way propagation, therefore the antenna side lobe requirements (one way) equal half the values indicated (dB s divided by 2).

Also note that structures near antennas (in some cases up to 100 metres) tend to distort wave propagation and, thereby, increase the azimuth side lobe level in the direction of such structures.

2.5.6.2.1 Doppler Side Lobes

Radars incorporating Doppler or MTI processing are also subject to Doppler side lobes which can limit detectability of smaller targets competing with large clutter, but these radars offer performance benefits when compared to radars without Doppler or MTI processing.

Currently (2015), typical VTS radars do not achieve Doppler side lobe levels which are comparable to the figures in table 18 due to cost constraints. 30 to 40dB is a realistic expectation and this imposes a corresponding limitation on the visibility of small targets competing with Doppler side lobes from large returns at the same range.

2.6 Functional Requirements

The radar service in a VTS should, as a minimum, support the operational functions specified by section 1.4 as well as the functions listed below.

These functions may be hosted by the radar sensors or other parts of the VTS system.

2.6.1 Operational Outputs

The output from a radar service should include radar image data and track data. In addition, the output from the radar service may include clutter data to enable identification of, for example; squalls, oil spills, ice detection, wave height, etc.

2.6.2 Operator Functions

Radar functions should be designed and implemented to optimise performance and minimize VTSO workload to the level practical. Ideally, the VTSO should only need to control basic functions such as start and stop.

Each radar site should be designed and equipped to reduce the adverse effects of rain and sea clutter and enhance the probability of target detection and it is recommended to make adaptation to changing weather conditions, etc. automatic to reduce VTSO workload. However, it might be necessary to implement dedicated operational modes e.g. for adaptation to weather.

Manual override of automatic functions should always be possible.

2.6.3 Clutter and Noise Reduction / Management

Appropriate, clutter reduction or clutter management should be available to meet the performance requirements.

This will typically include:

- White noise suppression
- Interference rejection
- Sea and rain clutter processing
- Adaptation to varying propagation conditions.

The features should preferably be automatic for systems requiring standard or advanced capabilities.

2.6.4 Elimination of False Echoes

The radar should also be designed and installed so as to eliminate, to the maximum extent possible, false echoes caused by side lobes, reflections from nearby structures or second/multiple time around echoes.

2.7 Radar Design, Installation and Maintenance Considerations

The radar systems should in general be designed taking the general considerations in Section 1 into account.

Special safety precautions for radar should include but not be limited to those applicable for Rotating Machinery, Radiation Hazards and Electrical Shock.

Special precautions should also consider lightning protection, wind load on antennas and access to the systems, including antennas for installation and maintenance. Turbulence, asymmetrical wind and vertical wind components should be considered with reference to the descriptions in Section 1.

Waveguides should in general be kept as short as possible. Their length and associated losses need to be included when determining system performance. Waveguides should always be equipped with dehumidifiers or simple desiccators.

Concerning the lightning rod it is recommended to place this in a blanked sector or in a direction of low practical importance.

2.7.1 Service Access

Service access should be possible at the individual radar location.

A local service display at each radar sensor, providing radar control, BITE results and other specified radar information is recommended.

To the extent practical, service access should be possible remotely, for example, at the central monitoring location for the VTS network.

2.7.2 Antenna Accessibility

When siting a radar, the accessibility should be carefully considered – for example an access ladder and maintenance platform may be required to ease maintenance on a tower or tall building.

2.7.3 Antenna Robustness

The installation of a radar can introduce problems resulting from high winds. In some cases it may be appropriate to separately specify both the survival wind limits and a lower operational wind limit within which the system should not be degraded due to the normal weather conditions specified for that location. High winds can affect the motor and gearbox design and can affect the instantaneous rotation rate at varying angles to the predominant wind direction. The build-up of ice in some climates should also be a consideration.

Plot accuracy can be affected by high winds and the overall system azimuth accuracy should consider torsional errors arising from high winds.

In extreme conditions, it may be appropriate to house the rotating radar antenna within a static radome although this can increase costs and RF losses and complicate maintenance of some components.

2.7.4 Choice of Upmast versus Downmast Transceivers

The radar designer may also have a choice of whether to locate the transceiver upmast or downmast. In the latter case, a waveguide run may be required to link the RF output / input of the transceiver to the antenna. Such a run of waveguide will introduce losses which should be considered as a part of the evaluation of the predicted performance of a given radar installation.

Conversely, an upmast transceiver installation may be more difficult to access for maintenance and servicing than a downmast transceiver which might also benefit from an environmentally controlled location and consequent improvement in equipment reliability.

Further issues might include the need to transfer high bandwidth video (on copper, fibre or microwave link etc.) which can influence the radar designer’s selection of whether to use an upmast or downmast transceiver. Incorporation of transceiver redundancy can also influence the choice of transceiver location.

2.7.5 Built In Test Equipment

BITE should include monitoring of functions and performance. Communication of summary alarms and system status to a central monitoring system may be required. It is recommended that detailed BITE results are made accessible for remote monitoring, especially for radars installed in locations that are difficult to access.

2.7.6 Protection against Extreme Events

Authorities responsible for VTS areas subject to adverse weather such as cyclones, typhoon, hurricane, and tornado should consider the potential impact and specify requirements to equipment survival. Radar operation is normally suspended in such conditions.

Refer to Section 1, Section 1.4.3 for further guidance

2.8 Verification of Function and Performance Requirements

Refer to section 13 for general guidelines.

It is recommended to base acquisition of radars and subsequent verification after installation on the basis of measured performance data using real targets.

Such measurements should be carefully analysed including the influence from weather and propagation.

> **Note**: Verification of radars using floating point targets, such as corner reflectors or Lunenburg reflectors, is subject to large inaccuracies due to sea surface movements and variations in propagation.

It is suggested to measure the radar cross section of real targets and use those for actual measurements.

Radar cross section measurement of targets should be made in calm sea conditions, at close range and using stable (not moving) Luneburg reflectors as reference.

3 AUTOMATIC IDENTIFICATION SYSTEM

3.1 Introduction

The purpose of this section is to support Competent and VTS authorities in the understanding of AIS performance, supporting the design of the AIS service and its contribution to the VTS traffic image (situational awareness).

AIS operates within the marine VHF band and has the same limitations as VHF communication. Secondly, an AIS reported position is primarily based on GNSS-sourced positional data with associated capabilities and constraints.

VTS Authorities could consider recommending Class-A devices for non-SOLAS vessels that participate in VTS or provide support for VTS operations.

3.2 Definitions and References

3.2.1 Definitions

For general terms used throughout this section, please, refer to reference [1].

3.2.2 References

[1] IALA Recommendation A-124 - On the AIS Service.

[2] IALA Binary message register - Collection of regional applications for AIS application Specific Messages of regional applications for AIS Binary Messages (http://www.iala-aism.org/iala/files/newitems3.php).

[3] IALA Guideline N° 1028 - On the Universal Automatic Identification System (AIS)

[4] IALA Recommendation V-125 - The use and presentation of symbology at a VTS Centre

[5] IALA Recommendation A.126 - Use of AIS in Marine Aids to Navigation Services

[6] IALA Recommendation e-NAV144 – On Harmonised Implementation of Application-Specific Messages

[7] IMO SN.1/Circ.289 - Guidance on the Use of AIS Application Specific Messages

[8] ITU-R M.1371- Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band

[9] IEC 62320 - Maritime navigation and radiocommunication equipment and systems – Automatic identification system (AIS) – Part 1: AIS Base Stations – Minimum operational and performance requirements, methods of testing and required test results

3.3 Objective of AIS

The objectives of AIS in VTS are:

- Automatically receive information from AIS-equipped vessels, including the ship's identity, ship type, position, course and speed over ground, navigational status and other safety-related information;
- Monitor and track AIS-equipped vessels;
- Exchange data with AIS-equipped vessels;
- Support value added functions over the AIS infrastructure;
- Manage AIS-based Aids to Navigation (including virtual and synthetic AtoN).
- Provision of vessel identification and location information to the VTS traffic image;
- Provision of vessel manoeuvring and voyage related data to the VTS;
- Provision of facilities to enable transmission of information between the VTS and the mariner.

3.4 Physical Implementation of VTS AIS

3.4.1 Equipment

The Physical Equipment options for a VTS Authority are as follows:

- AIS base station;
- AIS limited base station;
- AIS receiver;
- AIS repeater;
- AIS Aid to Navigation (AtoN).

In all cases, careful consideration should be given as to whether the information is sufficient to support the required VTSO tasks.

An AIS repeater may be used to extend the AIS coverage area of a VTS system.

AIS can be an integral part of an Aid to Navigation such that the AtoN position and other AtoN-related data can be transmitted over the AIS network and received by ships.

3.3.2 AIS Licensing and Siting

An AIS base station will need to be licensed by the appropriate national Radio Communications or Broadcast Authority in most countries. The licensing process will also determine any restrictions regarding the siting of the AIS base stations and their aerials. Potential AIS base station sites are determined based upon a cellular mapping of all base station sites (See section 7 of IALA Recommendation A-124). AIS Cells are 30NM x 30NM square with a limit of two (2) base stations to each cell. One of the AIS base stations within a cell is configured to transmit its Fixed Access TDMA (FATDMA) information on one of the AIS VHF frequencies and the other base station is configured to transmit its FATDMA information on the other AIS VHF frequency. However, if an adjacent cell has less than 2 base stations (this can include a cell that is adjacent and inland), then additional base stations can be included by borrowing the allocation from the adjacent cell. The cell size also means that AIS VHF aerials should not be positioned higher than approximately 35m above sea level.

The limit of two base stations per cell is to ensure that the number of FATDMA slots is not excessive in any one geographic area. AIS base stations can transmit their own position so that the port appears on the ECDIS display of incoming vessels. However, the position transmission is repeated in a fixed slot on every AIS net cycle and, therefore, it consumes a fixed amount of the AIS bandwidth. If there are too many timeslots allocated for FATDMA, it reduces the availability of TDMA slots which are used by the AIS transponders on-board vessels for their normal position and ID transmissions.

It should also be noted that if the base station does not need to transmit its own position and, therefore, does not use FATDMA, then the number of base stations per cell can be increased.

Every AIS base station has a MMSI (Maritime Mobile Service Identity). Where a VTS system has multiple AIS base stations to cover a large VTS Area, each base station can be given the same virtual MMSI so that the whole VTS system appears with a single identity. The MMSI will normally be issued by the appropriate national Radio Communications or Maritime Authority when licensing the use of AIS frequencies.

3.5 Operational Requirements

AIS may provide timely, relevant and accurate information to VTSOs to support the compilation of the VTS traffic display. It provides automatic vessel position reports and movement information as it is received at base station sites. Where radar is installed as part of the VTS sensor suite, the AIS information should be correlated with the radar target data to ensure that each vessel within the VTS area is represented by a single track on the VTS Traffic Display. AIS also provides supporting information about the ship and its current voyage that may be integrated with other port operations.

The provision of information from the VTS to the mariner and vice versa is supported by AIS through the use of short text messaging and the global and regional binary messages within the AIS protocol.

3.6 Functional Requirements

3.6.1 Support to the VTS Traffic Image

3.6.1.1 Target Tracking

The Automatic Identification System (AIS) provides identification and position to enable the VTSO to monitor and track vessels within the VTS Area. AIS transmissions consist of bursts of digital data 'packets' from individual stations, according to a pre-determined time sequence. AIS data consists of shipboard information such as position, time, course over ground (COG), speed over ground (SOG) and heading.

The AIS position reporting rate is dynamic and will change, depending on the speed of the reporting vessel and whether the vessel is manoeuvring or not. For a class-A transponder, the nominal position reporting rate is once every 10 seconds. For a high-speed and/or manoeuvring vessel, this rate may increase up to once every 2 seconds. Conversely, for a vessel, moored or at anchor, the position report rate may drop to once every 3 minutes.

Although the standard position reporting intervals are normally sufficient, an AIS Base station may be used to temporarily increase the position report rate of targets of interest. AIS may enhance situational awareness for the VTSO by improving the detection of vessels that are obscured from line of sight associated with other sensors. As a cooperative means of identification and detection, the AIS element of a VTS will receive data from any vessel that is equipped with a transponder even in severe sea and rain clutter conditions.

3.6.1.2 Aids to Navigation

AIS AtoNs (including real and virtual AtoNs) will be presented to the VTSO through the traffic image.

3.6.1.3 Voyage-Related Data

AIS provides facilities for mariners to enter details of their voyage, ETA and cargo etc. This static data is part of the standard AIS transmissions at 6 minute intervals or on request. The static data may be received by the VTS system and can be used to support VTMIS applications such a Port Information Management databases. Note, however, that, due to the absence of any commonly agreed procedure to update this data, it may not be present, be outdated or simply incorrect.

3.6.2 Information Exchange between VTS and Mariner

3.6.2.1 Text Messaging

A VTS Authority could use AIS to send free-format text messages to a vessel at sea. Such messages are intended to be for safety-related purposes. When received, AIS text messages will appear on the Minimum Keyboard Display (MKD) of the on board AIS system, and could also be displayed on other systems such as ECS/ECDIS. Note, however, that AIS text messages are not a replacement for voice communication; a VTSO should not assume that AIS text messages were received and read on-board.

AIS text messages can be addressed either to a specified destination (MMSI) or broadcast to all ships in the area. The content should be relevant to the safety of navigation, e.g. an iceberg sighted or a buoy not on station. Such messages are limited to a maximum of 156 characters for an addressed message and 161 characters for a broadcast message. Although unregulated, AIS messages should be kept as short as possible (preferable less than 48 characters for an addressed message and less than 53 characters for a broadcast message).

3.6.2.2 Binary Messaging

In addition, AIS has facilities for sending and receiving binary messages (there are 4 types of binary messages within the AIS protocol) and these can be used for supporting and 'value added' applications. Binary messages are specified as "global" or "regional", where the global messages are in accordance with reference [7] and the regional messages may be defined by appropriate authorities (see references [2] and [6] for further details).

The AIS infrastructure and protocol provides facilities to enable application developers to produce new functionality and capability though the use of the binary messaging features. All such developments and message sets should be consistent with the purpose of AIS in respect to enhancing Safety of Life at Sea.

It should be noted that the approval of the appropriate National Authority may be required for the use of the AIS VHF data link for a supporting application. One example of a supporting application is the transmission of specific hydrographical data.

It is recommended that National Authorities should monitor and coordinate the use of binary messaging within their area of responsibility to ensure that the necessary facilities for ship reporting via the VHF Data Link (VDL) are not compromised.

3.6.2.3 Aids to Navigation

AIS base stations, as part of a VTS System, can be configured to broadcast synthetic and/or virtual aids to Navigation (AtoN). See definitions detailed in IALA Recommendation A.126 [5]

AIS may be integrated with a physical AtoN for monitoring and control purposes and, also, in such a way that other data sources, hosted on the AtoN, can be managed through the main VTS Traffic Display. A physical AIS AtoN could be configured to transmit further virtual or synthetic AtoNs.

3.6.3 Assigned Mode

VTS may use the AIS Service capability to change the reporting mode (from autonomous to assigned mode, for example) of selected shipboard AIS units. This will enable the ship station to operate according to a specific transmission schedule, as determined by the VTS Authority.

3.7 Specific Design, Configuration, Installation and Maintenance Considerations

3.7.1 Interference

AIS may be susceptible to interference from adjacent channels. When siting AIS base stations, due consideration should be given to frequency allocations adjacent to AIS channels to avoid possible service disruption.

3.7.2 Coverage Aspects

In general, AIS design coverage ranges should approximate VHF voice communication ranges. However, actual vessel traffic density or geographic considerations (i.e., mountains or other VHF occlusions) may determine the need for additional base stations.

When estimating the size of the operational coverage (operational cell) for shore facilities, an important consideration is the traffic load – number of mobile AIS stations within the area.

For example, calculations in one port have indicated that an AIS base station could accommodate less than 300 active AIS units.

For further information, please refer to Reference [1].

Where the VTS Area extends beyond the coverage of a single AIS base station, the recommended approach is to extend the VTS Network with additional base stations or to connect to a separate AIS network, such that the required coverage is achieved. Where it is not possible to extend the VTS network, AIS repeaters could be used.

A repeater provides a simple means of extending the AIS coverage, however, at a cost of halving the capacity of the system! For this reason, AIS repeaters are not recommended for use in areas of high traffic density.

3.7.3 AIS Overload Conditions.

With the growth of the number of vessels, equipped with AIS, and the available bandwidth of AIS, there are more and more areas where AIS reception is degraded due to overload conditions. Possible consequences include decreased effective reporting rates of vessels, causing problems for data fusing, and Class-B transponders cannot report due to lack of time slots.

This may lead to a stale or incomplete vessel traffic image without notification to the VTSO, and vessels may not see each other when reliant on the use of Class-B transponders, especially in areas where there is limited or no radar coverage.

3.7.4 Data Integrity

AIS position information is, in principle, obtained through GNSS. There is a possibility of GNSS-sourced positional data being corrupted due to (satellite) equipment faults and intentional or unintentional interference (of the satellite-originated signals). Where possible, safeguards should be considered within the VTS system to assess the integrity of positional data when two or more sources of such data are available. Note, that corruption of position data may result from an incorrect time stamp

3.7.5 Installation and Maintenance

VTS is a shore based operation and as such it should use AIS physical equipment intended for on-shore use. VTS should therefore not use the physical (mobile Class A or Class B) transponder equipment intended for installation on a vessel.

The outdoor installations for AIS systems should be specified taking the considerations in Section 1 into account. This should also consider maintenance access, lightning protection and wind load on antennas. The build-up of ice in some climates should also be a consideration.

The AIS base station equipment should be housed indoors and in a controlled environment, as would be used for other IT network components. AIS base stations are typically 19" rack mountable and therefore all network and power connections will normally reside within the 19" equipment rack. Installation should therefore be simple and uncomplicated. For remote sites, where access may take more than 1 or 2 hours, the concept of a duplicated / hot standby configuration should be considered.

Standard maintenance procedures should apply to the base station and network connectivity. However, for the outdoor aerial equipment, regular checks should be made to ensure that the aerials, and cable runs to the aerials, are not damaged.

4 ENVIRONMENTAL MONITORING

4.1 Introduction

The aim of this section is to:

- Identify functional and operational requirements for gathering, processing and display of environmental data in VTS; and
- Provide guidance on design and installation of such equipment.

Hydrological, meteorological, Oil Spill and any other environmental information, that the VTS Authority requires, should be integrated into VTS applications to provide the VTSO a real-time assessment of the environmental situation in the VTS area. Information collected from this equipment may be provided to ships to assist in assessment of the prevalent conditions.

The protection of the environment is an issue that has grown significantly in importance, both politically and socially, over recent years. The environmental impact of normal commercial activities is analysed such that risk reduction measures can be determined and implemented. Traditionally, VTS Authorities have collected environmental data simply to support their VTS activities. However, many VTS Authorities have their VTS areas in, or alongside, marine protected areas or maritime reserves where any damage to the environment should be avoided.

Therefore, the VTS should consider two aspects of environmental monitoring:

- Navigation Data Collection;
- Environmental Protection.

Navigation Data Collection includes the traditional environment monitoring sensors, typically referred to as the hydrological / meteorological (hydro/meteo) systems. Typical meteorological variables are those provided by weather stations and include air temperature and humidity, wind velocity and direction, rainfall, air pressure and visibility. In certain locations, hydrological variables such as tidal level, and current direction and velocity may also be required. Hydrological data may be obtained through real sensors or available in predictive tables/databases from national authorities. Sensors, providing this data, usually are located at remote sites and communicate data to a VTS centre via a telecommunications or radio link. Alternatively, wave height, direction and surface current could be derived from the main VTS radar through software processing. The accuracy of such measurements from dedicated sensors and from analysis of radar-originated data should be evaluated as part of the VTS design process.

An Environmental Protection system could include implementing additional capability that provides early detection of any polluting incidents that may be caused by visiting vessels. This early detection of pollution could be achieved through the software processing of the VTS radar signals or by specialist sensors that are designed to detect oil, or other pollutants, in the water.

4.2 Definitions and References

4.2.1 Definitions

For general terms used throughout this section, please, refer to reference [2].

4.2.2 References

There are many applicable IMO, IEC, WMO and other requirements. These include, but are not limited to:

[1] WMO - Guide to Meteorological Instruments and methods of Observation

[2] WMO - International Meteorological Vocabulary

[3] IMO Resolution A.686(17) - Code on Alarms and Indicators (and MSC.39(63) Adoption of amendments to the Code on Alarms and Indicators)

[4] IMO Resolution A.694(17) - General Requirements for Shipborne Radio Equipment forming Part of the Global Maritime Distress and Safety System (GMDSS) and for Electronic Navigational Aids

[5] IEC 529 - Degrees of protection provided by enclosures (IP Code)

[6] IEC 721-3-6 - Classification of environmental conditions

[7] IEC 60945 - Maritime Navigation and Radio communication Equipment and Systems

[8] IEC 61162 - Digital Interfaces for Navigation Equipment within a Ship

[9] IMO Resolution A.915(22) - Maritime Policy for the Future Global Navigation Satellite System (GNSS)

4.3 Characteristics of Environmental Sensors in VTS

For hydro/meteo systems within a VTS system, measurement sensors should be installed and located by the VTS Authority in consultation with hydrologist/meteorologist(s) and Local Authority standards. The sensor identification and location should be provided.

The measurements/sensors may include:

- Wind speed / Wind direction / Wind gust;
- Air temperature / Relative humidity;
- Precipitation;
- Barometric Pressure (atmospheric pressure);
- Visibility;
- Water temperature / Water level;
- Height of tide;
- Current speed (may be required at various depths);
- Current direction (may be required at various depths);
- Wave height / direction (also used to indicate wave height anomalies that might indicate oil spill);
- Ice coverage / thickness;
- Salinity

The hydro/meteo data is transmitted to the VTS centre and presented to the VTSO in order to support decision making associated with the safe navigation of vessels and protection of the environment. In cases of severe weather conditions this information is particularly important.

4.4 Operational Requirements

4.4.1 Information Presentation

The results of the meteorological and hydrological measurements should be transmitted in WMO standard units and displayed in user-selectable format.

Refer to Section 10.4.2 for presentation requirements.

4.4.2 Malfunctions and Indicators

As a minimum requirement, malfunctions, warnings, alarms and indicators should respond to the requirements of IMO Resolution A.686(17) (ref. [1]). Additional requirements may be required, depending on the individual type or purpose of the sensor.

In particular, where measurements from a number of sensors overlap or provide coverage for adjacent areas, the identification of potentially anomalous readings should be included within the functionality of the data processing to reduce the possibility of incorrect decisions and to highlight the need for maintenance or inspection of the sensors.

4.4.3 Accuracy

Where a VTS Authority determines a need to establish their own monitoring stations, it should be noted that the individual VTS Authorities, in conjunction with hydrographical and meteorological experts, should determine the accuracy and availability requirements for each VTS Centre, as these will be based on individual circumstances. Table 19 gives an indication of typical measuring range and minimum accuracy requirements for various common environmental parameters.

Note: The availability requirement should be as prescribed by IMO A.915(22) (ref. [9]).

Table 19 Environmental Sensor Requirements

Parameter	Measuring Range	Minimum Accuracy	Remarks
Height of Tide	0 to 20 m (or greater)	≤ 0.01 m	
Rate of Tidal Stream/ Current	0 to 10 m/s	≤ 1%	Maximum value to reflect local conditions
Direction of Tidal Stream/Current	0° to 360°	≤ 5°	
Wave Height	0 to 20 m	≤ 0.1 m, for ≤ 5 m ≤ 10%, for > 5 m	
Wave Direction	0° to 360°	≤ 20°	
Wind Speed	0 to 75 m/s	± 0.5 m/s, for ≤ 10 m/s ± 5%, for > 10 m/s	
Wind Direction	0° to 360°	≤ 3°	
Visibility	10 to 20,000 m	≤ 50 m, for ≤ 600 m ≤ 10%, for 600 m – 1500 m ≤ 20%, for > 1500 m	
Air Temperature	-10° to +50° C	≤ 0.3° C	The measuring range should be aligned to the applicable hot/cold climate category area
Air Humidity	0 to 100% RH	≤ 2% RH	
Air Pressure	920 to 1080 hPa	≤ 0.3 hPa	
Sea Surface Temperature	-2° to + 40° C	≤ 0.5° C	The measuring range should be aligned to the applicable hot/cold climate category area
Ice Coverage	-	-	Typically, measured by satellite remote sensing
Ice Thickness	-	-	Typically, measured by satellite remote sensing
Oil Spill	-	-	Typically measured by satellite or radar remote sensing
Salinity	0 to 70 PSS	≤ 1%	

Note: For air temperature, air humidity, air pressure and salinity accuracy. The accuracy values may be sufficient for shipping activities but if the information is to be used for scientific purposes (e.g. oil spills, environmental responses etc.) these values may need to be more stringent.

The VTS system requirements should also specify the time periods over which the various data parameters should be updated and may be averaged, if required, as these factors will depend upon the local circumstances pertaining to the VTS system.

4.5 Functional Requirements

This section describes the essential functions of the hydro/meteo system for inclusion and integration within the overall VTS system.

Environmental measurements are made by dedicated and/or multipurpose sensors positioned throughout the VTS area (and its approaches) such that an overall environmental picture can be determined, taking account of the possibility of anticipated variations arising from the particular geography of the VTS location.

Measurements are transmitted by the communication system to a VTS centre for analysis, system wide processing and subsequent display to the VTSO in user-selectable format. The measured data is to be presented both numerically and graphically (in chronological order).

The VTS Authority may also require such data to be stored for a predefined period (e.g. up to one year).

It is essential that a VTS Centre also has access to external local hydro/meteo information relevant to the VTS area(s). In addition, the VTS system can, if required by the VTS Authority, disseminate the available environmental data to the VTS users (shipping etc.) and to external allied services.

4.6 Design, Installation and Maintenance Considerations

The environmental monitoring systems should be specified taking the considerations in Section 1 into account. This should also consider maintenance access, lightning protection and wind load on antennas. The build-up of ice in some climates should also be a consideration.

Key aspects, related to design and installation, include:

- Suitability to meet range, accuracy and update rate requirements;
- Location within the VTS area and its approaches;
- Durability and resistance to environmental conditions;
- Interference;
- Power supply requirements / options;
- Installation;
- Maintenance;
- Interfacing;
- Back-up arrangements;
- Safety Precautions.

4.6.1 Suitability to Meet Range, Accuracy and Update Rate Requirements

Individual sensors (multipurpose where appropriate) should be selected to provide the specified range, accuracy and update rate requirements.

4.6.2 Location within the VTS Area and its Approaches

The network of environmental sensors should be part of a coherent sensor network designed to achieve the VTS system needs (coverage, appropriate accuracy in areas of different assessed risk, redundancy etc.)

4.6.3 Durability and Resistance to Environmental Conditions

Electronics installed externally should be in a suitable environmental enclosure. IEC requirements for environmental conditions should be applied as practicable.

4.6.4 Interference

These sensors should comply with applicable international standards and regulations. IEC requirements (IEC 60945) (ref. [7]) refer.

4.6.5 Power Supply Requirements / Options

Relevant IEC requirements should be applied. In remote locations, due to the low power consumption of hydro/meteo sensors, authorities should consider use of alternative power (e.g. solar panels or wind vanes), in lieu of generators, when commercial power is not available.

4.6.6 Installation

Requirements concerning the installation of sensors, wiring and the arrangement of the equipment providing hydro/meteo information to the VTS centre should be determined in accordance with national and international standards where applicable. Operational requirements will determine where sensors are to be located and how many are required. Sites for sensors should be selected based upon optimising data relevant to the VTS. Other considerations include:

- Availability of power;
- Protection against vandalism;
- Housing and co-location with existing VTS, AtoN, or other suitable infrastructure.

Relevant IEC requirements should be applied. For example:

- IEC 529 'Degrees of protection provided by enclosures (IP Code)' (ref [5]);
- IEC 721-3-6 'Classification of environmental conditions, Part 3: Classification of groups of environmental parameters and their severities; Ship environment' (ref. [6]);
- IEC 60945 'Maritime navigation and radio communication equipment and systems - General requirements, methods of testing and required test results' (ref. [7]);
- Local national wiring standards / regulations.

The environmental requirements for operation and survivability of environmental sensors and associated equipment should be determined by the VTS Authority and referred to Section 1.4.3 - General design, configuration installation and maintenance consideration.

4.6.7 Maintenance

Possible requirements, in addition to IMO Assembly Resolution A.694(17) (ref. [4]) concerning maintenance, should be determined. Location considerations for sensors should include maintenance, repair, and accessibility requirements.

4.6.8 Interfacing

The typical information to be interfaced for the hydro/meteo service are described under the Operational Requirements, see Section 4.4.

For the interfacing of hydro/meteo services to VTS equipment, several different standards are in use. Among those standards, IEC 61162, Digital Interfaces for Navigation Equipment within a Ship (part 1 and part 3) (ref. [8]), has been applied for these applications. In addition, the WMO has developed an interface standard for hydro/meteo applications (ref. [1]).

For the interface between a VTS and its users, hydro/meteo data should follow standardised data exchange formats, e.g., XML. (In addition, a time stamp and source should be provided.)

4.6.9 Backup Arrangements

Depending on the individual type of the equipment, requirements concerning back-up and fall-back arrangements should be determined based on VTS requirements, availability and risk assessment.

4.6.10 Safety Precautions

Depending on the individual type of the equipment, requirements in addition to IMO Resolution A.694(17) (ref. [4]) should be determined based on local occupational health and safety requirements and regulations.

5 ELECTRO-OPTICAL SYSTEMS

5.1 Introduction

An Electro-Optical System (EOS) consists of imaging devices, such as daylight CCTV, day/night CCTV, Infrared- and laser-illuminated cameras.

Imaging devices (or sensors) provide visual situational awareness and can be used as primary VTS sensors, as additional sensors to Radar, AIS and other sensors and for perimeter and building surveillance.

When used as a VTS sensor, EOS data may be integrated into VTS applications to provide the VTSO real-time situational awareness within the range of the EOS equipment.

5.2 Definitions and References

5.2.1 Definitions

The following definitions are used within the context of an imaging system:

Detection: The VTSO can observe an object on the water surface.

Recognition: The VTSO can recognize an object and classify it according to its shape (such as a container ship or a ferry boat)

Identification: The VTSO can positively identify the object (e.g. ship name or MMSI)

5.2.2 References

[1] Electronics Industry Association (EIA) - Recommended Standard RS-170

[2] Convention on Safety of Life at Sea (SOLAS) (Chapter V, Regulation 12)

[3] IEC 529 - Degrees of protection provided by enclosures (IP Code)

[4] IEC 721-3-6 - Classification of environmental conditions

[5] IEC 60945 - Maritime Navigation and Radio communication Equipment and Systems

[6] IEC 60825-1 - Safety of laser products

[7] ISO/IEC 13818-2 - Generic coding of moving pictures and associated audio information: Video

[8] ITU-T H.263 - Video coding for low bit rate communication

[9] ITU-T H.264 - Advanced video coding for generic audio-visual services

5.3 Characteristics

An EOS is made up of the following components:

- The imaging device that produces the actual electronic image;
- The lens that creates the field of view and focuses the incoming light onto the image device;
- The sensor housing;
- For Pan, Tilt, Zoom (PTZ) EOS, the electromechanical system that moves the camera and allows the lens to zoom in and out.

In most cases, EOSs are used in limited areas, not necessarily covered by other sensors, or are used to provide supplementary information, such as visual identification. In some cases, EOSs are used as the primary surveillance system, for example, within a port, harbour or locks.

Within the context of EOS, there is an extensive range of technology and characteristics available. These characteristics range from simple, short range, day light only surveillance capability up to very sophisticated long-range thermal and day / night capable technology.

Additional characteristics to be considered with regard to EOS include, the use of fixed cameras versus the benefits of pan, tilt, zoom (PTZ) cameras, as well as width and depth of field of view, image sensor resolution, and light sensitivity.

The level of sophistication of the EOS determines whether the sensor continues to operate in less than optimum conditions, i.e. in fog and rain and during night time. This aspect should be taken in to account when considering the use of EOS for VTS surveillance.

The output of an EOS can be displayed on a dedicated display or be integrated within the VTS traffic situation display, including the control of the EOS system itself.

In order to support high definition video with useable frame rates, data bandwidth requirements for remote high-definition EOS sensors can be very demanding. Care should be taken in analysing the bandwidth requirements when planning the implementation of high-definition EOS sensors.

Where more than one camera is installed to cover a VTS area, it may be desirable for the output from multiple cameras to be provided in one composite picture.

In addition to the sensors themselves there is also a wide range of image processing capability available. These capabilities range from simple video presentation to sophisticated image processing including image recognition and analysis, automated tracking and alerting/alarm capabilities.

5.4 Operational Requirements

5.4.1 Sensor Site Selection

Factors to be taken into account, when deciding on where to place an EOS sensor, include:

- The desired line of sight, field of view and the required operational range for the sensor;
- The availability of existing infrastructure, such as power, data communications and physical security;

  Where possible, consideration should be given to co-locating a new EOS sensor with existing or planned sensors, e.g. radar.
- Maintenance should be considered in view of access to the camera location, the replenishment of consumables (e.g. wiper liquid) and installation of replacement parts as well as vehicle access;
- The presence of strong and/or intermittent light sources that can adversely affect the performance of the EOS sensor, in particular for low-light and infrared cameras;
- The presence of man-made structures, such as cranes, cooling towers and chimneys, all of which can either block the field of view or significantly affect local environmental conditions – consider, for instance, emissions from cooling towers.

5.4.2 Sensor Selection

Requirements to be considered, when selecting a particular type of EOS, include:

- VTS night time operation – extended night operations in a particular area will typically require use of low-light, day/night, IR- or even laser-illuminated capable imaging sensors;
- The intended use of the EOS as either primary sensor for the area or the anticipated use as a supporting sensor;
- The typical environmental conditions in the operational area.

  Prevailing dust conditions, the proximity to salt sprays, the occurrence of heavy rains and high ambient temperatures and so on, will dictate the minimum technical capabilities of the imaging sensor.

5.4.3 Detection, Recognition and Identification

Performance should be carefully considered when specifying the detection, recognition and Identification requirements for an EOS sensor. This should include at what maximum range a VTSO should be able to detect given targets in given conditions.

5.4.4 Recording and Replay

EOS sensor data should be recorded automatically where regulations permit. VTS Authorities should be able to replay this data synchronised with other sensor recordings. Replay of EOS data should not interfere with the on-going VTS operation and may require separate display systems.

The impact of storage requirements for high-resolution video data, especially if several EOSs are used, can be quite significant. The VTS Authority should carefully consider the quality of recording as well as meeting the legal requirements for the storage of historical data.

5.5 Functional Requirements

5.5.1 Pan, Tilt and Zoom

EOSs can be fitted on a fixed platform or mounted on an electromechanical Pan, Tilt, and Zoom (PTZ) frame. The latter allows a considerable amount freedom in pointing the EOS to a target or a particular area of interest.

Fixed sensors are typically placed so as to provide general surveillance of a fixed area of interest, such as fairways and approaches to bridges and locks.

PTZ sensors can be controlled directly by the VTSO, typically using a joystick or keyboard. PTZ sensors can be a shared resource between, for example, a Harbour Master and VTS, therefore the VTS Authority may need to publish a code of practice to govern EOS sensor operation.

Depending upon the level of integration with the VTS system, the PTZ could also be controlled through the VTS application.

The VTS application could:

- Control the sensor via automated tracking of a target, observed by the VTS;
- Configure the sensors to react to various events, such as:
    - Anchor watch violations;
    - Traffic separation violations.
- Allow the VTSO to direct a PTZ sensor to survey a specific area, zone or activity, for instance, pilot boarding and disembarking operations;
- Allow the VTSO to set up automated scan sequences to cover selected areas in turn.

5.5.2 Precision and Repeatability

Precision refers to the ability to set the pan, tilt and zoom to the requested position within a certain tolerance. Repeatability refers to the ability to reliably recreate a certain setting.

The required degree of precision will depend on the application of the EOS. For example, a long range surveillance sensor, at maximum zoom will have a narrow field of view. Therefore, in this case, the PTZ should have a high degree of precision. Conversely, an EOS sensor with a wider field of view will not require such a precise PTZ. In both cases, the repeatability should be more or less the same.

5.5.3 Auto Focus

Focus should be an intrinsic and automated function within the EOS and should be specified accordingly.

5.5.4 Image Processing

EOS systems are susceptible to vibrations, due to wind or nearby equipment, such as a rotating radar antenna. VTS authorities should consider specifying anti-vibration capabilities in the EOS, such as image stabilizers.

There are many processing techniques available which enhance images or derive information from images and these continue to evolve. For example, objects within the field of view of the EOS can be tracked by the EOS, allowing the EOS to automatically follow a designated target.

VTS authorities should work with equipment suppliers to determine which of these techniques and the resulting capabilities are appropriate for the VTS in question.

5.5.5 Configuration

VTSOs should only need to have access to an agreed set of operational functions. Configuration, tuning, maintenance and advanced set-up functions should be restricted to designated support personnel.

5.6 Design, Installation and Maintenance Considerations

The EOS should be specified taking the considerations in Section 1 into account. This should also consider maintenance access, cleaning, lightning protection, vibrations and wind load. The build-up of ice in some climates should also be a consideration.

5.6.1 Durability and Resistance to Environmental Conditions

5.6.1.1 Vibration

EOS systems may be susceptible to performance degradation due to excessive vibration of the installation. This is particularly relevant in strong wind conditions.

VTS authorities should ensure that the supporting infrastructure for the EOS is able to handle the expected environmental conditions and meets any appropriate building regulations.

5.6.1.2 Specific Environmental Safeguards

VTS authorities should require EOS systems to have the following external and internal environmental safe guards where appropriate:

- Lens wash/wipers;
- Replaceable clear lens filters to protect exposed optics;
- Internal heaters and anti-condensation capabilities;
- Mechanical lens protection – e.g. for thermal cameras.

5.6.2 Data Communications

EOS data has significant demands on available bandwidth and due consideration should be given to ensure that sufficient bandwidth is available. Bandwidth requirements can be reduced by using video data compression techniques. It is recommended that VTS authorities consider using standard video data compression for EOS data, such as MPEG-2 (IEC 13818-2), H.263 or H.264. An added benefit of data compression is reduced storage requirements for recordings. Depending on the EOS system, proprietary compression techniques could be considered, however these may not necessarily improve the bandwidth efficiency.

It should be noted that when using a particular video data compression technique, image quality may be reduced as compared to uncompressed data.

Modern Cameras are typically supplied with direct digital output. Where cameras are selected that do not have digital output, it is recommended that digital encoders are included in the overall design and installed at the sensor head. The reason for this is that analogue signalling will require a separate infrastructure, whereas encoded video can be distributed across existing networks.

5.6.3 Maintenance

The routine maintenance effort for EOS sensors can be quite considerable. In particular, high-end, thermal and laser-gated sensors may include features, such as cooling, housing wash and wipe and PTZ units that require maintenance of the mechanical parts. This has significant impact upon EOS MTBF figures. VTS authorities should consider these issues when selecting such devices.

Given that EOS sensors are often installed high on towers or on dedicated poles, care should be taken to ensure that access for cleaning, maintenance and replacement is taken in to account.

5.6.4 Laser Safety Precautions

Some types of EOS sensors use laser devices to illuminate the area of interest. Such equipment should conform to IEC 60825-1 (ref. [6]) and relevant national standards.

6 RADIO DIRECTION FINDERS

6.1 Introduction

RDF is a sensor system that supports VTS and SAR operation by indicating the direction/bearing to a VHF transmitting station. Since a RDF only indicates bearing, two or more appropriately located RDFs are needed to estimate the position of the transmitting station.

RDF can be used to correlate a VHF transmission with a particular target thereby identifying the target in question. This is particularly useful if the target does not have AIS and cannot be identified otherwise.

Another use of RDF is to estimate the position of a transmitting station that is not detected otherwise, e.g. because of its small size.

RDF is not suitable for continuous tracking since it can only estimate a position while the target is actually transmitting.

6.2 Operational Requirements

VTS authorities should consider the need for an RDF system based on the type of traffic in the VTS area, such as the presence of non-SOLAS class vessels and recreational vessels that do not carry an AIS transponder (assuming the VTS is able to receive AIS data). The VTS Authority should assess the requirement for a RDF system based on a risk assessment of these and other relevant factors.

When a RDF system is assessed as being necessary, the VTS authorities should, at least, consider the following:

- The required RDF coverage area, based on:
    - Possible RDF location(s);
    - Waterway structure and navigational hazards;
    - The types of ships to be detected;
    - Expected meteorological conditions.
- The declared VTS level of capability and possible responsibilities for SAR;
- The required bearing accuracy;
- The required frequency range of the RDF equipment (this may e.g. include frequencies used for SAR);
- The number of simultaneously monitored VHF channels;
- Other influencing factors, such as obstructions in the line of sight and the presence of potential reflective surfaces, which may reduce the performance of an RDF system.

6.2.1 RDF Coverage Area

The RDF coverage area needs to be consistent with the results of risk assessment and possible VTS responsibilities for SAR. Factors affecting the detection performance of RDF systems, including potential interference and propagation characteristics, should be taken into account as well as special local conditions, such as heavy rainfall.

In order to allow accurate identification in the main area of operation with two or more RDF stations, the bearing angles on target should cross close to 90º (the position accuracy with two or more RDF stations degrades very rapidly when the bearing angles do not cross at 90º; in the extreme cases of 0º and 180º crossing angles no position estimation is possible). This may pose significant restrictions on the potential locations of the RDF stations.

The recommended method for determination of RDF coverage and range performance is a combination of site inspections and RDF system performance calculations. Figure 15 provides an example of such a calculation.

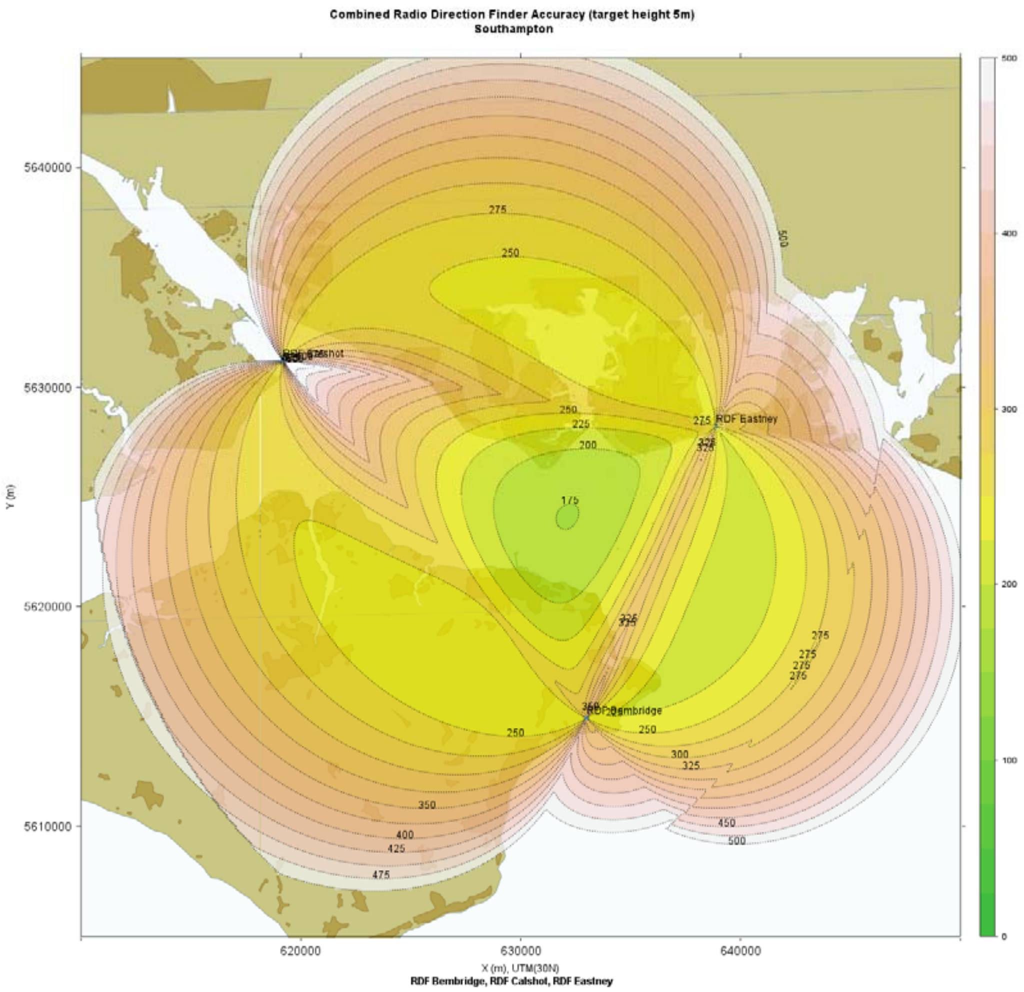

Figure 15 Estimated Position Accuracy of a RDF Configuration

The evaluation should include:

- Calculation of VHF Radio Range based on RDF antenna height and minimal VHF antenna height on the target of interest;
- Calculation of all applicable losses (target's VHF transceiver power, required RDF sensitivity, losses in VHF cable etc.);
- Evaluation of the effects from propagation conditions and obstructions;
- Influence of meteorological conditions.

The calculations may be supplemented by comparison and/or validation test.

6.2.2 Bearing Accuracy

One of the most important performance parameters of the Radio Direction Finder system is the bearing accuracy. Besides the technical characteristics of the RDF equipment, many other factors may significantly reduce the bearing accuracy in real conditions. Therefore, the following aspects should be taken into account when assessing bearing accuracy:

- The specified RDF equipment bearing accuracy - typically specified for "near to ideal" conditions;
- The environment of the RDF antenna.

  Multipath signal propagation, caused by reflections from surrounding objects, can significantly deteriorate the bearing accuracy;
- The received signal strength. Low received signal levels may significantly reduce the bearing accuracy. Major factors affecting received signal strength are:

- Distance to the target;
- RDF receiver(s) sensitivity, antenna gain and feed losses;
- Weather conditions;
- Output power and duration of transmitted signal.

- The delay between signal detection and output for presentation should be no more than 3 seconds.

  The main cause of this delay is the internal processing of the received signal within the RDF system to achieve declared accuracy.

In order to achieve the best possible performance, proper calibration is essential and will mitigate against the adverse effects of some of the factors listed above.

The recommended bearing accuracy for different levels of capability is provided in table 20.

Table 20 Recommended Standard Deviation of the RDF Bearing Accuracy

Level of Capability		
Basic	**Standard**	**Advanced**
≤ 5º	≤ 3º	≤ 2º

6.2.3 Frequency Range

Since the main purpose of RDF is detection of VHF communication devices, the frequency range of RDF should, at least, correspond to the frequencies used for marine VHF communications. Additionally, support for standard SAR frequencies (121.5 MHz, 243 MHz and 406 MHz) may be required if the VTS Authority has a responsibility for SAR operations.

6.2.4 Number of Simultaneously Monitored VHF Channels

RDF may support simultaneous or almost simultaneous reception on multiple VHF frequencies. This can be achieved using one or several VHF receivers (typically 4-8).

The single-receiver RDF can be switched to any VHF channel at any time. This can be done manually or automatically (when the RDF receiver scans a pre-defined list of VHF channels).

There may also be a need to monitor several VHF channels at the same time. For example, SAR channels and VHF channel 16 may be required to be monitored simultaneously, while all other VHF working channels are monitored selectively. In such a situation, the use of a multiple-receiver RDF is required.

6.3 Functional Requirements

6.3.1 VHF Channel Management

There are two types of RDF systems available on the market:

- RDF systems with a single-channel receiver;
- RDF systems with a multi-channel receiver.

RDF systems with a multi-channel receiver may simultaneously receive and process multiple frequencies. Which RDF system is appropriate for the VTS Authority should be determined from the operational requirements.

Single-channel receiver RDF systems should, as a minimum, include:

- Remotely controlled selection of VHF channel;
- Automatic channel scan function from a pre-defined list of working channels;
- If relevant, prioritisation of SAR channels in scanning mode.

Multi-channel receiver RDF systems should, as a minimum, include:

- Remotely controlled selection of VHF channels for each receiver;

- Automatic channel scan function from a pre-defined list of working channels for one or more receivers;
- Simultaneous output of detected bearings for all receivers.

6.3.2 SAR Functionality

Where VTS authorities have SAR responsibilities, additional functionality of RDF equipment may be required, such as:

- Detection of devices transmitting on SAR frequencies;
- Automatic filtering of Emergency Location Transponder (ELT) tones of Man-Overboard EPIRB devices;
- Receiving and decoding of COSPAS/SARSAT signals.

6.3.3 Man Overboard EPIRB Detection Capabilities

This capability ensures detection of specific standardized ELT codes transmitted by EPIRB devices. It minimizes the probability of false alarms, caused by spurious transmissions on SAR frequencies.

6.3.4 COSPAS/SARSAT Detection and Decoding

This capability ensures reception and decoding of digital data transmitted by COSPAS/SARSAT radio beacons. Received data contains the identification number and the measured geographic coordinates of the radio beacon, which can be used for SAR planning.

6.4 Design, Installation and Maintenance Considerations

The RDF systems should be specified taking the considerations in Section 1 into account. This should also consider maintenance access, lightning protection and wind load on antennas. The build-up of ice in some climates should also be a consideration.

6.4.1 Antenna Installation

RDF antenna installation requires careful consideration, especially with regard to the site. The following aspects should be considered:

- The RDF antenna should be placed on a very stable support to avoid any rotation or torque as this directly affects RDF bearing accuracy;
- The antenna height should be sufficient for detection of VHF transmissions from the targets of interest across the coverage area;
- The presence of objects and geographic features that might cause reflections or the blocking of signals;
- Rotating or moving objects (like radar antennas and PTZ CCTV) should be a safe distance from the RDF antenna (refer to the manufacturer’s instructions).

6.4.2 Lightning Protection

Typically, a RDF antenna is placed on the very top of a mast, so special attention should be paid to lightning protection of the structure. It should provide adequate lightning protection without causing reflections and/or obstruction of the incoming VHF signals.

6.4.3 Calibration

Calibration should be performed according to the manufacturer’s instructions and should be revisited if there are significant changes to the equipment and/or environment.

6.4.4 Built-In Test and Diagnostics

Built-in test features should include monitoring of functions and performance and should be accessible remotely.

7 LONG RANGE SENSORS

7.1 Introduction

VTS equipment provides the VTS Authority with real-time data from short range line-of-sight sensors, such as radar, CCTV and AIS. On occasions, the use of information, derived from long-range sensors (typically long range radar, satellite communications systems and satellite AIS), can provide supplementary information. It may assist in locating vessels that have not arrived on schedule or detect vessels that arrive unannounced. It allows authorities to assess potential security risks or, should the need arise, provide input data for search planning in case of a SAR incident.

Typical long range sensors include:

- LRIT (Long Range Identification and Tracking);
- Satellite AIS (SAIS);
- HF Radar;
- Satellite-based Synthetic Aperture Radar (SARSAT).

This section provides an overview of each of the above and identifies the applicability, benefits and limitations of these sensors to VTS Authorities.

7.2 Long Range Identification and Tracking (LRIT)

LRIT is a mandatory carriage requirement for SOLAS vessels. It provides a ship position report at regular intervals based upon the area of operation. The normal reporting interval is every 6 hours. LRIT data is received by International Data Centres (IDC) and is available to the flag authority and to the maritime authorities of transit and destination countries.

In circumstances where a vessel has arrived unexpectedly or gone missing, the historical LRIT information may provide the additional information needed for a security assessment or the planning of search activities.

LRIT is an established service and, subject to approval by the national maritime authority, the VTS Authority can access the International Data Centre and integrate appropriate LRIT data.

It should be noted that LRIT data normally carries an airtime cost per position report and that the IDC may charge for the provision of the data.

As the applications for LRIT data continue to evolve, other uses and benefits may be determined and implemented.

7.3 Satellite AIS

An AIS satellite listens to AIS transmissions within its footprint area and stores the data on-board until it passes over a ground station, to which the data can be downloaded. Satellite AIS has a potentially global coverage, particularly now that dedicated VHF channels are allocated to satellite AIS.

The AIS satellite may receive several AIS transmissions in the same time slot, particularly in dense traffic areas. Such data collisions may make it impossible to properly decode the individual AIS messages, resulting in inaccurate or completely wrong positions, despite the use of advanced de-collision algorithms.

An AIS satellite will only be able to download data when it is in range of a ground station. This means that the data received by the VTS Authority will not be real time and may be up to 2 hours old (or possibly more).

AIS satellite systems comprise several satellites in different constellations, i.e. a polar-orbiting constellation or a mix of equatorial and polar orbiting satellites. The effect of different orbiting constellations will impact when and for how long ground stations can be accessed to download AIS data. The more frequently the satellite can download the data, the less latency between the received data and the real time position of the actual vessels.

Satellite AIS data is provided through a Service Provider to which the VTS Authority will need to subscribe and is now becoming increasingly available via commercial as well as national government-sponsored satellite AIS operators.

The main difference between the terrestrial and satellite AIS data, besides the geographic coverage, is the data latency, i.e. the age of the AIS message when it is actually received by the VTS system. This is generally not a problem, because long range data is used for strategic purposes, where accuracy is less relevant than coverage.

Satellite AIS is an established service that does not require any special design, configuration or installation on the part of the VTS Authority as these are handled by the satellite AIS Service Providers. Once the VTS Authority has subscribed to the AIS satellite service, it will be able to integrate the satellite AIS data as appropriate for its operational requirements.

As the applications for satellite AIS data continue to evolve, other uses and benefits may be determined and implemented.

7.4 HF Radar

One rarely used technology that can offer long range detection of vessels is HF radar. HF radar has one major advantage over other long range detection technologies in that it does not require cooperation from the vessels to be detected.

There are generally two types of HF radars, those that use the low level earth surface “hugging” refraction duct and those that use reflection from the layer to layer boundaries in the ionosphere above the earth (sky wave). Both system types suffer from unpredictable propagation path characteristics, which can support medium and large object detection (metal ships) to hundreds of nautical miles in some conditions, but often offers very little detection performance. This makes specification of achievable performance and detection “availability” a challenge to both radar customers and radar suppliers. The vagaries of the propagation paths can also introduce unpredictable positional measurement errors affecting both angle and range even when an object is clearly detected.

HF radar installation requires some careful selection of suitable coastal terrain which may not suit all potential VTS locations. Similarly, suitable sites will rarely support the necessary infrastructure (power, communications, access for installation and maintenance) and these need to be factored into the installation and operational costs.

Finally, optimising the nature of HF radar may impose high workload on specialised, highly trained operators.

If the limitations are acceptable, this technology offers valuable passive detection in open waters, expensive to obtain by other means (airborne sensors and satellite). Realistically, however, HF radar systems are not used for VTS purposes.

7.5 Synthetic Aperture Radar (SARSAT)

Satellite-based Synthetic Aperture Radar (SARSAT) can provide vessel target information at ranges beyond that of shore-based sensors, including HF Radar. However, such services will probably only provide a single image of a specific area once per day through a few orbiting satellites. Images are stored on-board the satellite until they can be downloaded as the satellite passes over a ground station. The image is processed, following download from the satellite, to detect ships within the area and radar information (without identity) can be derived that can be used to recognise the type of vessel. This type of service is for analysis of vessel movement and not for any form of near real time monitoring. In addition to the latency between the required image capture and the download when passing over a ground station, there is also a further latency related to the processing of the received data.

SARSAT may, for example, be useful for detecting illegal fishing activity in remote areas of a country’s Exclusive Economic Zone and for detecting oil spills and pollution.

SARSAT is available from a variety of established service providers and does not require any special design, configuration or installation on the part of the VTS Authority. The VTS Authority will need to subscribe to a SARSAT image service and costs are involved on a per image basis. Once access to such a service has been established, the VTS Authority will be able to integrate the SARSAT target data as appropriate for his operational requirements.

8 RADIO COMMUNICATIONS

8.1 Introduction

Radio communication equipment is typically integrated into VTS applications to provide the VTSO with a real-time assessment of the situation in the VTS area of responsibility as well as a means to deliver timely services to VTS participants. Information collected and disseminated via this equipment can assist in assembling the traffic image and in supporting safe navigation of the VTS area.

8.2 Definitions and References

8.2.1 Definitions

For general terms used throughout this section, please, refer to references.

8.2.2 References

[1] Convention on Safety of Life at Sea (SOLAS) Chapter IV (Radio Communications)

[2] Convention on Safety of Life at Sea (SOLAS) Chapter V (Safety of Navigation) – Regulation 12

[3] Convention on Safety of Life at Sea (SOLAS) Chapter V (Safety of Navigation) – Regulation 19

[4] IMO Resolution A.686(17) - Code on Alarms and Indicators (and MSC.39(63) Adoption of amendments to the Code on Alarms and Indicators

[5] IMO Resolution A.694(17) - General Requirements for Shipborne Radio Equipment forming Part of the Global Maritime Distress and Safety System (GMDSS) and for Electronic Navigational Aids

[6] IALA World Maritime Radio Communications Plan

[7] IEC 60945 - Maritime navigation and radio communication equipment and systems - General requirements, methods of testing and required test results

[8] IEC 61162 - Digital Interfaces for Navigation Equipment within a Ship

[9] ETSI EN301 929-2 v1.2.1 - Electromagnetic compatibility and radio spectrum matters (ERM): VHF transmitters and receivers as Coast Stations for GMDSS and other applications in the maritime mobile service

[10] ITU-R M.493-11 - Digital selective-calling system for use in the maritime mobile service

[11] ITU-R M.541-9 - Operational procedures for the use of Digital Selective Calling equipment in the Maritime Mobile Service

[12] ITU-R M.689-2 - International maritime VHF radiotelephone system with automatic facilities based on DSC signalling format

[13] ITU-R M.1082-1 - International maritime MF/HF radiotelephone system with automatic facilities based on DSC signalling format

[14] ITU-R M.1084-5 – Interim solutions for improved efficiency in the use of the band 156-174 MHz by stations in the maritime mobile service

[15] ITU-R M.1842-1 - Characteristics of VHF radio systems and equipment for the exchange of data and electronic mail in the maritime mobile service

[16] IMO Resolution A.801(19) – Provision of Radio Services for the GMDSS

8.3 Characteristics of Radio Communication Equipment

Radio communications links are used to collect position, safety, and general information from shipboard personnel and remote sensing devices. These links are also the primary means through which services are delivered to VTS participants.

8.3.1 Coverage

Radio communication equipment is adapted to guarantee the coverage of the GMDSS (refer to [16]):

- Area A1 - Within range of VHF coast stations with continuous DSC (digital selection calling) alerting available (about 20-30 nautical miles);
- Area A2 - Beyond area A1, but within range of MF coastal stations with continuous DSC alerting available (about 100 nautical miles);
- Area A3 - Beyond the first two areas, but within coverage of geostationary maritime communication satellites (in practice this means INMARSAT).

  This covers the area between roughly 70°N and 70°S.
- Area A4 - The remaining sea areas. The most important of these is the sea around the North Pole (the area around the South Pole is mostly land).

  Geostationary satellites, which are positioned above the equator, cannot reach this far.

8.3.2 VTS Radio Communication

VTS radio communication comprises both voice and data services and potentially video applications using equipment consistent with the GMDSS Sea Areas indicated above.

8.3.2.1 Very High Frequency (VHF)

The Maritime VHF band comprises a number of channels within the frequency range of 156 MHz to 162.025 MHz. These are mainly used for voice communication except channel 70 (DSC) and the channels allocated specifically for AIS. The VTS Authority may require VHF Channels to be designated / licensed by the National Radio Authority for specific types of operations (e.g. Coast Station Radio License). Specific channels are determined to provide safety watch, DSC and VTS information.

The VHF equipment should comply with national and international regulations, particularly with the Master Plan of shore-based facilities for GMDSS. The use of simplex, duplex and semi-duplex channels as well as 25 kHz channels can be used in accordance with the appropriate ITU-R and national regulations. Additionally 12.5 kHz channels are also allowed under Appendix 18 of the Radio Regulations in accordance with ITU-R M.1084 (ref. [14]).

VTS Centres require a means of clear and easy to use voice communication for interacting with ships. Within the VHF band, the VTS Centre will require the availability of a number of radio channels relative to the number of ship movements and the size of the VTS area. In addition to distress calling, DSC provides a means of direct calling to vessels through the use of the MMSI and other routine call functions.

As it evolves, e-Navigation will rely more and more on data communication between ship and shore. Such data communication between ship and shore or ship to ship can be implemented within the VHF Marine Band in accordance with ITU-R M.1842-1 (ref. [15]). Following the introduction of this regulation, it is anticipated that a digital infrastructure over Maritime VHF will become available.

8.3.2.2 Medium and High Frequency (MF and HF)

MF and HF may be used on a regional basis where medium and long range communication is required. The VTS Authority may require specific channels to be designated by the National Radio Authority for specific types of operations. The equipment should comply with national and international regulations. Also, MF is used for the distribution of DGNSS correction signals.

8.3.2.3 Satellite Communications

Exceptionally, communication via satellite may be required, depending on geographic terrain, shoreline of country and service provided by the VTS.

8.4 Operational Requirements

8.4.1 Radio Communications Coverage

The VTS Authority should ensure that the VTS radio infrastructure provides adequate coverage for the VTS area.

VHF radio reception is generally dependent upon the line-of-sight distance between VTS receive site and the ship antenna heights. As a minimum requirement, the radio communications range should facilitate VTS ship communications before the ship enters a VTS area of responsibility.

8.4.2 Recording and Playback of Data

The VTS Authority should have the facility to automatically record radio communications and play back these recordings in synchronisation with the recorded traffic situation.

8.5 Functional Requirements

Shipborne equipment should meet the functional requirements of the relevant IMO performance standards and the ITU-R Radio Regulations (see Section 8.2, Definitions and References au-dessus). Shore based equipment should also conform to the appropriate local technical standards.

8.5.1 Digital Selective Calling

Routine calls using DSC can be initiated by the VTS in order to direct a VHF call to a specific vessel through MMSI-based addressing. DSC is a standard feature of the GMDSS.

The use of DSC makes more efficient use of the available bandwidth. In addition, DSC is also used for distress calling. Further details are provided in ITU-R M.541-9 (ref. [11]) and ITU-R M.689-2 (ref. [12]).

8.5.2 Malfunctions, Warnings, Alarms and Indications

Please refer to the relevant requirements of IMO Resolution A.686(17) (ref. [4]).

8.6 Specific Design, Installation and Maintenance Considerations

The radio communication systems should be specified taking the considerations in Section 1 into account. This should also consider lightning protection, wind load on antennas and maintenance access. The build-up of ice in some climates should also be a consideration.

8.6.1 Durability and Resistance to Environmental Conditions

Externally installed electronic equipment should be in an appropriate environmental enclosure. IEC requirements should be applied as far as relevant.

8.6.2 Interference

Radio communications equipment complies with applicable international standards and regulations - see IEC 60945 [7], which covers the general requirements for navigation and radio equipment and includes interference. The avoidance of interference is essential, therefore equipment should be installed in accordance with manufacturer’s instructions and monitored to ensure that instances of interference are investigated and rectified.

Special attention should be given during the design stage to ensure electromagnetic compatibility (EMC) of radio communication equipment used. Frequency spectrum (i.e. VHF working channels), used for VTS radio communication, must be agreed with the national radio licensing authority.

8.6.3 Power Supply

IEC requirements should be applied as far as relevant. In remote locations, authorities should consider the use of renewable power sources (e.g. solar panels or wind turbines, in combination with batteries) as an alternative to diesel generators. In addition, uninterruptible power supplies could be considered as a backup to the primary power supply.

8.6.4 Site Selection and Installation

Operational requirements will determine where radio communication transceivers and antennas are to be located and how many are required.

Consideration should be given to the power output of the radio system at the antenna instead of the power output at the radio equipment. Note that, where multiple transceivers are combined and/or filtered through to a single antenna, the effective radiated power could be reduced significantly.

Care must also be taken that proper separation is maintained when co-locating antenna sites (see also section 8.6.2).

To avoid channel saturation, consideration should be given to subdividing the VTS area into communications sectors based upon channel use with adjacent sectors using separate channels.

Sites for radio communication equipment should be selected based upon optimizing the coverage of the VTS area and the ability to provide the required services e.g. telecommunication links and access. Considerations include availability of electrical power, physical security of the site, housing and possible co-location with existing infrastructure.

8.6.5 Maintenance

In addition to the requirements of IMO Resolution A.694(17) (ref. [4]), the siting and installation of radio communication equipment should make provision for accessibility, maintenance and repair.

8.6.6 Interfacing

Although there are internationally agreed interface standards for interfacing electronic equipment on board ships (IEC-61162-1 and IEC-61162-3 [8]), VTS radio communication interfaces ashore are mostly vendor-specific. An exception is VoIP, which is standardised by industry and the Internet Engineering Task Force (IETF). Interface standards will thus be dependent on the requirements of the VTS Authority and the equipment being installed.

However, work within the IALA e-NAV committee and other organisations aim for open systems architecture with associated international standards, which may be adopted as developed.

8.6.7 Back-Up and Fall-Back Arrangements

Backup facilities can be provided by duplicated radio communication equipment based on an availability assessment.

Fall-back arrangements, via a business continuity plan, should be considered such as handing over operations to another VTS.

Built-in test features should include monitoring of functions and performance.

8.6.8 Development and Innovations

VTS authorities are currently making use of IP technology such as VoIP solutions on radio sites and internal communications. This allows for a more efficient use of infrastructure, more flexibility and optimised system design. VoIP technology (especially when applied for VTS radio communications) is very sensitive to delays in the IP network. Excessive delays may cause significant degradation of VHF communication quality. Additional challenges include the need to use the IP packet “Quality of Service” functionality by the IP network to minimize negative effects such as latency and jitter

9 DATA PROCESSING

9.1 Introduction

The purpose of this section is to support Competent and VTS authorities in the understanding of Data processing, its performance parameters and its contribution to the VTS traffic image (situational awareness).

The section focuses on establishment of a recognised up-to-date traffic image using the principles of target tracking and data fusion. Additionally, it introduces the issues of managing various types of information required within and outside the VTS.

9.2 Definitions and References

9.2.1 Definitions

For general terms used throughout this section refer to:

IEEE Std 686-1997 IEEE Standard Radar Definitions.

Specific terms are defined as follows:

Confirmed track – a track that has previously passed the criteria for track initiation, tentative track formation and has been subsequently promoted to a confirmed track.

Data Fusion – in the tracking context, data fusion is the combining of observation updates from more than one sensor to create one track based on all available sensor information.

False Plot – a plot resulting from a phenomenon unrelated to VTS operation or from a reflection of an actual object.

False Track – A track created using sensor data that happens to behave in target-like manner but actually relates to phenomena unrelated to VTS operation or results from reflections of actual objects.

Note, the sensors and indeed the tracking process may not be able to differentiate between small detectable objects unrelated to VTS operation (birds for example) and at the same time to correctly detect and track small objects that are related to VTS operation.

Latency - a measure of time delay experienced in a system. Used here to indicate the time from a sensor first gathering data relating to a target, to the time the corresponding data is presented to the user (e.g. VTSO display or decision support process).

P_D – is the probability of target detection at the output of a sensor, subsequent to plot extraction, but prior to tracking, and presentation. Note, in some systems the boundary of the sensor and its achieved P_D complicate this definition – clarification may be required to avoid misunderstanding arising from, for example, data compression or video processing.

Plot - A generic term to describe the report resulting from a sensor observation.

Plot extraction – the process of determining measurement values for a sensor observation from the raw sensor data. In the case of a radar sensor, this typically consists of comparing the video level with a threshold which can be (dynamically) adapted to local background noise and clutter conditions.

Plot to Track Association – the process of determining correlation of new sensor plots with existing tracks.

Radar - as referred to in this document, this relates to all aspects of the radar from sensor through to the availability of radar information (for presentation) from one or more radar sensors to the VTSO.

Radar track (report) - A target report resulting from the correlation, by a special algorithm (tracking filter) of a succession of radar-reported positions (radar plots) for one object.

Radar video – a time-varying signal, proportional to the sum of the radio frequency (RF) signals being received and the RF noise inherent in the receiver itself. Radar video can be an analogue signal with associated azimuth reference information, and/or video data (including amplitude) in digital format.

Sensor – in the tracking context, a sensor is a device for observing and measuring, as a minimum, position information for a target or potential target.

Sensor P_{FA} – is the probability of false alarm (plot) at the output of a sensor, subsequent to plot extraction, but prior to tracking, and presentation. This is generally expressed as an average number per unit area.

Signal to Noise ratio – the ratio of a measurement of the power of a return from a target vs. the local sensor noise around the location of the target

Tentative track – in the early part of the track lifecycle, a track is considered to be a tentative track until sufficient criteria are passed for it to be promoted to a confirmed track or for it to be discarded as a likely false track.

Track –the geo-spatial data, accumulated by the system, relating to an object of interest. As a minimum, this consists of unique identity, timestamp, current position and velocity, the associated quality of that information and other relevant attributes.

Track Coasting - A feature that maintains tracks in the absence of expected sensor updates.

Tracking - The process of following an object to enable historical, current and future target positional and velocity information to be displayed and otherwise processed in support of the VTS system objectives.

Tracking P_{FA} - is the probability of false track at the output of the tracking process, prior to presentation. This is normally defined as number of occurrences per unit area per unit time.

Track initiation – this is the process of first creating a track from plots that could not be associated with existing tracks.

Track Merging – as two approaching tracks come together, it may not be possible for the available sensors to individually discriminate and therefore to measure their continued presence and position. If this situation persists for some time, one of the tracks may be maintained whilst the other is terminated.

Track Splitting – a single track may unpredictably split into two or more discernible objects which may invoke rules for track initiation on some or all of the resultant likely tracks.

Track swapping – the (usually unwanted) transfer of a track identity (track label) to another track. This can break the intended association between a track and a physical object.

Track termination – the process of permanently removing a track.

9.2.2 References

[1] NIMA Technical Report TR8350.2 - Department of Defense World Geodetic System 1984, Its Definition and Relationships With Local Geodetic Systems, third edition - amendment 2 (June 23, 2004)

[2] IEEE Std 686-1997 - IEEE Standard Radar Definitions

[3] IHO S-57 – IHO Transfer Standard For Digital Hydrographic Data

[4] IHO S-101 – IHO ENC Product Specification (still being developed in 2015)

9.3 Tracking and Data Fusion

An up-to-date established traffic image is essential to the successful operation of a VTS. This is typically presented as a map showing fixed geographical and man-made features and moving objects to aid decision support and general traffic management of the VTS area. The traffic image is created by processing the raw data from the available sensors of the VTS network.

All individual sensor measurements have limited accuracy and are affected by random errors. In order to obtain a more reliable estimate of a target position and speed vector, measurements need to be processed.

The Tracking and data fusion process accepts sensor data from the available VTS sensor network and other available sources. Then, it attempts to combine these with existing tracks for the purposes of building a traffic image. When such data do not successfully combine with existing tracks, the

Track Initiation process postulates new tentative tracks which are subsequently monitored until they either become confirmed tracks or are discarded as likely false alarms.

The resulting traffic image is displayed to the VTSO, can be used in decision support and may be provided to other agencies and allied services.

The tracking process uses models of the sensors and a set of concurrent models of the target movement to provide a best estimate of, at least, the target position, course and speed over ground (COG, SOG). These models are also used to optimise the association process to combine new measurements with the existing tracks.

Some standard terms need to be outlined for clarity (see figure 16).

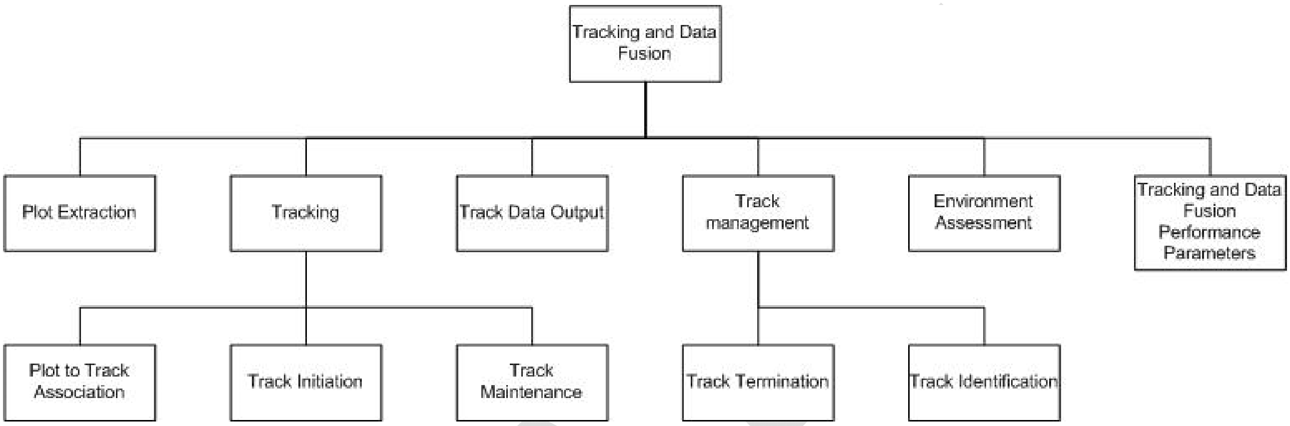

Figure 16 Typical Terminology of Tracking Functions and Processes

It is recommended that a VTS system takes advantage of data available from multiple sensors and external sources by integrating this data in an appropriate way. Integration can be as simple as overlaying, selectable, multiple layers of track data on the VTSO display but significant advantages can be gained by processing and combining the data within the Data Processing function. The use of data from all available sources can significantly improve the positional accuracy of the track and other associated track information (identity, target type, COG, SOG, manoeuvre etc.). In addition, track fusion can include error and anomaly detection in the data from single sensors (which may incorrectly differ from other sensor derived data).

Fusion of the data can be either combining tracks created from individual sensors or introducing the raw measurements from all sensors directly into the track filtering process. In both cases, the track fusion process may have to deal with (un-calibrated) biases in the data originating from the different sensors (e.g. the North alignment of radar sensors).

In a fully calibrated system (i.e. with minimum measurement bias), the output of a data fusion tracker (multi-sensor tracker) should not reduce the quality of the information coming from the most reliable source and in general additional accuracy or other benefits should reasonably be expected. Track fusion also provides redundancy to minimise the consequences of sensor failure or poor detection.

Track fusion is an automatic process and as such, it is recommended that VTSO interaction with this process is limited.

Within this Guideline, the Tracking and Data Fusion sections consider sensor data from various sources including:

- Radar sensors;
- Adjacent VTS area or other agency tracks;
- AIS and Satellite AIS;
- LRIT;
- Electro-Optical Systems (EOS).

Note, contributions from mobile sensors (ship borne sensors etc.) are not normally considered, although this additional enhancement and complexity may become more widespread in the future. The availability of more data bandwidth from ship to shore may facilitate this enhancement in the future.

The design of the Tracking and data fusion process should take into account the need to translate positional information into a common geographical reference system. One common standard datum for this is WGS84. This translation process requires an understanding of the attributes of each sensor, for instance AIS provides geographic coordinates whereas radar measures position in terms of polar coordinates, i.e. range from the sensor and bearing relative to North, even though the data may have been translated at source, the measurement errors used within the track correlation process should reflect the type of data.

As mentioned above, there is also the need to accurately calibrate various sensors to the common reference system, and to each other, so that a detectable point target is measured to have a common location from all sensors providing data on such a target. Such calibration can take the form of manual set up and routine checking and/or on-the-fly identification and correction of measurement bias within the tracking process.

The time stamping of sensor data, accurately reflecting the time of observation and measurement, is essential to enable the correct and accurate traffic image to be established and maintained. Another important performance parameter to consider is communication and processing latency through the VTS system and in particular within the Tracking and data fusion process. This is a separate design consideration to that of time stamping to ensure that the data is presented in a timely fashion to the VTSO (or external system).

9.3.1 Plot Extraction

The plot extraction process lies between the collection of raw sensor data and the extraction of useful information from that data. It is highly dependent on sensor type:

- An AIS, satellite AIS or LRIT plot is known to originate from a single GNSS receiver and provides a time stamped position which can be assumed, with significant confidence, to originate from one target;
- A radar or EOS plot has to be extracted from raw data using a thresholding process to separate it from noise related excursions. In addition, multiple candidate plots may arise from one object (due to target physical size, sensor attributes etc.) and these need to be associated and reduced to one plot where possible within the extraction process. Ambiguities may also exist in the plot measurement and they need to be resolved, or, at least, highlighted for downstream resolution.

The plot extraction process requires specialised and dedicated processing to optimise the trade-off between target detection probability and false alarm rate whilst also extracting positional data. In addition, a strong radar plot may originate from any reflecting surface or surfaces and may not be related to a vessel or object of interest. The subsequent plot to track association process contributes significantly to the selection of wanted radar plots from unwanted radar plots. Besides the extraction of single object plots, the plot extraction process may also provide additional attributes or extended object information to enable subsequent tracking of, for example, icebergs or oil slicks.

Extracted plots include the following attributes:

- Time of measurement;
- Measured position (Cartesian or polar) and positional uncertainty;
- Originating sensor.

In addition, the plots attributes may include:

- Identity;
- Radial (Doppler) speed;
- Physical extent of the plot;
- Signal strength.

In general, the plot extraction process is fully automatic, relying on programmed algorithms tuned to optimise the process to the sensor characteristics and the topography of the coverage area.

9.3.2 Tracking

9.3.2.1 Plot-to-Track Association

Plot-to-Track Association is the selection of the most likely track, representing the object, for each (incoming) plot and the identification of plots which do not associate with any existing track.

The extracted plots are passed to the tracking process and those which fail to correlate with existing tracks become candidates for the initiation of new tracks. Those plots which correlate successfully with existing confirmed or tentative tracks will be used to update the associating track.

Plot-to-Track association involves the forward prediction of the track attributes (e.g. position) to a time which corresponds with the time-stamped update(s) contained within the new plot. After allowance for elapsed time since last update, measurement noise and the possibility of reasonable target manoeuvre, a test for correlation with the new plot is used to either associate the plot or discard the plot (from this track). This process is repeated for all tracks (and plots) so that the discarded plots can be passed to the track initiation process.

Note: plots arrive asynchronously from any available sensor.

9.3.2.2 Track Initiation

The plots remaining un-associated following the plot to track association process may contain plots originating from real targets. These plots are used in the track initiation process to establish a list of uniquely identified, tentative tracks.

In general, the track initiation process is automatic but geographic limitations may be invoked upon areas where automatic initiation should and should not occur. Although VTS systems often include the possibility for manual track initiation, reliance on this method of initiation can significantly load and distract the VTSO. The dependence on this type of track initiation should, therefore, be kept to a minimum.

It can be assumed that an externally sourced (and likely to be externally maintained) track is very likely to become a track in the VTS area of interest and therefore a track can be initiated. AIS plots which have failed to associate, typically initiate a new tentative track. Radar plots, which have failed to associate, require additional confidence building algorithms before completing the initiation of new tracks.

The track initiation process in combination with the plot extraction process needs to strike a balance between the ability to detect true targets of a certain type (especially small targets) and the possible initiation of false tracks. Lowering the plot detection threshold or relaxing the initiation rules, allows more true targets to be detected at the expense of an increased false track rate. This will require system level tuning (supported by modelling if appropriate) to optimise performance and achieve the VTS operational needs.

In other words, there is a trade-off between a higher target detection probability, a larger initiation delay or a larger false target rate.

9.3.2.3 Track Maintenance

Within a tracking system, the tracks generally pass through the following stages:

- Tentative tracking;
- Confirmed tracking (including the possibility of coasting);
- Track termination.

The following sections, track updating and track validation, describe the regular repeated processing that occurs within these stages.

9.3.2.3.1 Track Updating

The extracted plots which associate with existing tracks are used to update those tracks by combining the plot data with the track predictions in accordance with the chosen tracking filter(s). Various mathematical techniques are available to forward predict and update the track position and trajectory information. These techniques vary from simple to very complex with a more or less increasing level of performance. In complex traffic situations it may be appropriate to consider the use of the more advanced algorithms.

As track paths approach or cross each other, additional rules are required to minimise the chances of lost tracks as all the available update information may tend to be associated with one rather than with both tracks. The use of AIS sensors and high resolution passive sensors reduces this possibility, but in some circumstances lost updates to one or both tracks may be inevitable. In real traffic situations, the approach of a small pilot vessel to a large shipping vessel will create this situation on an everyday basis.

9.3.2.3.2 Track Validation

Tracks should be validated against the possibility that they are, or have become, false tracks. Assessment of track quality and erratic track update behaviour may be considered as techniques to provide validation. The tracking system should be able to react quickly and initiate termination rules once it becomes clear that a false track may have been created (see Section 9.3.4.1 for further information). False tracks, from whatever mechanism, should be avoided in safety critical areas and occasionally accepted in other areas where surveillance and traffic monitoring is the priority. Note; operational requirements regarding the detection of small targets may result in an increase in the probability of false tracks.

It may be appropriated to not terminate tracks immediately when there are no sensors measurements but allow some time during which the track is coasting. In such cases, coasting rules may be defined to take into account the need for intentional track coasting such as in areas obscured from sensor coverage.

9.3.3 Track Data Output

Consideration needs to be given to the output of track data to other VTS sub-systems such as the display of the established traffic image to the VTSO. The display is not normally considered to be part of the Tracking Function, but the appropriate tracking information will need to be available for display and for presentation on demand. It may also be appropriate to offer the ability to access and display raw sensor data, plot data and tentative track data.

The display of confirmed tracks is likely to be essential to the VTSO tasks and therefore it is recommended that the display HMI minimises the possibility of unintentionally hiding this information.

The HMI aspects of the display function will consider the use of symbols, colours, text etc. for the display of track information. Typically, track information will be presented onto an electronic chart (using a common reference) of the VTS area.

Track information, which might be required for display to the VTSO, includes:

- Current location;
- Vessel Identity;
- Speed and course over ground;
- Track history;
- Contributing sensors (and lack of updates i.e. coasting);
- Associating plot data;
- Destination and ETA;
- Passage plan;
- Cargo;
- Crew and passenger details.

Note: there is a trade-off in the HMI to be considered between presentation clarity, data overload, track density and VTSO interaction to interrogate a track for additional information.

9.3.4 Track Management

9.3.4.1 Track Termination

If a confirmed track either

- Moves outside a user defined coverage area,
- Moves into a user defined non-tracking area,
- Has track updates which do not follow the expected behaviour, or
- If the track cannot be updated with new plots over a certain length of time,

then the track should be terminated. In certain cases, as defined by the VTS Authority, the VTSO should receive a warning of imminent track termination, and also the VTSO may be provided with a facility, via the HMI, to manually terminate a track.

Track loss may occur as a result of targets not being detected by sensors for a certain time. Note: the loss of target detection is likely to occur in the vicinity of obstructions such as bridges, land masses etc. In order to cover expected areas of poor detection, the system may be configured to bridge gaps in coverage e.g. by coasting previously reliable tracks. The VTS Authority should address any critical areas, such as the vicinity of bridges, and explain expectations to tracking to allow VTS suppliers to design appropriate rules in such critical areas. Another source of track loss is the occurrence of target manoeuvre outside the expected behaviour.

The conditions for track termination may need to be adaptable and adjustable in different areas or traffic / weather conditions. This additional complexity may be set up on system commissioning, user adjustable or even automatically reactive to real world data.

In addition to the above there may be some special classes of tracked objects that require special track processing. Special rules may be required to allow for unexpected appearance and disappearance of submarines, the possibility of obscuration by moving objects in the area of interest or the need to track extended objects such as icebergs, oil slicks and weather effects (and to monitor their size and changes in their shape).

9.3.4.2 Track Identification

Tracks should be uniquely identified, noting that other methods of vessel identification may conflict or overlap, such as internal and external databases (Lloyd's, SafeSeaNet, single-hull database, various incident/black lists, on-board identity, adjacent VTS and other allied services etc.) and local identification methods such as those arising from AIS data, voice communications and associated direction finding, camera recognition (manual and automatic).

9.3.5 Environment Assessment

The VTSO may need to be informed of environmental changes which may affect VTS operations and/or the ability to detect objects within the VTS area. The VTS system may provide special features to facilitate environment monitoring and assessment including, for example, hydrographic sensors and cameras to further aid environmental monitoring.

9.3.6 Tracking and Data Fusion Performance Parameters

The effective use of the VTS traffic image, reliant on accurate and reliable tracking and positioning of the objects of interest in relation to fixed and movable hazards within the VTS area, is fundamental to safe and efficient management of the VTS traffic. The following sub-sections describe the relevant parameters.

9.3.6.1 Input Parameters Required to Design and Implement a Tracker

Key tracking system input parameters to be specified by the VTS system designer, based on the parameters specified by the VTS Authority, include:

- Range of target characteristics (size, speed, manoeuvrability, height, type etc.);

- Maximum number of targets to be tracked;
- Typical desirable and undesirable traffic behaviour, including traffic “lanes”, traffic density, shallow waters, low bridges, narrow waterways etc.;
- Anticipated variations in weather and sea/water conditions;
- External inputs and outputs to / from the tracking function;
- Acceptable VTSO interaction with the tracking function;
- Sensor network design including its specific characteristics including latency

9.3.6.2 Performance Parameters

The determination of performance parameters to specify a VTS tracking system design is a complex task and the achieved tracking performance is heavily dependent on the sensor data provided as inputs to the tracking process. The sensor requirements should consider information provided elsewhere in the other sections of this document.

The location and configuration of the sensor network determines the attainable performance of the VTS system. A tracker design needs to be tuned to optimize overall performance (i.e. accuracy, resolution and minimal track confusion) and the overall performance is unlikely to be constant throughout the VTS area. The VTS system design should therefore ensure that the achievable performance is aligned with the required performance for each of the areas within the VTS coverage area. It should be noted that track formation range is not the same as the sensor network detection range – this needs to be considered when deriving the network coverage and how this relates to the tracker behaviour;

Test scenarios may be developed jointly with users and the tracking experts to explore the anticipated performance of the VTS system as a whole, especially in critical (hazardous) areas of the VTS. Generic traffic test cases can be proposed for a generic sensor solution, but the resultant tracker may have weaknesses in an actual application even though it demonstrates compliance with such generic test cases.

The tracking characteristics needed are highly dependent on local conditions which should be analysed individually. The following tables discuss some of the tracker performance parameters and criteria that may be considered.

Table 21 Typical System Tracking Performance Parameters

Parameter	Typical span of Parameter
Number of confirmed tracks	From ≤ 500 to ≥ 2500 dependant on area covered, traffic density and smallest size of objects to be tracked.
Time for initiation of a tentative track	From 5 to 60 s, or 3 to 10 sensor observations
Time for classification as a confirmed track	From 5 to 60 s, or 3 to 10 sensor observations
Time from data loss to automatic track termination	≥ 60 s, or ≥ 10 sensor observations, whichever occurs first
Speed of tracked surface objects	From ≤ 50 knots to ≤ 70 knots dependant on fastest target in the VTS area
Turn rate of tracked objects *)	From ≤ 10°/s (SOG ≤ 5 knots) to ≤ 20°/s (SOG ≤ 5 knots)
Transversal acceleration of tracked objects *)	From ≤ 2.5 m/s^2 (SOG > 5 knots) to ≤ 5 m/s^2 (SOG > 5 knots)
*) The transversal acceleration = SOG * turn rate, thus for slow moving targets the turn rate is the limitation, whereas the transversal acceleration is the limitation for fast targets.	

Table 22 Single Radar Sensor - Tracking Performance Parameters (specific)

Parameter		**Receiving data from Basic radar sensor**	**Receiving data from Standard radar sensor**	**Receiving data from Advanced radar sensor**
Accuracy in track position	Range (relative to sensor location)	The greater of: • ≤ 0.5 % to 0.75 % of range covered by the individual radar • ≤ 5m to 10m + selected effective pulse length • or half the target extent in range		
	Bearing (relative to sensor location)	≤ 1°, X-band radar sensor ≤ 2°, S-band radar sensor		≤ 0.5°
Accuracy of track speed	Speed over Ground (SOG)	≤ 2 knots	≤ 1 knot	≤ 1 knot
	Course over Ground (COG)	≤ 5°	≤ 2°	≤ 2°
Timing	Time from track confirmation to achievement of specified track accuracy	≤ 120 s		

Note: the accuracy figures suggested above need to be assessed as RMS error (measured parameter vs. truth) for well-behaved (non-manoeuvring) targets in moderate environmental conditions. Positional accuracy should be verified with a small but detectable target, whereas SOG and, especially, COG should be verified using large targets moving under power (i.e. not tidal), without manoeuvre and, for the determination of COG, a recommended minimum speed of 10 knots.

Table 23 Single Sensor - Tracking Performance Criteria

Parameter	Discussion	Operational Consequence
Time to initiate tracks	This can be measured from the point of first observation to either the creation of a tentative track or the establishment of a confirmed track. In addition, the contribution of the display function to latency may need to be assessed separately.	The design has to consider the trade-off between fast establishment of new tracks vs. the associated false track rate.
Probability of false (confirmed) tracks	This is dependent on clutter conditions, traffic density, sensor sensitivity, sensor resolution and the perceived need to detect and track very small targets – the acceptable rate should be specified per area per unit time. Typical values might be 3 to 4 per hour although this is likely to conflict with a requirement for very small target detection.	Displaying tracks which do not represent real targets will increase workload and may result in incorrect VTSO actions being taken.
Average false track duration before termination	The tracker should react quickly to confirmed tracks which subsequently fail to exhibit reliable track behaviour	Continued display of tracks which do not represent real targets will increase workload and may result in incorrect VTSO actions being taken.
Probability of failure to confirm a genuine track	The tracker performance in combination with the sensor network should minimise the probability of failing to establish a genuine track after the first reliable sensor observation.	Delays to the establishment of a track will impact the traffic image and may result in incorrect VTSO decisions.
Probability of track loss	This concerns track continuity. Assuming good sensor visibility of the target, the tracking function should provide reliable and accurate track updates over the entire life time of the track.	Frequent track loss will lead to reduced confidence in the track measurement accuracy and the ability of the system to follow manoeuvring targets. In congested traffic areas, this could be critical to safe vessel passage.
Probability of successful management of two targets merging and then correctly splitting	In the highly likely event of two (or more) targets merging into one sensor resolution cell, the tracker should be able to use the combined and unresolved observation to update the merged tracks until after some time when the targets "de-merge", the tracker should successfully split and update the previously merged tracks with correct numbering and track identification.	The VTSO needs to be presented with the best tracking information available before, during and after the merging event.
Track identity swap rate	The tracker design should minimise the probability of track identities incorrectly swapping between two tracks (and ensure that incorrect swapping is quickly corrected)	The VTSO needs to be presented with accurate and correctly associated tracking information against targets of interest.
The probability of multiple tracks being created from one target	This parameter is often specified for VTS applications in areas covering inland waterways in which large vessels, travelling close to the (radar) sensor location create multiple plots which result in multiple tracks.	Presentation of multiple tracks, relating to a single large object, can create confusion and inappropriate VTSO decision making. The tracker should be able to identify group behaviour within plots and tracks and reduce these to a single track representing the large vessel. The positional reference point for such a target needs to be understood and interpreted appropriately.

Parameter	Discussion	Operational Consequence
Latency of track update	This parameter needs careful definition – time of sensor observation to track update (i.e. not including display function etc.).	Minimal latency will provide a traffic image which is close to real time, but some latency is inevitable, especially when microwave links are included in the VTS network to link remote sensors sites to the VTS centre. (Satellite AIS can also suffer significant and often unacceptable latency). Delays in presentation of the surface picture can lead to delayed awareness of the need for VTSO action.
Coasting period (before track termination)	The time, measured from the last track update with an associated sensor measurement, to automatic track termination.	Genuine target tracks do not just disappear (unless they are at the extremes of available sensor coverage) so the deletion of tracks is a trade-off between lost genuine tracks, prolonging of track seduction (e.g. onto clutter), and prolonging of incorrectly confirmed false tracks

Requirements for sensor fault detection and loss of sensor data integrity should also be considered; for example, the tracker may be used to identify consistent bias errors in the data from one sensor;

9.3.6.3 Additional Track Management Requirements

The tracker should be able to provide advance warning of track capacity overload.

The track capacity should be sufficient to accommodate ≥2 times the heaviest traffic predictions, including an allowance for false tracks.

9.4 Management of VTS Data

Besides the Tracking function, there are other Data Processing functions that may need to be considered within the VTS design. Typically, data processing is the collection and extraction of data to provide information.

The *data* is everything that is potentially useful and relevant to the VTS operation.

Processing involves summarising, analysing, converting, recording, sorting, calculating, disseminating, storing, aggregating, validating, tabulating etc.

The *information* is the result of the processing of the input data. It should be appropriately useful and appropriately clear to aid the VTSO, external users and the manual and automatic decision making processes. In the context of a VTS, there are many pieces of data, each with its own importance, validity and integrity.

Centralised data fusion aims to integrate data from different systems at regional or national level using inter-system data exchange.

Types of information may include:

- Voyage Data;
- Vessel Data;
- Incident Data;
- Contacts Data;
- Charts;
- Pilots and Tugs;
- Data of Berths and Capabilities plus Other Port Resources;

- Traffic Analysis Data;
- Local Hazards;
- VTS Equipment Status, Build State, Version Records;
- VTS Spares and Consumables Stock and Storage Locations;
- VTS Equipment Fault Records;
- VTS Equipment Scheduled and Unscheduled Maintenance;
- VTS Personnel.

It may be appropriate to integrate shipping accounts data to automate alignment with cargo movements, shipping movements, handling charges etc. to facilitate account management by systems associated with the port (i.e. not directly associated with VTS operations). Often this functionality may be managed by the Local Port Authority.

10 VTS HUMAN / MACHINE INTERFACE

10.1 Introduction

The purpose of this section is to support VTS authorities in the specification for, and the selection of, VTS Human / Machine Interface (HMI) sub systems for VTS systems.

This section should be read in conjunction with IALA V-125 (ref. [1]).

10.2 Definitions and References

10.2.1 Definitions

The Human / Machine Interface (HMI) can be broadly defined as the User Interface. The User Interface is the space where interaction between humans and machines occurs. The goal of this interaction is effective operation and control of the machine on the user's end, and feedback from the machine, which aids the VTSO in making operational decisions.

The design considerations applicable when creating user interfaces are related to or involve such disciplines as ergonomics and psychology.

A user interface is the system by which people (users) interact with a machine. The user interface includes hardware (physical) and software (logical) components.

Specific terms used are as below:

Chart – a map to aid navigation support

Map – a representation on a flat surface of the whole or part of an area on earth

10.2.2 References

[1] IALA Recommendation V-125 - The Use and Presentation of Symbology at a VTS Centre

[2] IHO S-57 – IHO Transfer Standard For Digital Hydrographic Data

[3] IHO S-101 – IHO ENC Product Specification (still being developed in 2015)

10.3 Characteristics of User Interface

The HMI provides the major operational interface between the VTS equipment and the users, such as VTSOs and maintenance personnel. The principal goal of the HMI is to provide the users with an intuitive, fail safe, accurate and efficient way of interacting with the system so as to be able to provide an effective service.

This goal is achieved through a combination of:

- Information presentation style and methodology – windows, menus, status bars;
- Ergonomically designed physical interface technologies such as mouse, keyboard, touch pad, roller ball, touch screen;
- Ergonomically designed VTSO workstation layout – number and size of screens, daylight capability, seating, desk arrangements;
- VTS Centre layout with respect to the overall VTS operational sector layout;
- Reliable voice communications – radio and others, combined with an ergonomically designed voice communications control capability;
- Visual and audible indications.

Validity testing of the data and information presented to the VTSO is a system-wide functional requirement. The HMI accurately portrays the data and information supplied to it by the VTS system.

The entire HMI should be reliable, designed and built to contribute to the achievement of the overall availability requirements of the entire VTS system design. A failure of individual elements in the HMI should not disable the entire HMI, e.g. a failed workstation should not disturb the remainder of the HMI or the VTS as a whole.

10.4 Operational Requirements

10.4.1 Traffic Image and Information Display

10.4.1.1 The VTS Map/Chart

The map displayed to the VTSO should be an up-to-date representation of the VTS area and relevant navigational features. This map forms the background for the display of dynamic information (vessel traffic locations, asset availability etc.). The VTS Authority should specify required charts, coverage and scales.

Map data can be obtained from:

- Electronic Navigational Chart (ENC) (e.g. based on S-57 or S-101) and other types of vector charts;
- Raster charts;
- Satellite images;

The use of ENCs is recommended to maximise consistency with charts used on board ships.

Other factors to consider include, but are not limited to:

- The requisite map layers selected for display;
- Optional map layers for selection by the VTSO;
- Use of locally-derived map layers.

The VTS HMI should support both automated and manual management of map layers. It should be possible to automatically update map data without affecting the continuity of VTS operations.

The map presentation should utilise a consistent symbology set and colour pallet suited to the local operating environment.

The current ENC standards, i.e. S-57/S-101, (reference [2] and reference [3]) are designed for navigational purposes and care should be taken when using them in a VTS environment. Specifically, it should be ensured that the VTS HMI specification includes the capability for the authorised personnel to amend the contents of the map display to suit the VTS operational needs.

The map display should be able to support zoom and pan operations, without introducing errors and distortions, i.e. all distances, depths and bearings should remain consistent during zooming and panning of the display.

10.4.1.2 Vessel Presentation

Vessel presentation is addressed by IALA Recommendation V-125 (ref. [1]). Each vessel should be displayed in a consistent manner such that the VTSO can intuitively understand the true geographical position of the vessel. This is achieved by displaying the vessel symbol in its true position relative to the underlying or reference map. In addition this positional information can be augmented by the presentation of the geographical coordinates of the vessel or by its bearing and distance from a selected location.

The HMI should be capable of displaying all of the information associated with each vessel displayed in the VTSO's view. The VTSO should be able to select all the information, or predefined subsets of the information for display. A straight forward and intuitive method should be employed to ease selection.

The information should be displayed either in textual or in graphical form as appropriate, e.g. course and speed vectors.

10.4.1.3 Sensor data

The HMI should have the ability to display sensor data in accordance with the needs defined by the VTS Authority. The display of sensor data (e.g. radar video or AIS) may support operational objectives such as:

- Detection and identification of small targets e.g. in support of SAR or security;
- Visual confirmation of the presented traffic situation;

- Fall-back feature to support partial system failure or degradation.

10.4.1.4 Other Operational Information

As well as being able to display map and vessel track data, the HMI system should be able to display other VTS relevant data including AIS AtoN, Search and Rescue information and the like, where appropriate. Display of these additional information sets should be selectable by the VTSO. Specifications for specific VTS implementations should include functional descriptions of the various operational information sets that are required to be displayed to the VTSO.

10.4.2 Environmental Information

The HMI should be able to display the information derived from the available meteorological and hydrographical data gathered from both local sensors and remote agencies as required.

Depending upon the nature and extent of the available data, and the operational context in which the data may be used, the data may be tightly integrated with the traffic image display or the data may be displayed on a standalone display device.

Care must be taken to ensure that the display of environmental data is complementary to the VTSO role and that the display of this data does not “distract” the VTSO.

10.4.3 Decision Support Presentation

The HMI system should be able to support the decision support functionality.

The functionality can be made available to the VTSO in a number of different implementations including, but not limited to:

- Graphically explicit “tool buttons” often supported by short descriptive phrases. It should be possible, in the HMI, to select display of buttons, text or both. User configurable “tool bars” may be used to group tool buttons;
- Context sensitive menus, with content depending on cursor location;
- Dedicated function keys and/or key-stroke short-cuts.

The HMI interaction should be intuitive and efficient. Wherever possible, the number of key strokes should be minimised. Input fields should be, where possible, filled with appropriate default values by the system.

10.4.3.1 Alerts

When specifying a VTS system, care has to be taken to specifically define terms such as Alert, Fault, Warning, Notice, Hazard and Alarm, as user reactions will be dictated by those definitions.

10.4.4 Electro-Optical Sensor Data Display and Control

EOS derived data (video) is typically displayed separately to the main traffic image displays.

EOS control (PTZ) can be tightly integrated with the traffic image display such that that target vessels can be indicated to the EOS system for identification and tracking.

In addition various methods of manual PTZ control can be utilised.

10.5 Functional Requirements

10.5.1 System Status and Control

The HMI should be capable of presenting the overall status of all the major system elements/subsystems and the infrastructure. Typically this will include:

- Communications – Data and Voice;
- Sensors;
- Main IT hardware elements - servers, processors, PC, workstations, data storage.

It is essential that the VTSO, VTS Supervisor and maintenance personnel are provided with an intuitive, timely and readily accessible view of the VTS System status and health. The required level of detail may depend upon the role of the user in the system. Sub-system status may be summarised hierarchically to suit each anticipated situation.

The HMI for system status and control should accommodate the specific roles and rights of the users.

The HMI should provide the VTSO with the ability to enter appropriate commands to control the system sensors. However, where possible, the sensors should be fully autonomous.

The HMI should provide for the control, operation and status of the record and replay capability.

10.6 Specific Design, Configuration, Installation and Maintenance Considerations

10.6.1 Physical Layout

The provision of Vessel Traffic Services is the prime objective of the VTSO and the physical layout of the VTS centre should serve to enhance the ability to provide the service.

The VTS centre layout should consider:

- Room layout;
- Ambient lighting and comfort settings;
- Noise levels, background machine noise as well as voice communications;
- Screen specifications, including resolution, size, etc.;
- Number of screens per VTSO workstation and their arrangement;
- Number of workstations and operational sectors;
- Wall screen displays.

The VTS centre user environment is of paramount importance to create a comfortable and safe office type background to facilitate concentration and to minimise distractions.

Ergonomics should offer comfort for long periods of use and offer adjustments to minimise fatigue factors.

The environment should consider the advantages of air-conditioning, good and appropriate lighting, minimisation of externally and internally generated noise distractions, nearby rest facilities to minimise user downtime, and well-designed interaction with the available voice communications e.g. via voice switching system to combine telephone, hotlines, ship to shore, VTSO to VTSO, VTS to VTS, VoIP, etc.

The layout should also consider emergency procedures and the role of the VTS centre in emergencies, as part of a coherent regional or national infrastructure.

When contemplating a new or refurbished VTS centre, consideration should be given to seek ergonomic design consultancy to assist in defining the optimum design for the centre.

10.6.2 Screen Layout

The monitor / display real estate design needs to consider the appropriate use of multiple windows, pop-up windows, locked and flexible window positioning, overlapping and side by side windows containing chart data, textual information and dedicated status information etc. The relative importance of each information type needs to be accommodated within the adopted design, in particular the traffic image should remain visible

In the case of workstations employing multiple screens, care should be taken to ensure that the same concepts of window management are extended over the entire screen real estate.

It is also important to ensure that the VTSO can easily keep track of the cursor position.

The HMI should also allow selection and filtering of the presented information to tailor the display to the task in hand, including dedicated search functionality.

The HMI should also support the interactive and automated provision of help text to the VTSO. For example, hovering the mouse over a particular tool button can result in the display of a concise help reference for the use of that particular tool.

A specific button, such as F1, could be provided to enable quick and easy access to an on-line help reference menu, related to the VTS system and other specified support information.

11 DECISION SUPPORT

11.1 Introduction

Decision Support Tools process data in order to help decision-makers to assess situations and make decisions or plans. Decision Support Tools and Functions analyse and model processes, possibly involving multiple sources of information, applying temporal and/or spatial prediction to assist decision-makers in their tasks.

The subject of Decision Support in VTS is under continuous evolution to support the Operation, Planning and Management of VTS. This section contains a list of common functions which may assist in the decision making process. This list is not exhaustive and, considering current developments, there is scope for expansion of the range of available tools and functions.

VTS Authorities should consider those tools and functions that are appropriate for their operational requirements see IALA Guideline 1110 [1].

11.2 Definitions and references

11.2.1 Definitions

Decision Support Tool (DST) - A VTS decision support tool assists the decision-maker at an operational, planning and management level. This may be in real-time or at a tactical or strategic level.

Decision Support Function (DSF) - A VTS decision support function assists the VTSO at an operational level.

Decision-maker – a person or group with the power or authority to make decisions.

Alert – The provision of advice about operational issues

Alarm – An Alert that requires action

11.2.2 References

[1] IALA Guideline 1110, Use of decision support tools for VTS personnel

11.3 Characteristics of Decision Support Tools

Decision Support may consider such aspects as environmental monitoring and forecasts, vessel behaviour, vessel traffic development, legal criteria, incident management, organisational and operational procedures. It can correlate and combine these aspects to give validated advice.

Decision Support Tools and Functions may be self-learning, make real-time risk assessments and/or provide recorded and statistical data to the VTS Authority to improve safety, efficiency and environmental protection. In view of this, Decision Support Tools and Functions should be configured or tailored for each VTS, as appropriate. Alerts, raised by Decision Support, should be presented in a timely and relevant manner aligned to operational needs.

Decision Support Tools and Functions are reliant on the timeliness, accuracy and integrity of the incoming data and the underlying model-based analysis of that data. Note that two decision support tools used for the same purpose may give similar, but not necessarily identical, results. Decision Support Tools may also be used to evaluate the performance of the VTS itself.

For example, as stated in Section 1 (Core Operational and Technical Requirements), the process of establishing a Vessel Traffic Service supported by a VTS system starts with a risk assessment of a potential VTS area. The risk analysis process leads to the identification of mitigation measures which will contribute to the definition of operational requirements for the VTS.

Decision Support Tools should be able to assist decision-makers by providing facilities that aid the management of risk situations and, thereby, reduce the level of risk. In addition, appropriate Decision Support Tools may also provide a means of measuring the level of risk reduction achieved.

11.4 Operational Requirements

Decision Support Tools may help the VTSO and other decision-makers with the implementation of the appropriate predefined and approved procedures.

Decision Support Functions aim to reduce the workload of VTSOs. They may be based upon a real-time assessment of risks associated with the traffic situation. Where the risk level exceeds a pre-defined threshold, an alarm or alert may be raised and the VTSO may be advised of the recommended risk mitigation options.

Management facilities should be provided for the adjustment of alert thresholds and the possibility of de-activation. However, it is recommended that the appropriate alarm or alert thresholds should be part of the agreed operational procedures to ensure that the deployed system is fit for purpose. Alarm and alert facilities should not generate excessive alarms that may increase VTSO workload.

To reduce repeated alarms relating to the same vessel and situation, the reporting of alarms should incorporate filtering techniques, such as hysteresis.

Management reports may be generated from alarm and alert statistics and/or VTSO actions for off-line analysis.

The following is a list of common Decision Support Functions that may assist achievement of operational requirements.

11.4.1 Collision Avoidance

CPA and TCPA are numerical indices characterizing the imminence of a close approach between two vessels. These indices must be pre-defined and interpreted together with a logical AND function. The definition of these indices should consider the range and azimuth (bearing) accuracy of the sensors, especially in the case of radar-only vessel tracking, as the sensor accuracy will impact the accuracy of the CPA and TCPA calculations.

If different areas are monitored according to different rules concerning CPA / TCPA alarms thresholds, it should be possible for the VTSOs to visualize the different zones and the associated alarm levels.

If different alarm levels are supported, the display of an alarm should provide clear indication of the criticality of the alarm.

11.4.2 Anchor Watch

Anchor watch should alert a VTSO that an anchored ship has drifted beyond the safe limits of its defined anchorage. Anchor Watch zones are Monitoring Zones that are based on a given vessel position and include its legitimate movement due to tidal conditions and the relevant sensor accuracy. The boundary should therefore be derived according to the greatest distance from the anchorage point (low tide limit). The ship should remain inside this zone in all but the most extreme conditions and alerts should advise the VTSO that the vessel has drifted beyond the Anchor Watch limits.

Distances should be expressed in the standard unit of distance.

Where meteorological and/or hydrographical forecast information is available, a Decision Support Tool may be able to alert the VTSO that changing conditions could put certain vessels at risk of breaching their Anchor Watch limits.

11.4.3 Grounding Avoidance

A Grounding alarm requires details of the draught of the vessel, the bathymetry and tidal information. The alarm is raised if the estimated under-keel clearance along the predicted path of the vessel is less than a pre-defined threshold. The source of draught information should be checked to ensure accuracy.

Depending on the capabilities of the VTS, the accuracy of bathymetric maps, of water height due to the tide and of the draught of the vessel, the grounding threshold may be adjusted by VTS authorities based upon their assessment of acceptable risk parameters, e.g. to allow for squat and variations in water density. It is recommended that these thresholds should be determined assuming worst case data accuracy.

11.4.4 Air Draught Clearance

Air Draught is an alarm that requires the air draught of the vessel, the obstacle clearance, bathymetry and tidal information. The alarm is raised if the estimated clearance is less than a threshold.

Depending on the capabilities of the VTS, the accuracy of bathymetric maps, of water height due to the tide and of the air draught of the vessel, the Air Draught threshold may be adjusted by VTS authorities based upon their assessment of acceptable risk parameters e.g. to allow for squat and variations in water density. It is recommended that these thresholds should be determined assuming worst case data accuracy.

11.4.5 Sailing Plan Compliance

Sailing Plan Compliance warns VTSOs when a ship's track is outside of the route spatial or temporal boundaries that have been defined for that specific ship.

11.4.6 Area related

These warn the VTSO that a ship has, or is about to, penetrate a pre-defined area or cross a pre-defined navigational line.

International regulations, national recommendations or VTS authorities may define areas where no shipping is allowed under normal circumstances. These areas may be Traffic Separation Schemes, Special or Marine Protected Areas, Prohibited zones, or Particularly Sensitive Sea Areas as defined by IMO or national authorities.

11.4.7 Speed Limitations

These warn VTSOs whenever a ship's speed is outside pre-defined speed boundaries (SOG).

Competent and VTS authorities may define upper and lower speed limits for navigation in certain areas such as port zones and traffic lanes. To implement this functionality, sufficiently accurate and reliable speed estimation should be available to avoid false alarms.

11.4.8 Incident or Accident Management

Where the VTS is tasked to support Incident Management, Decision Support Tools could help visualize and plan the allocation of resources within the incident area. These tools may help the VTS to organize different teams in order to efficiently cover a given area. This can be done with graphical overlays, identification of the resource locations and historical track display in order to identify the areas already covered during the operation. This can also be achieved by displaying zones unsuitable for navigation and factors influencing the decision processes such as the prevailing and forecast sea currents and wind conditions. It may include assistance for planning and monitoring the operation.

Where forecast data is included, Decision Support Tools may assist the VTSO or other decision makers to assess the probable impact of the incident. Drift modelling and area protection assessments may be performed on a regular basis throughout the incident to ensure that the impact of the incident is minimised.

Incident Management alerts and alarms may all be recorded and formatted into an Incident Management Report such that action can be assessed and confirmed alongside the Emergency Management Plans of the Competent Authority.

11.4.8.1 Specific Design and Installation Considerations

Refer to IALA Guideline 1110 [1]

12 EXTERNAL INFORMATION EXCHANGE

12.1 Introduction

This section describes the technical issues that need to be addressed to support the requirement for VTS systems to be able to communicate with relevant allied services, National Points of Contact for services such as LRIT, and neighbouring VTS systems. Details, regarding legal issues and processes recommended for sharing maritime data (more specifically terrestrial and satellite AIS), may be found in IALA guideline N° 1086 (ref. [1]).

12.2 Definitions and References

12.2.1 Definitions

For general terms used throughout this section, please, refer to references.

12.2.2 References

[1] IALA Guideline N° 1086 – The Global Sharing of Maritime Data and Information.

[2] ITU-R – Radio Regulations

[3] IALA Recommendation V-145 – On the Inter-VTS Exchange Format (IVEF) Service.

[4] IHO S-100 – IHO Universal Hydrographic Data Model.

12.3 Characteristics of External Information Exchange in VTS

VTSs can be considered focal points for data since they integrate data from various sources (e.g. AIS, radar) for their day-to-day operation. This data may be shared with parties outside of VTS where there is an operational need.

Table 24 and table 25 provide a list of purposes for maritime information exchange. This list is not exhaustive and simply provides an indication of the range and diversity of such maritime data.

Table 24 Information Exchange between VTS and Vessel

Purpose	Type of Information Exchange
General information exchange	• Risk identification and avoidance • Monitoring of cargo, vessel status and resources • Voyage planning and execution (e.g. under keel clearance and track keeping) • Meteorology and hydrography • Cargo management (planning, loading and discharging) • Logistics support (shipboard)
Regulatory Compliance	• Reporting • Environmental protection
SAR response (pending individual VTS responsibilities)	• Medical and aeronautical support • Incident assistance

Table 25 Information Exchange between VTS and Shore-based Entities

Purpose	Type of Information Exchange
Traffic management	• VTS tactical support • Anchorage and berth management • Bridge and lock management
Hazard management	• Risk analysis • Incident reporting and investigation • Contingency planning • Emergency towage and salvage
SAR	• Medical and aeronautical support • Incident assistance
Logistic chain support	• Voyage monitoring • Port operation • Forward planning movements • Pilotage and allied services
Law enforcement	• Maritime contraventions • Fisheries enforcement • Customs • Port state control • Border control / immigration • Port health inspections • Security
Environmental protection	• Pollution monitoring • Incident response • Waste management
Waterways infrastructure management (including inland waterways)	• AtoN operations and system optimisation • Infrastructure maintenance and update
Maritime safety information (MSI)	• NAVTEX

12.4 Data Management Considerations

12.4.1 Suitability for Purpose

Users need to be aware of the limitations of the data to avoid taking actions based on outdated, inappropriate, incomplete, inaccurate or corrupted data.

To guarantee the quality of data exchange, the parties involved in a data-sharing agreement should establish a Service-Level Agreement (SLA). The SLA should clearly define the responsibilities for quality and delivery of the data.

It is recommended that data exchange performance is monitored in accordance with key performance indicators (KPI) as agreed in the SLA.

12.4.2 Access to Information

SLAs should clearly state requirements for provision, security, confidentiality and permitted use of all externally exchanged information.

Clear and realistic principles and rules regarding access to AIS and other broadcast data should be established by the VTS Authority. These principles and rules should recognise national and international legislation and guidance.

The reception and use of data, broadcast by radio, is subject to ITU-R: Radio Regulations (ref. [2]), article 17 on Secrecy.

12.4.3 Data Security and Confidentiality

There are many instances where data is deemed sensitive and needs to be protected for competitive and privacy reasons. Examples of this include fleet information or location of fishing grounds. In both cases, unsecured data could compromise investors or introduce competitive advantages/disadvantages.

In many cases confidentiality is already protected by legislation but this is not universal throughout the maritime domain. Furthermore, the requirement to protect access to data may go beyond the limits of primary legislation. Confidentiality measures should to be taken to protect information to the required security level through data encryption, password protection, proper authentication, and restricted data access privileges.

Authentication means that the sending and receiving parties are able to unambiguously identify each other.

Encryption may be used to ensure that data is only accessible to authorised parties. The level of encryption required depends on the sensitivity of the data.

12.4.4 Legal Limitations

Many national states, in the lawful exercise of their authority, place legal limits on the exchange and public dissemination of data and information. These include protections on intellectual and commercial property rights, and limitations on third party use of data and information.

In the course of exchanging maritime data and information in the interest of safety, security and efficiency, these limitations shall be respected and the authorities involved should be aware of their rights and obligations under law. In particular, data transmitted should be consistent with the laws of the national authority. Authorities need to be aware of any exposure to liability that might occur from their actions or inactions with regard to data and information exchange.

12.4.5 Data Integrity

Data integrity is a key concern for users and providers alike. For instance, key navigation decisions should be based upon timely, accurate and consistent data.

Timely data is data that is received when needed. This may be in advance of an event or real-time as appropriate. For data that is required in advance of an event, such as notification of arrival, legislation typically determines the lead time in which the data is required by the VTS Authority. It is the responsibility of the sender to ensure that sufficient time is allocated for the data to be communicated and received ahead of the event.

Real-time data should be time stamped as close as possible to the time of capture. Network latency should also be considered when exchanging time-critical data. Within IP networks, the concept of Quality of Service (QoS) may be used to prioritise the delivery of time-critical data. In such a case, it is important that QoS be implemented from source to destination, as data may travel through multiple IP networks.

Data often travels circuitous routes undergoing multiple handovers, from source to destination, allowing for corruption to occur either accidentally or through deliberate actions. Where required, appropriate measures should be taken to avoid such data corruption (e.g. by encryption of the data).

12.4.6 Data Models

Exchange of data requires an understanding of how the data values are represented and their meaning. The former is specified by data format, the latter is reflected in the data model.

The data model unambiguously defines the:

- semantics of the data fields,
- structure of the data and
- Permissible ranges of a data field.

The IHO S-100 standard (ref. [4]) is a framework standard intended to allow development of data models and associated product specification for a variety of common and maritime specific information. Data models, used in the domains of maritime safety, security or, more generally, describing data for exchange by VTS, are maintained in the IHO GI Registry.

12.4.7 Architecture of Sharing

Transfer of data may initiated by the sender or the receiver. This may be an automated process or require manual intervention.

12.4.8 Storage

The volume of data generated and stored is, in many cases, considerable. Given that much of the historical data collected is required for analysis and planning, consideration should be given to providing adequate capacity for retaining and archiving these records.

Some formats are well-suited for transfer and sharing of data and maritime information whereas others are better suited for long term archiving of data.

12.4.9 Communication Links

The transfer of data between sender and receiver requires connectivity via a network. A network comprises appropriate hardware and software interconnected by communication channels. In the maritime world, both aboard ship and shore side, data links may consist of a combination of wired and wireless network segments.

Different technical solutions and architectures can be used when establishing a data sharing network. Consideration should be given to:

- The physical distance between the sending and receiving parties;
- The services provided by the network;
- The quality of services requested by the users;
- The constraints on infrastructure.

Global sharing of maritime data and information can take place either through the internet or through dedicated private networks. The internet is public, while dedicated networks are generally closed. Consideration should be given to the security related characteristics of these network types.

Systems used for global sharing of maritime data and information are in reality a network of networks. When designing a network for global sharing of maritime data, consideration should be given to transmission protocols, bandwidth limitations, communication / data distribution strategy, security aspects such as authentication and confidentiality as well as data integrity.

A selection between the options available should be based on a number of criteria, including the type of data being transferred, volume of data, types and number of clients connected to the network.

Although bandwidth cost is in decline, the value of conveyed information has to be balanced against the cost of transmitting it. Additionally the required data transmission speed needs to be assessed and agreed in context with associated costs. Another trade-off is the speed at which the data needs to be transmitted. Higher bandwidth links infer higher costs.

13 VERIFICATION AND VALIDATION

13.1 Introduction

The performance of VTS equipment should be verified prior to operation. This may include the following verification activities:

- Type approval of individual equipment, as required by law in individual countries;
- Other equipment specific verification tests as required by the individual VTS Authority;
- Verification of equipment prior to delivery in the form of Factory Acceptance Tests;

Verification of individual equipment or systems upon installation and Setting-to-Work, but prior to operational use, should be carried out in the form of Site Acceptance Tests. The overall specifications should be agreed in contractual documents. It is recommended that FAT, SAT, and other procedures are agreed before conducting tests.

Procedures may be generic to the individual equipment and/or specific to the individual contract.

13.2 Planning and Management of Activities

Implementing, extending or upgrading an existing VTS should be planned and managed in detail. This could include planning of cutover activities to minimise disruption of the VTS operation.

The establishment and agreement of acceptance plan(s) and verification matrices may be necessary to assist all stakeholders. This may, for example, call upon:

- Proper attention on HMI acceptance and ergonomics;
- Verification of interfaces;
- Verification of fall back modes, graceful degradation, and redundancy within the VTS system;
- Latency checks of data presentation;
- Verification of performance parameters, including coverage;
- Verification of radio communication parameters, such as bit-error rates, signal-to-noise ratios, etc.;
- Verification of overlapping sensor coverage, including different sensor types and associated correlation;
- Coordination and definition of Factory Acceptance Test, Setting to Work and Site/System Acceptance Tests.

Early prototyping to validate critical parts (e.g. user interfaces) can minimise risk at a later stage in the programme.

For renewal, update or extension of an existing VTS, the supplier(s) and the VTS Authority should propose and agree on a Cutover Plan that may take into account parallel service delivery, the use of temporary interfaces between the old system and the new system components and, in some cases, recognising that the new equipment may have to form part of the interim and/or final system configuration prior to final acceptance.

In many circumstances, it may not be possible to maintain the desired continuity of service throughout the planned installation activities and this may need to be carefully considered by all stakeholders. Alternative procedures offering minimal safety provisions, possibly including reduced service levels, should be considered by the VTS Authority. Penalties associated with unforeseen system downtime should be agreed during contract negotiation.

13.3 Acceptance Testing

13.3.1 The Acceptance Test Plan (ATP)

The Acceptance Test Plan (ATP) is a collection of stages, tests, analysis, and acceptance criteria that allows the suppliers to demonstrate to the customer that their requirements have been met. For example, Factory Acceptance Test (FAT) and Site Acceptance Test (SAT) may be two key tests within an ATP.

The Contractor, in cooperation with the Customer, may be responsible for the creation of the ATP. The agreed Acceptance Test Plan should be available prior to the commencement of the acceptance testing. The ATP scope should cover the complete system that forms the overall deliverable.

For each stage of acceptance testing, a test procedure should be issued by the Contractor based on the agreed acceptance methods and procedures captured in the ATP.

Test procedures should demonstrate compliance to the Customer's functional and performance requirements. They should include an agreed test script which includes a list of requirements and corresponding verification tests, with their measurements, to demonstrate compliance.

At each stage of acceptance testing, test records should be issued and retained. Test records may include, as a minimum:

- Configuration details;
- Date of the test;
- Who performed the test;
- The outcome of the test such as pass/fail, measurements, or findings.

Upon successful completion of the acceptance activities, described in the ATP, the system is considered ready for operational use.

13.3.2 Factory Acceptance Test (FAT)

If applicable, the Factory Acceptance Test demonstrates, prior to shipping and as far as agreed, that the equipment and/or system conform to contractual specifications. The VTS Authority may elect to attend or to be represented at the FAT.

The FAT will normally include Functional and Performance testing to agreed procedures. Tests will normally be performed for individual units and, in some cases, for pre-assembled systems.

The FAT may also include Functional Configuration Audit (FCA) and Physical Configuration Audit (PCA) type reviews.

Personnel conducting the test should be familiar with the set-up and operation of the equipment in test. The Customer's representative(s), if in attendance, should be appropriately qualified to accept the equipment and understand issues that may arise during the testing. Safety Instructions should be noted.

The outcome of a FAT should be recorded in a test report or certificate. These typically include:

- References to project name, customer, software revisions, hardware revisions, parts and serial numbers etc.;
- List of instruments and their calibration status;
- Functional test results including verification of safety measures;
- Performance test results;
- Signatures.

After the FAT, the Supplier should ensure that any issues that arise are addressed.

13.3.3 Installation and Site Acceptance Test (SAT)

Prior to the installation of equipment, the Supplier and Customer should agree that preparatory work, such as civil works and structures, is satisfactorily completed.

After installation and setting-to-work, the SAT should take place. The purpose of the SAT is to confirm full functional compliance and system integration of the installed equipment.

The SAT may also include final Functional Configuration Audit (FCA) and final Physical Configuration Audit (PCA) type reviews.

The Supplier should confirm to the Customer that:

- All supporting documentation is available;

- Equipment is as tested during FAT, i.e. the software and hardware revisions do not invalidate the FAT results.

If these conditions are not met, additional activities should be jointly agreed and resolved.

The outcome of a SAT should be recorded in a test report or certificate. These typically include:

- References to project name, customer, software revisions, hardware revisions, parts and serial numbers etc.;
- List of instruments and their calibration status;
- Functional test results including verification of safety measures;
- Performance test results;
- Signatures.

After the SAT, the Supplier should ensure that any issues that arise are discussed and appropriate actions are agreed and managed to a satisfactory conclusion.