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EUROCONTROL Guidance Material for Minimum Safe Altitude Warning

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Abstract

This document contains comprehensive guidance material to assist in implementing the EUROCONTROL Specification for Minimum Safe Altitude Warning. It covers the full MSAW lifecycle, including definition of objectives; implementation or change; tuning and validation; as well as operating and monitoring.

Keywords

Safety Nets
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CONTENTS

Note: Appendices are contained in separate documents

EXECUTIVE SUMMARY

This document contains comprehensive guidance material to assist in implementing the EUROCONTROL Specification for Minimum Safe Altitude Warning. Specifically, the document contains guidance related to the MSAW lifecycle, including:

- Defining MSAW (Specification of objectives)
- Implementing MSAW (Procurement or Enhancement)
- Optimising MSAW (Tuning and Validation)
- Operating MSAW (Training and Monitoring)

1. INTRODUCTION

1.1 Purpose of this Document

MSAW is a ground-based safety net intended to warn the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles.

The European Convergence and Implementation Plan (ECIP) contains an Objective (ATC02.6) for ECAC-wide standardisation of MSAW in accordance with the EUROCONTROL Specification for Minimum Safe Altitude Warning.

The EUROCONTROL Specification for Minimum Safe Altitude Warning contains specific requirements, a number of which must be addressed at organisational or managerial level and others, more system capability related, which need to be addressed with significant input from operational, technical and safety experts.

The purpose of this document is to provide practical guidance material to assist in implementing the EUROCONTROL Specification for Minimum Safe Altitude Warning. The guidance material covers the full MSAW lifecycle.

1.2 Structure of this Document

Chapter 2 contains a general introduction and overview of the MSAW lifecycle, including defining, implementing, optimising and operating MSAW.

Chapter 3 elaborates organisational issues regarding MSAW, including definition of roles and responsibilities, consideration of the Reference MSAW System, definition of operational requirements, and development of a policy and a safety case.

Chapter 4 contains a guide to MSAW System procurement and improvement.

Chapter 5 addresses MSAW System tuning and validation aspects.

Chapter 6 highlights MSAW System management and training issues.

This document contains the following appendices, most of which can be used as stand-alone documents for particular purposes:

Title	**Purpose**
Appendix A: Reference MSAW System	Detailed technical explanation of typical implementation details of MSAW with emphasis on parameterisation and performance optimisation. Optimisation concepts are also covered in detail.
Appendix B: Safety Assurance	A set of three documents that can be used as a starting point for MSAW safety assurance work in a particular local context.
Appendix B-1: Initial Safety Argument for MSAW System	ANSPs may find it convenient to present the safety argument as a stand-alone document initially, as is the case with this document. However, the argument will ultimately become part of the safety case document and the stand-alone version will then become defunct.
Appendix B-2: Generic Safety Plan for MSAW Implementation	Describes what safety assurance activities should be considered at each lifecycle phase, who should do them, and what the criteria for success are.
Appendix B-3: Outline Safety Case for MSAW System	Addresses in detail the assurance and evidence from the System Definition stage and outlines the likely assurance and evidence for the later stages.
Appendix C: Cost Framework for the Standardisation of MSAW	Assists in identifying potential financial implications of standardisation of MSAW in compliance with the EUROCONTROL Specification for Minimum Safe Altitude Warning.
Appendix D: Case Study	A set of two documents describing the (partial) application of the optimisation and safety assurance guidance material in a demanding environment.
Appendix D-1: Enhancement of MSAW for Skyguide	Identifies potential solutions for extending MSAW coverage throughout Skyguide's Area of Responsibility.
Appendix D-2: Functional Hazard Assessment of MSAW for Skyguide	Describes the Functional Hazard Assessment of the identified potential solutions for extending MSAW, performed as initial step of safety assurance activities.

1.3 Reference Documents

[Doc 4444]	ICAO Doc 4444: Procedures for Air Navigation Services - Air Traffic Management
[SRC-ESARR4]	ESARR 4: Risk Assessment and Mitigation in ATM, Edition 1.0, 05-04-2001
[SRC28.06]	SRC Policy on Ground Based Safety Nets – Action Paper submitted by the Safety Regulation Commission Co-ordination Group (SRC CG) – 15/03/07.

1.4 Explanation of Terms

This section provides the explanation of terms required for a correct understanding of the present document. Most of the following explanations are drawn from [Doc 4444] and [SRC28.06] as indicated.

alert	Indication of an actual or potential hazardous situation that requires particular attention or action.
altitude [Doc 4444]	The vertical distance of a level, a point or an object considered as a point, measured from mean sea level (MSL).
ATS surveillance service [Doc 4444]	Term used to indicate a service provided directly by means of an ATS surveillance system.
elevation [Doc 4444]	The vertical distance of a point or a level, on or affixed to the surface of the earth, measured from mean sea level.
false alert	Alert which does not correspond to a situation requiring particular attention or action (e.g. caused by split tracks and radar reflections).

flight level [Doc 4444]	A surface of constant atmospheric pressure which is related to a specific pressure datum, 1 013.2 hecto-pascals (hPa), and is separated from other such surfaces by specific pressure intervals. *Note 1.– A pressure type altimeter calibrated in accordance with the Standard Atmosphere:* *a. when set to a QNH altimeter setting, will indicate altitude;* *b. when set QFE altimeter setting, will indicate height above the QFE reference datum;* *c. when set to a pressure of 1 013.2 hPa, may be used to indicate flight levels.* *Note 2.– The terms "height" and "altitude", used in Note 1 above, indicate altimetric rather than geometric heights and altitude.*
ground-based safety net [SRC28.06]	A ground-based safety net is functionality within the ATM system that is assigned by the ANSP with the sole purpose of monitoring the environment of operations in order to provide timely alerts of an increased risk to flight safety which may include resolution advice.
height [Doc 4444]	The vertical distance of a level, a point or an object considered as a point, measured from a specified datum.
human performance [Doc 4444]	Human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.
level [Doc 4444]	A generic term relating to the vertical position of an aircraft in flight and meaning variously, height, altitude or flight level.
minimum safe altitude warning [derived from Doc 4444]	A ground-based safety net intended to assist in the prevention of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles.
nuisance alert	Alert which is correctly generated according to the rule set but is considered operationally inappropriate.

warning time	The amount of time between the first indication of an alert to the controller and the predicted hazardous situation. *Note.– The achieved warning time depends on the geometry of the situation.* *Note.– The maximum warning time may be constrained in order to keep the number of nuisance alerts below an acceptable threshold.*

1.5 Abbreviations and Acronyms

ANSP	Air Navigation Service Provider
APM	Approach Path Monitor
ATC	Air Traffic Control
ATCC	Air Traffic Control Centre
ATS	Air Traffic Service
CFIT	Controlled Flight Into Terrain
CFL	Cleared Flight Level
DTED	Digital Terrain Elevation Data
EC	European Commission
ECAC	European Civil Aviation Conference
ECIP	European Convergence and Implementation Plan
(E)GPWS	(Enhanced) Ground Proximity Warning System
ESARR	EUROCONTROL Safety Regulatory Requirement
FAT	Factory Acceptance Test
FDPS	Flight Data Processing System
FUA	Flexible Use of Airspace
GAT	General Air Traffic
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ISA	International Standard Atmosphere
MOCA	Minimum Obstacle Clearance Altitude
MSAW	Minimum Safe Altitude Warning *Note.– Not to be confused with MSA (Minimum Sector Altitude).*
MRVA	Minimum Radar Vectoring Altitude
MSA	Minimum Sector Altitude
MSL	Mean Sea Level
OAT	Operational Air Traffic

QFE	Atmospheric pressure at aerodrome elevation *(or at runway threshold)*
QNH	Altimeter sub-scale setting to obtain elevation when on the ground
SAT	Site Acceptance Test
SES	Single European Sky
SFL	Selected Flight Level
SID	Standard Instrument Departure
SRC	Safety Regulatory Commission
SSR	Secondary Surveillance Radar
STAR	Standard Arrival Route
VFR	Visual Flight Rules

1.6 Reference Material from the EUROCONTROL Specification

The EUROCONTROL Specification for Minimum Safe Altitude Warning should be referred to for a description of the MSAW concept of operations.

Furthermore, chapter four of the EUROCONTROL Specification for Minimum Safe Altitude Warning contains specific requirements, which are referred to in relevant sections of this document.

2. THE MSAW LIFECYCLE

2.1 Overview of the MSAW Lifecycle

The MSAW lifecycle represents an ideal process followed by ANSPs to ensure a solid and consistent development of MSAW from the initial procurement to and during the operational use.

Figure 2-1 is a concise representation of the whole lifecycle. Each phase is covered by appropriate guidance in the document.

2.1.1 Defining MSAW

The initial step of the lifecycle is the *definition of roles and responsibilities* inside the organisation, to establish who has the responsibility for the management of MSAW. Roles are made clear and well known inside the organisation to ensure a consistent development of the system (section 3.1)

Then, the core issue is the definition of the *operational requirements* of MSAW, based on a careful consideration of the local needs and constraints of the operational context in which the MSAW is being introduced (section 3.4). Other two strictly interrelated processes are: the *consideration of a reference MSAW* (section 3.3) and the *development of a policy and safety case* (section 3.4.5.1).

In performing the whole phase, representatives from different kinds of roles in the organisation should be involved: operational, technical and safety experts.

2.1.2 Implementing MSAW

The previous steps are all needed to take an appropriate decision about the *MSAW procurement*, either when the product is purchased from an external manufacturer (section 4.2) or when MSAW is *enhanced* (section 4.3).

This phase is mostly performed by technical experts.

System verification (section 4.6) is performed either when implementing a new MSAW from scratch or when enhancing an MSAW.

Based on a verification methodology, an appropriate feedback loop ensures that the phase is not terminated if the MSAW is not functioning according to the technical specifications previously established.

2.1.3 Optimising MSAW

The third phase is aimed at optimising the system in order to meet the operational requirements identified in the first phase. It also addresses validating the system before making it fully operational. The most essential steps are MSAW tuning and validation (chapter 5).

This phase relies on close collaboration between technical staff and operational experts.

Based on acceptance tests with controllers and/or on the use of optimisation tools, an appropriate feedback loop ensures that the phase is not terminated if the MSAW does not meet the established operational requirements.

2.1.4 Operating MSAW

When MSAW is deemed optimised, adequate *training* is provided to both ATCOs (section 6.2) and engineers (section 6.3).

Once MSAW is fully operational, a set of parallel processes are put in place:

- Collection of feedback from ATCOs
- Analysis of Pilots/ATCOs reports (section 6.4)
- Monitoring of MSAW performance (section 6.5)
- Maintenance (section 6.6)

Also this phase requires a close collaboration between operational and technical experts. Safety experts should also be involved, to ensure that the MSAW role is adequately considered in evaluating the safety performance of the ANSP.

Based on the parallel processes described above, an appropriate feedback loop ensures reverting to a tuning process, every time MSAW is not providing the required safety benefits.

It is to be noted that the whole MSAW lifecycle is not a linear process, due to the ever-changing nature of the operational context in which MSAW is embedded. Thus iterations are still possible not only within each phase, but also between the different phases.

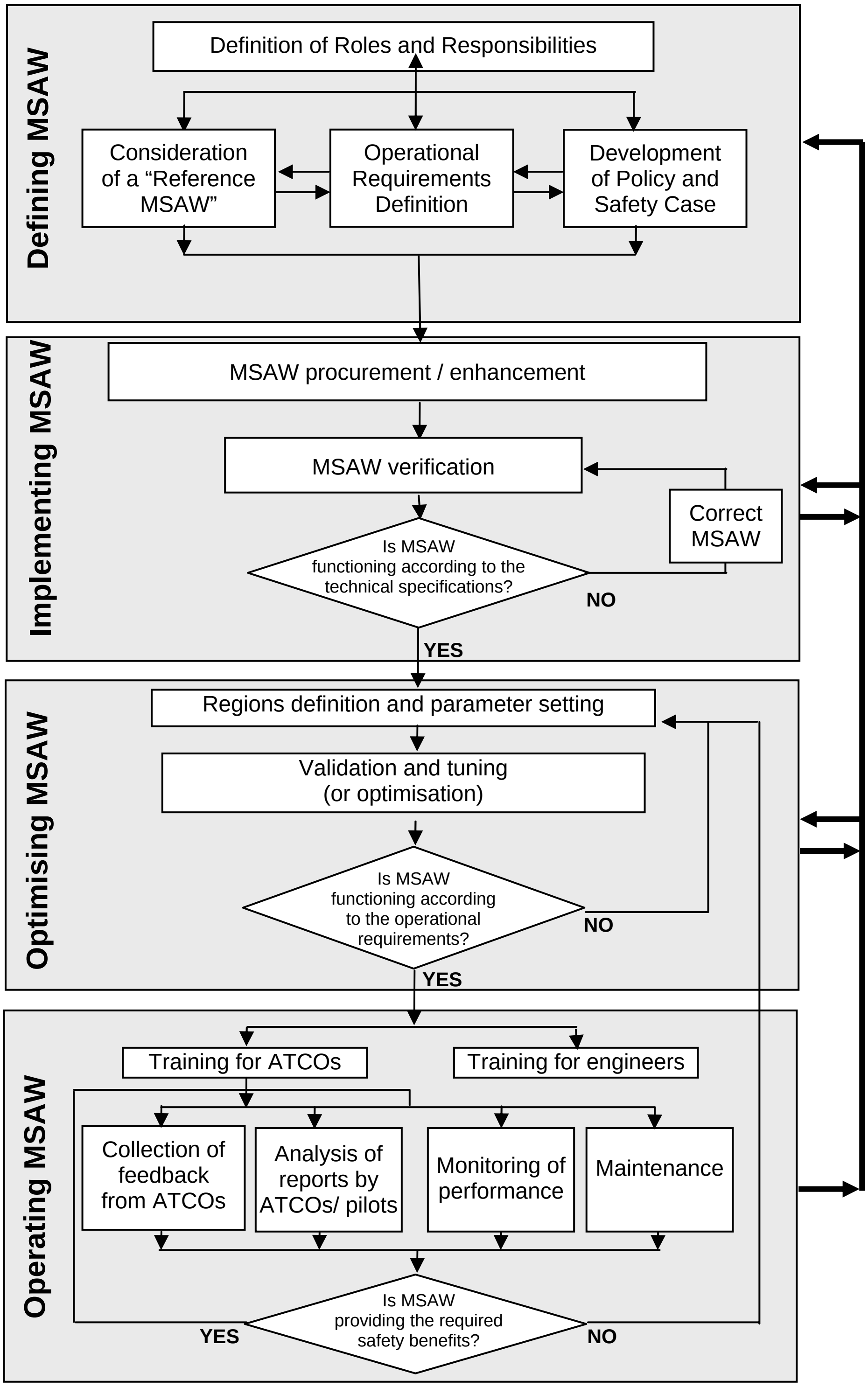

Figure 2-1 The MSAW Lifecycle

3. DEFINING MSAW

3.1 Introduction

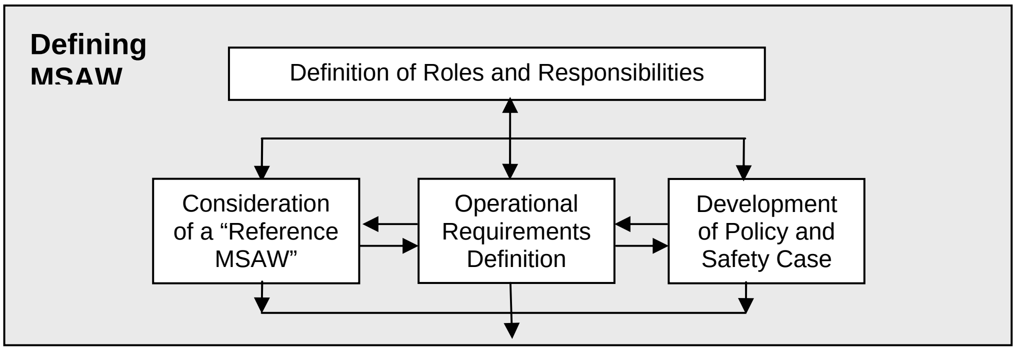

Figure 3-1: First phase of the MSAW Lifecycle

A preliminary step for defining the MSAW is making clear and well known the roles and people inside the organisation responsible for the MSAW. Three parallel processes should then be started: (a) considering a "Reference MSAW" as technical input for the following phases, (b) defining the Operational Requirements and (c) developing a specific Policy and Safety Case.

3.2 Definition of Roles and Responsibilities

The EUROCONTROL Specification for Minimum Safe Altitude Warning requires that:

MSAW-02 The ANSP ***shall*** assign to one or more staff, as appropriate, the responsibility for overall management of MSAW.

It ***should*** be possible for other staff in the organisation to identify the assigned staff. The assigned staff ***should*** seek advice from the MSAW manufacturer, as appropriate.

Management of MSAW can be addressed in different ways, according to the specific characteristics and constraints of the ANSP. Nevertheless, through various phases of the MSAW lifecycle, a mix of different staff will be required, including technical, operational and safety specialists. Despite that fact that developing an MSAW may appear as a purely technical exercise, it is of paramount importance that MSAW is fit for the purposes of the specific operational context and consistent with the safety policy established inside the ANSP.

In all ANSP organisations an adequate flow of information between engineering and operational staff is constantly required, especially in the tuning and validation phases.

The operational staff should have experience in the various areas where MSAW will be active. MSAW is often applied in the TMA, or at lower altitudes, and then only for civil ATC. Nevertheless, in the appropriate environment, MSAW could be applied en route, and en route controllers and/or military controllers should be consulted when gathering operational requirements if MSAW could affect their operations.

Finally, an adequate involvement of Safety Management should be ensured both when developing the Policy and Safety Case and when monitoring MSAW performance. For example, the role of MSAW should be adequately considered when evaluating the overall safety performance of the ANSP.

Note that roles and responsibilities can change or be adapted as far as new needs emerge in following phases of the lifecycle. However roles should remain clear and well established inside the organisation, to ensure reliable management of the system.

3.3 Consideration of the Reference MSAW System

The *Reference MSAW System* is the description of a generic MSAW implementation, with a number of optional features, to be used by the ANSPs as a reference, when setting the objectives of their own MSAW. Rather than being a standard, it is a set of recommended practices aimed at identifying the basic elements of a typical MSAW and the advantages and disadvantages of various applicable options.

The most essential parts of the reference MSAW system are summarised in this chapter, to allow an understanding of how MSAW fits into the ATC system, and the main technical features and options.

For a more in depth description of MSAW, please refer to chapter two of *appendix A: Reference MSAW System*.

3.3.1 MSAW in the ATM System Environment

The inputs to and outputs from the reference MSAW system are best understood in the MSAW context diagram, shown in Figure 3-2 below:

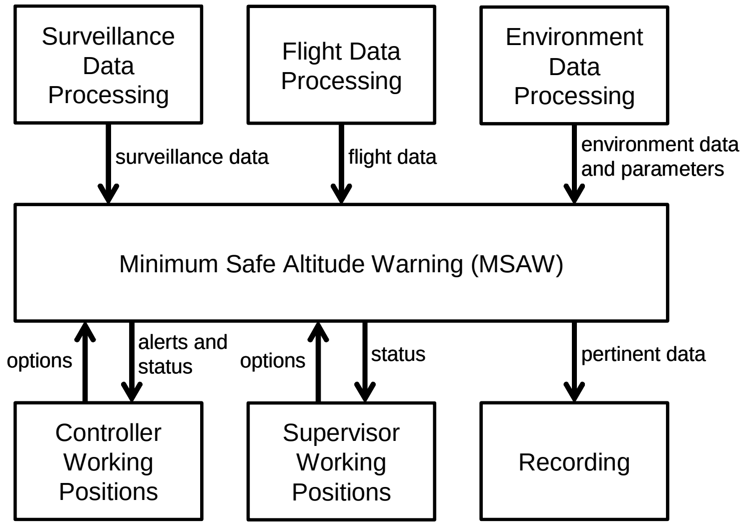

Figure 3-2: MSAW Context Diagram

As illustrated in the diagram, the reference MSAW system obtains information from Surveillance Data Processing and Environment Data Processing. As an option, the reference MSAW system can additionally make use of data from Flight Data Processing.

Surveillance track data including tracked pressure altitude is used to predict hazardous situations. Tracked pressure altitude data (via mode C or mode S) is used to make a prediction in the vertical dimension.

Environment data and parameters are used to define:

- Terrain and obstacle data
- Alerting parameters
- Additional items (QNH, temperature, etc.)

Flight data is used to provide additional information, such as:

- Type/category of flight: to determine the eligibility for alert generation
- Sector(s) of concern: to address alerts
- Cleared Flight Levels: to increase the relevance of conflict prediction

Alerts should be presented at least at a Controller Working Position of the control sector working the aircraft. Status information regarding the technical availability of MSAW is to be provided to all Working Positions. Selectable options of MSAW related to eligibility, configuration and technical availability may be available at Controller and Supervisor Working Positions.

All pertinent data for offline analysis of MSAW should be recorded.

3.3.2 System Tracks Eligible for MSAW

Most essentially, MSAW must recognise which tracks belong to aircraft under responsibility of the control centre, and further for which tracks MSAW alerts are relevant.

Depending on local requirements, the determination of system track eligibility can be done in a variety of ways. Often only tracks that are correlated with a flight plan are processed. Alternatively, the SSR code of the track may be used to determine whether the track should be processed.

An MSAW inhibition list is often part of the off-line MSAW parameters. In this respect it is a static list that would be updated when necessary by technical or supervisory staff. On the other hand, MSAW provides the possibility to inhibit alerts for predefined volumes of airspace and for specific flights.

3.3.3 MSAW polygons, terrain and obstacles

In many cases MSAW uses polygon volumes to model terrain and obstacles. The polygon volumes may be set several hundred feet below the lowest minimum safe altitudes that could be applicable (Minimum Radar Vectoring Altitude (MRVA), Minimum Obstacle Clearance Altitude (MOCA) or Minimum Sector Altitude (MSA) as appropriate), or if desired may be set to more closely follow the terrain.

The margin of several hundred feet must be allowed for tracker lag and apparent undershoot of safe altitudes. That is, the polygon volumes must be below the lowest minimum safe altitude, otherwise almost every aircraft that levels off at the safe altitude will generate a nuisance alert.

Digital terrain data based on satellite survey information or other sources provides a more precise terrain definition for MSAW. An additional height margin should be added to the terrain elevation to take account of temporary obstacles (e.g. cranes) and vegetation.

MSAW may allow obstacles (e.g. towers, radio masts) to be specified as polygons or as cylinders with a defined altitude limit. This feature of MSAW systems is particularly suited to supplement digital terrain data, since the terrain data itself does not include obstacle information.

The size of each obstacle volume does not necessarily need to match the size of the object. Indeed, it is prudent to add lateral and vertical safety margins to the obstacle definition. If necessary, one or more polygons or cylinders may be used to represent a cluster of objects, or an object with a complicated shape.

3.3.4 MSAW Configurations with and without Digital Terrain Data

In this document, MSAW is assumed to be capable of operating in one of two configurations:

Configuration 1 – use of polygons

The terrain and obstacles are modelled by a mixture of polygon and cylinder-shaped volumes.

Figure 3-3 below shows in profile how the terrain and obstacles may be modelled using polygons. The figure shows some high elevation terrain topped by a man-made obstacle:

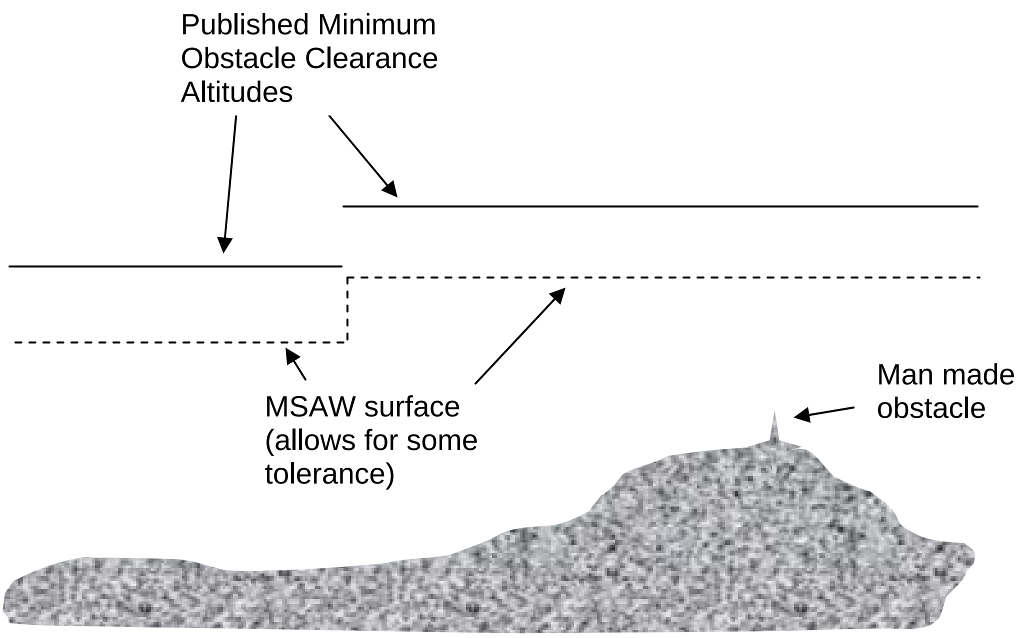

Figure 3-3 Typical MSAW use of polygons

Configuration 2 – use of digital terrain data

In this configuration, terrain and obstacles are modelled by digital terrain data, usually with a vertical margin added to take account of vegetation, and temporary obstacles. This terrain data may be supplemented by a set of user-defined polygons and cylinders, which represents permanent, static obstacles.

Figure 3-4 below shows the same terrain defined in MSAW by digital terrain data (sampled at regular intervals), which is a vertical distance above the terrain, and the obstacle defined as a cylinder or polygon.

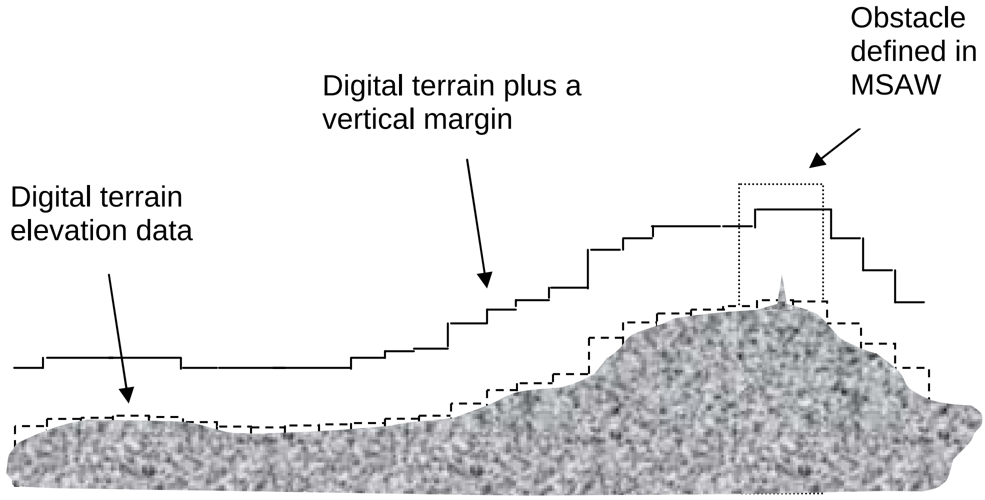

Figure 3-4 Typical MSAW use of digital terrain data

Appendix D illustrates the advantages and disadvantages of the two configurations in a specific, demanding environment. Similar trade-off studies should be performed in close cooperation with (potential) terrain and obstacle data supplier(s) to determine the optimum configuration for a specific environment.

3.3.5 MSAW Exclusion Areas

MSAW exclusion areas may be defined where no MSAW detection of hazardous situations will be done.

3.3.6 Conflict Detection

The future position of the aircraft is extrapolated forwards from the current track position for predefined look-ahead time.

In the lateral dimension, the prediction is a straight-line extrapolation made using the current track position and velocity.

In the vertical, the prediction is a straight-line extrapolation made using the current altitude (with barometric correction), and the vertical rate of the track. If the CFL is used then this is taken into account.

If an infringement of the relevant surface (polygon, terrain or obstacle) then a conflict 'hit' is registered. Otherwise a conflict 'miss' is registered.

3.3.7 Alert Confirmation

The alert confirmation stage in MSAW has a number of objectives:

- To test if a conflict is imminent and an alert is required immediately;
- To suppress an alert which might be caused by spurious track data;
- To suppress an alert which might be caused by a transitory situation;
- To test whether an alert is required on this cycle, or should be delayed, with the hope that the situation will be resolved before an alert is necessary;
- To continue an alert when there are temporary perturbations in the track data.

Essentially, the alert confirmation stage determines whether to issue an alert based upon the number of conflict "hits" from previous track cycles and the time of violation (i.e. the remaining time until the modelled terrain or obstacle is reached).

3.4 Operational Requirements Definition

In general terms, operational requirements are qualitative and quantitative parameters that specify the desired capabilities of a system and serve as a basis for determining the operational effectiveness and suitability of a system prior to deployment.

This part of the MSAW lifecycle is very important, since time spent defining a set of high quality operational requirements is time spent reducing the risk of partial or complete project failure.

For MSAW, the scope of the operational requirements covers both functional and non-functional requirements, including, but not limited to, the following:

Functional requirements:

1. capabilities or features of the system (e.g., MSAW surface definition, types of alert inhibition, etc)
2. system capacities (e.g. number of MSAW surfaces, obstacles etc)

3. requirements on environment data (both on-line and off-line)
4. HMI requirements (as far as is relevant for the system)
5. data recording requirements

Non-functional requirements:

1. usability requirements (e.g. clarity of alerts, ease of data input)
2. quality attributes (e.g. reliability, maintainability, supportability, testability, safety, standards and availability requirements)
3. constraining factors imposed externally (e.g. cost, legislation, policy)
4. interoperability/interface requirements (e.g. physical, process, support and information interfaces to other capabilities/systems)

Defining the operational requirements of a new or modified MSAW can be a challenge, especially for individuals who have had no previous experience in either MSAW or operational requirements definition. Therefore, this section is focussed on the process of defining operational requirements.

The convention is to consider the definition of operational requirements as a three-stage process.

1. Initial Requirements capture - gather an exhaustive list of requirements.
2. Requirements Analysis - analyse the list to address ambiguous, incomplete or contradictory requirements.
3. Requirements Recording - record the final requirements in an operational requirements document.

3.4.1 Initial Requirements Capture

The aim of the requirements capture stage is to produce a list of requirements, but to refrain from analysing them closely. The list of requirements should be refined later during requirements analysis. During the capture stage, too narrow a focus can result in costly oversight, which can only be pre-empted through engagement with all key stakeholders early on in the process.

There are a number of techniques and tools that can be used to derive requirements. Some of the more widely used ones are:

- Key Stakeholder Workshops for the resolution of discrepancies by consensus
- Re-use of requirements *(requirements from previous MSAW)*

- Product research *(product surveys, web searches, ANSP feedback)*
- Use of guidance material *(Reference MSAW System)*
- Interviews with stakeholders, usually on a one-to-one basis, to facilitate detailed consultation (ATCOs, technical specialists)
- Use of a requirements checklist *(see section 3.4.4)*
- Brainstorming techniques are particularly suited to where requirements are considered vague *(In groups of six or fewer domain specialists)*
- Hazard Analysis *(finding potential hazards can generate requirements for mitigation)*
- System Modelling *(real time or fast time, as appropriate)* may be used as a facilitating mechanism
- Capability gap analysis *(a study comparing the current capability to the desired future capability).*
- Prototyping
- Lessons learned *(from previous projects or programs)*
- Use of an MSAW demonstrator to show example situations and alerts.

It is suggested that a number of these techniques/tools be employed, depending on the amount of effort that is available, and the anticipated complexity of the requirements.

The people involved in the requirements capture depends to some extent on the methods employed. Nevertheless, it is always essential to involve operational, technical and safety experts in the process. The experience of operational staff should cover the entire airspace in which MSAW will be active. Important input into the requirements capture will also come from a number of technical experts who should have knowledge of MSAW, other associated ATM functions (e.g. flight data processing, surveillance data processing, data recording) and issues related to system interfacing.

The requirements checklist is a non-exhaustive list of areas that should be considered in the requirements capture, and may be used to give structure to interviews and brainstorming sessions.

Models and prototypes can be powerful tools for establishing both functional and non-functional requirements. However, the model or prototype may require a significant amount of resources to produce.

The output of the previous activities is typically a loose collection of lists of requirements and related issues. These need to be engineered into one cohesive database.

3.4.2 Requirements Analysis

Requirements analysis should be undertaken by a small group of qualified staff with operational, technical and safety expertise.

The purpose of the exercise is to sort through the list of requirements obtained from the previous stage to check that each is complete and unambiguous, and does not contradict other requirements. It may be necessary to clarify some requirements with the originator.

It is also useful to organise the requirements into groups of related requirements or categories.

3.4.3 Requirements Recording

The final stage is to record the requirements in an operational requirements document.

This is a living document. In discussion with manufacturers or other ANSPs, it is likely that requirements will change or be added that were not foreseen in the original requirements capture.

Requirements may also be removed. To avoid unnecessary repetition of effort, it is important that a permanent record of the each removed requirement is kept, as well as the reason for its removal.

It should also be agreed with the manufacturer at which point in the development of MSAW the requirements will be frozen.

Each requirement should be:

- Correct
- Unambiguous
- Complete
- Consistent
- Ranked for importance
- Verifiable
- Atomic

- Modifiable
- Traceable

3.4.3.1 *Correct*

It is recommended that each requirement be reviewed for correctness, if necessary, tracing back to the originator, or originating document that lead to the requirement. Ask whether the requirement is strictly true, and whether it is necessary. If the answer to either question is “no”, then the requirement should be reworded, re-ranked (for importance), or deleted.

3.4.3.2 *Unambiguous*

Each requirement should have as far as possible only one interpretation. Requirements need to be contractually taut. If not, then the supplier might misinterpret what was asked for and the recipient cannot know if they have received what was meant to be delivered and so may not know whether to accept it. An independent review of the requirements can help identify ambiguous use of language.

3.4.3.3 *Complete*

Consider whether, given the operational requirements document alone, the product developers would be able to deliver a suitable system.

3.4.3.4 *Consistent*

Each requirement should neither contradict nor repeat any other requirement.

3.4.3.5 *Ranked for Importance*

Some requirements may be essential, whereas others may simply be desirable, so it is important to assign a priority to each one. This may help decision-making if, at a later date, it becomes apparent that some requirements are difficult to achieve within the anticipated budget. Requirements can be prioritised as follows;

- Key requirements are critical to the capability and the satisfaction of the operational need. They bound the contract and encapsulate the characteristics of the capability
- Priority 1, Priority 2 and Priority 3 requirements in decreasing importance. The ability to trade these requirements is to be defined within the project
- Mandatory requirements are compulsory but not unique to the capability (e.g. legislation/safety)

3.4.3.6 Verifiable

It is important to consider whether reasonable means exists to check that the product meets the requirement. If a method cannot be devised to determine the product meets the requirement, then it should be reworded or removed.

To satisfy the need for testability, the requirement should also be defined in precise terms. For example, replace phrases such as “immediately” and “appropriate HMI” with phrases like “within 3 seconds of the event 99% of the time”, and “pop-up menu, realised by a click of the right mouse button”.

3.4.3.7 Atomic

There should be only one action or concept per statement.

3.4.3.8 Modifiable

Avoid duplication of requirements and structure the operational requirements document to be easily modifiable.

3.4.3.9 Traceable

It is often useful to be able to determine the original reason for a requirement. A requirement is traceable if its origin is clear.

3.4.4 The MSAW Requirements Checklist

Table 3-1 below outlines a number of questions that an ANSP will find useful to address in order to help define the requirements for MSAW. The list is not exhaustive, and ANSPs will no doubt need to define requirements that are not covered in the list.

The ANSP may also use parts of the checklist as a basis for compiling a list of questions for MSAW manufacturers.

1. Current and Future Operational Environment

1.1 Within which classifications/types of airspace will MSAW be adopted?

Airspace Classification (e.g. Class A – G), en route, off-route, TMA, approach, departure, stacks, military airspace, danger areas

1.2 What aerial activity is conducted in the proposed MSAW airspace?

Straight flight, vertical transitions, turns, aerobatics, military operations, high energy manoeuvres

1.3 What types of flights are of concern?

Civil, Military, General Aviation, IFR, VFR, GAT, OAT

1.4 What is the nature of the traffic and terrain?

Traffic hotspots close to terrain, MSAW protection around SIDs and STARs, busy periods, temporary obstacles

1.5 How is the Airspace used?

FUA either now or in the future, Civil/Military sharing airspace, uncontrolled flights

1.6 What is the impact of ATM Procedures?

Standing agreements? Silent co-ordination?

2. Current and Future ATM System Components

2.1 Flight Data Processing System

Correlation used for MSAW eligibility? Flight plans available over area of interest?

MSAW function in FDPS Failure Modes?

2.2 Data Recording System

Recording of Tracks and Alerts? Recording of internal MSAW values?

Sufficient to allow verification of MSAW, or alert analysis?

2.3 Other Data Inputs

QNH, Temperature

3. Current and Future Surveillance

3.1 Surveillance Coverage

Coverage sufficient (especially at lower altitude)? Known problem areas? What is the operational requirement?

3.2 Track Quality

Reliability of lateral and vertical track? Tracking blunders? Transponder Faults? Reflections?

3.3 Data Content

Turn information? Track Age? Track Quality? Mode S Data? SFL?

4. Track Eligibility, MSAW Regions and Parameters

4.1 Eligibility

Between all aircraft or selected?

Eligibility based on tracks correlated to a flight plan and/or SSR code lists?

Tracks without pressure altitude?

Use of track quality? Track Age?

Are some tracks/flights to be Inhibited (manually or automatically)?

4.2 MSAW surface definitions

Use of Digital Terrain Data, use of polygons, or both?

MSAW should use actual polygon shape or superimpose on a grid?

Constraints on grid dimensions and cell size?

Use of an obstacle data base?

4.3 MSAW exclusion areas

Number of MSAW exclusion areas?

Exclusion area shapes?

Exclusion area activation (on and off) either manually or automatically?

4.4 Regions (regions could be used to apply different predictions or parameter values according to the airspace)

Regions required (now or in future)?

Region shapes?

Region activation (on and off) either manually or automatically?

4.5 Parameters

Which parameters must be tuneable (e.g. sensitivity, false alerts)?

Parameter ranges sufficient for optimisation?

5. MSAW Features (see Reference MSAW System for more information) 5.1 Treatment of Special Conditions (radar reflections, known transponder faults) 5.2 Conflict Detection Mechanisms (Linear prediction, Current position, Turning prediction, uncertainty etc) 5.3 Use of CFL/SFL. 5.4 Alert Confirmation Stage (Time of Violation Tests, Conflict Counts, Conflict Probability) 5.5 Conflict Alert Message Supports Multi-level alarms? Contains pertinent data (TOV, MSAW volume)?
6. Issues related to HMI (where HMI requirements are an issue) 6.1 Effective use of colour, flashing etc for an alert? 6.2 Effective use of aural alarms 6.3 Conflict Alert Box used? Appropriate information in the box? 6.4 Display of Multilevel (multi-severity) alarms? 6.5 Alert acknowledgement (the suppression of a current MSAW alert)? 6.6 Alert inhibition (the suppression of one or more tracks from MSAW processing)? 6.7 Display of MSAW status (to controller(s), supervisor)?

7. Tools and Support
7.1 Tools
Data Recording and playback?
Display of internal MSAW values?
MSAW analysis and tuning tools?
Plot/track/flight generator to create test scenarios?
Other display tools for MSAW surfaces, exclusion areas, encounters or hot spots?
7.2 After Sale Support
Support for set up and optimisation?
Training / documentation for technical staff and controllers?

Table 3-1 MSAW Requirements Checklist

3.4.5 Specific Issues

3.4.5.1 The Implications of Using Digital Terrain Data

The use of DTED can be an attractive option for ANSPs. Because the digital data is naturally a much finer representation of the terrain than a series of hand-made polygons, its use normally results in a reduced number of nuisance alerts. This then allows the user to set longer prediction time and/or warning time parameters, resulting in a good balance between the timeliness of the alert and the nuisance alert rate.

For MSAW configurations that allow the importation of DTED, the operation of loading the data itself is normally straight forward, and generally less effort than manually constructing polygons for the whole area of interest.

Before using DTED data, ANSPs should ensure that the data is fit for purpose. The DTED product supplier should be able to provide basic information on the accuracy and integrity of the data. Nevertheless, the user should check the data independently, looking to see if there are any missing data, any gross errors, or unacceptable errors on local peaks.

Some of the most effective analyses of DTED have been done by taking two sources of data, and effectively taking the elevation differences between the two sets of data (where they cover the same ground). The analysis normally requires a specially produced computer program, which subtracts the elevation from one DTED source from another and outputs the result to a colour coded bitmap. Gaps in either data source should also be colour coded (perhaps in black or white to distinguish it from an elevation difference). The resulting bitmap is then viewed, and the user can immediately see any gaps in the data and the areas where there is significant discrepancy between the two data sources. The user may have to compare a number of data sources before it is clear which data source is actually better.

Extra checks should also be done by taking known local peaks (mountain peaks especially). A missing or erroneous peak is likely to impact MSAW performance more than an error elsewhere. Hence, the user should aim to manually check a generous portion of spot elevations against the published elevations.

3.4.5.2 The Use of Obstacle Data in MSAW

The purpose of using obstacle data in MSAW is to supplement the DTED data. MSAW configurations that use DTED include a vertical margin parameter, to take account of obstacles that are not included in the terrain data, such as man-made objects, buildings, and vegetation. Nevertheless, some objects may be sufficiently tall to warrant inclusion in an MSAW obstacle data base.

The decision to include obstacles will depend on a number of factors:

- How closely the DTED models the terrain, and how closely it models the reflective surfaces (i.e. the trees and buildings)
- The vertical margin the ANSP intends to use and whether this is sufficient to cover all the tall man-made obstacles

The permanent static obstacles, such as towers, sky-scrapers are relatively easy to include in a data base. However, the user should also consider if temporary or moveable objects are also to be included, and therefore how the inclusion in the MSAW obstacle data base will be managed.

3.4.5.3 The use of temperature in MSAW

Pressure altimeter systems on aircraft are calibrated for the International Standard Atmosphere (ISA), which includes an assumed air-temperature at mean sea level of 15°C. In simplistic terms, every 1°C deviation from 15°C will result in a deviation from the true altitude of approximately 0.4%. That is, if the air temperature at sea level were 5°C, an aircraft altimeter indicating an altitude of 1000ft (after QNH correction), would in fact be at about 960ft (assuming all other errors were negligible).

The table below illustrates the actual aircraft altitude for various combinations of indicated altitude and temperature (at MSL).

Altimeter Reading	**1000ft**	**2000ft**	**3000ft**	**5000ft**	**10000ft**
0°C	940ft	1880ft	2820ft	4700ft	9400ft
5°C	960ft	1920ft	2880ft	4800ft	9600ft
10°C	980ft	1960ft	2940ft	4900ft	9800ft
15°C	1000ft	2000ft	3000ft	5000ft	10000ft
20°C	1020ft	2040ft	3060ft	5100ft	10200ft
25°C	1040ft	2080ft	3120ft	5200ft	10400ft
30°C	1060ft	2120ft	3180ft	5300ft	10600ft

Table 3-2 Actual Aircraft Altitudes at various Temperatures

ANSPs should decide how temperature (particularly cold temperature) could affect the performance of MSAW in their particular environment, and possibly give further consideration of how it could practically be provided to the MSAW system, if required.

3.5 Development of a Policy and a Safety Case

3.5.1 Development of a Policy

The EUROCONTROL Specification for Minimum Safe Altitude Warning requires that:

The ANSP shall have a formal policy on the use of MSAW consistent with the operational concept and SMS applied.

The policy should be consistent with the following generic policy statements:

MSAW IS A GROUND-BASED SAFETY NET; ITS SOLE PURPOSE IS TO ENHANCE SAFETY AND ITS PRESENCE IS IGNORED WHEN CALCULATING SECTOR CAPACITY. **MSAW IS DESIGNED, CONFIGURED AND USED TO MAKE A SIGNIFICANT POSITIVE CONTRIBUTION TO AVOIDANCE OF CONTROLLED FLIGHT INTO TERRAIN ACCIDENTS BY GENERATING, IN A TIMELY MANNER, AN ALERT OF AIRCRAFT PROXIMITY TO TERRAIN OR OBSTACLES.**

MSAW is only effective if the number of nuisance alerts remains below an acceptable threshold according to local requirements and if it provides sufficient warning time to resolve the situation.

The policy should be developed in collaboration with controllers who have experience of using MSAW operationally, as well as staff who understand the specific operational environment. Local factors, such as the density and type of air traffic, may be taken into account when developing the policy.

The policy statements define how MSAW is to be used. Consequently, these statements should steer much of the MSAW lifecycle, including operational requirements definition, system specification, parameter settings and controller training.

3.5.2 Development of a Safety Case

It is Safety Management best practice and an ESSAR4 requirement to ensure that all new safety related ATM systems or changes to the existing system meet their safety objectives and safety requirements. ANSPs and National Safety Authorities will need documented assurance that this is the case before putting the new or changed system into operation. Typically, the assurance is presented as a safety case.

Comprehensive guidance on how to develop a safety case for MSAW is available in the following three documents:

Appendix B-1: Initial Safety Argument for MSAW System

Appendix B-2: Generic Safety Plan for MSAW Implementation

Appendix B-3: Outline Safety Case for MSAW System

An ANSP’s own documented assurance should contain the evidence, arguments and assumptions as to why a system is safe to deploy. The process of developing and acquiring the necessary safety assurance is considerably enhanced if the activities to obtain it are planned from the outset, ideally during the system definition phase of a project.

Each document in Appendix B represents a snapshot of the safety assurance work already undertaken at different stages of a project. The document set includes:

Appendix B-1: Initial Safety Argument for MSAW System - Ideally, produced during the definition phase of a project to introduce a change to the ATM system e.g. to introduce MSAW. The process of developing and acquiring the necessary assurance is considerably enhanced if the safety arguments are set out clearly from the outset.

Appendix B-2: Generic Safety Plan for MSAW Implementation - Initially produced at the outset of a project as part of the project plan, but focused only on those activities necessary to provide assurance information for inclusion in a safety case. The safety plan will be subject to development and change as the project unfolds and more detail becomes available.

Finally, *appendix B-3: Outline Safety Case for MSAW System* - Commenced at the start of a project, structured in line with the safety argument, and documented as the results of the planned safety assurance activates become available.

4. IMPLEMENTING MSAW

4.1 Introduction

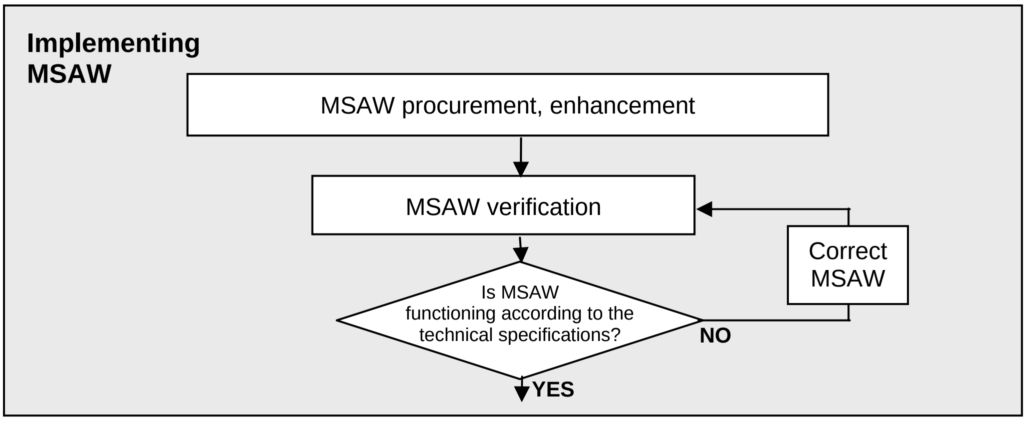

Figure 4-1: Phase 2 of the MSAW Lifecycle

ANSPs will normally choose between two alternative options when covering this lifecycle phase: (a) purchasing an MSAW product from a manufacturer or (b) enhancing an already implemented system. For both cases guidance is provided in the following sections of this chapter and in the two Appendixes referenced below.

Appendix A: Reference MSAW System describes a generic or reference MSAW system, with a number of optional features. This document can provide useful information for those making decisions related to system procurement or enhancement.

A cost framework is provided in *appendix C: Cost Framework for the standardisation of MSAW*. This gives guidance to the cost of implementing or enhancing MSAW to meet the requirements prescribed in the EUROCONTROL Specification for Minimum Safe Altitude Warning

4.2 Procurement of MSAW

The aim of any purchase is that the delivered product is fit for purpose.

Manufacturers of MSAW have a responsibility to ensure that the products they sell are fit for operational use. Conversely, the ANSP also has a duty to inform the manufacturer of any specific requirements at an early stage.

MSAW, like other safety nets, is often included as part of a manufacturer’s ATM system. If this is the case, it is important to make sure that the MSAW is appropriate.

At a very early stage in the purchase decision, it is essential that the manufacturer supplies a specification of the proposed MSAW so that the purchaser can assess if the MSAW will be appropriate for their needs. It is also helpful if at the earliest opportunity, the manufacturer is able to demonstrate the MSAW, and explain the functional aspects. If the MSAW is part of an ATM system to be purchased, then the HMI and visual/aural aspects of the MSAW alerts should also be demonstrated.

The purchaser should review the MSAW specification in detail to ensure that the system will not only be fit for current use, but can be configured to meet anticipated future needs (such as changes to airspace, or new input data). The purchaser should also seek the manufacturer's advice, to check whether the MSAW will meet the purchaser's needs. It is likely that several meetings between the respective experts will be required specifically to discuss requirements, system capabilities and capacities.

If the MSAW is not being designed from a set of operational requirements, it will be useful at the outset for representatives from both the manufacturer and the purchaser to compile a list of relevant questions. An example list is given in Table 4-1 below:

What is the extent of the airspace to be covered by MSAW?
What is the nature of the air traffic (TMA, en route, approaches, departures, stacking)?
What are the main features of MSAW, and are they in accordance with aircraft behaviour, tracker behaviour and local operational procedures? (Perhaps think about how much manoeuvring occurs, the number of tracks from radar reflections, and whether reliable CFL or SFL data is available)
What SDP (tracking) data will be provided to MSAW, and is it of sufficient coverage and quality?
What other data will be supplied to MSAW? Flight plan data? Data input by the controller?
How will MSAW alerts be presented to the controller?
Does the facility exist for the controller to be able to manually inhibit alerts?
How are parameters set, and regions defined?
How are terrain and obstacles modelled in the operational system?
Is the maximum number of polygon volumes sufficient for current and future needs?
Can exclusion regions be dynamically activated / deactivated?

How many exclusion areas can be defined?
Are other MSAW capacities sufficient for both current and future needs?
Do the parameters (or range of values) allow MSAW to be optimised for the airspace?
What MSAW analysis tools are provided?
Is the MSAW capable of recording its internal values, and are they sufficient for testing?
Who will test MSAW? And how will it be tested?

Table 4-1 Example List of Relevant Questions

The answers to these questions will help both the purchaser and the manufacturer determine whether the purchaser's requirements can be met.

The purchaser may wish to ask the manufacturer for specific features, or the manufacturer could offer a number of advanced features. With any of the advanced features, it is important to make sure that it is relevant in the airspace of interest and local operational procedures.

MSAW should be subject to factory acceptance testing (FAT) and site acceptance testing (SAT).

It is normal practice for not only the manufacturer to perform tests on the system but also the purchaser. The purchaser in particular will want to test the system to make sure that:

- It behaves as specified
- It is fit for operational use

The manufacturer should be able to supply tools and, if necessary, human resources to help the purchaser test MSAW.

4.3 Enhancement of an Existing MSAW

4.3.1 Introduction

This section provides guidance on how to manage the enhancement of an existing MSAW.

The need to enhance MSAW is very often driven by a need to solve performance issues. In particular, it is not unusual for one or more of the following problems to exist:

- MSAW is giving irrelevant alerts (e.g. alerts for aircraft not under ATC)
- MSAW is producing too many false or nuisance alerts
- MSAW is not providing sufficient warning time, or provides sufficient warning time only in a limited number of situations

As well as improving alerting performance, MSAW can also be enhanced by making improvements to the presentation of the alert, or the controllers HMI. A number of HMI options are described in section 4.5.

Enhancing MSAW is normally less expensive than buying a new one from scratch. In any case, a new MSAW may not necessarily solve the original problem(s). Furthermore, the ANSP is generally familiar with how their MSAW operates, and can often foresee how MSAW will perform after improvements have been implemented.

Nevertheless, in order to make the improvements, the ANSP must commit some resources to the task, and must either already have a good technical understanding of MSAW, or draw on external technical expertise.

A practical example of MSAW enhancement is given in *appendix D-1: Enhancement of MSAW for Skyguide.*

4.3.2 The Improvement Process

The improvement process can be broken down into a number of essential steps:

- Identifying and understanding the nature of the problem(s).
- Designing appropriate solution(s)
- Implementing the change
- Measuring the effect of the change

Identifying and understanding the nature of the problem is the crucial first step to designing an appropriate solution. In some cases, the precise nature of the problem will be revealed simply by looking at a controller display.

However, in many other cases, the only way to fully comprehend the problem is to record a sample of traffic, and analyse in detail the situations that trigger the problem. This analysis is greatly aided by the availability of a complete and accurate specification of the MSAW algorithms.

It is important at the analysis stage to involve both technical and operational staff. This is because technical staff alone may identify solutions that would not be operationally appropriate.

If a number of problems are present, it may be appropriate to implement one solution at a time, in order to test it and measure its effect separately.

An MSAW model is an ideal instrument for testing many proposed improvements to MSAW, and allows the effect of the change to be measured before it is put into the operational system. However, if a model is not available, an alternative could be to use an MSAW running on a non-operational partition of the ATC system.

When adding new logic to MSAW, it is essential to include parameters that will allow the new logic to be fully tuned, and bypassed in the event that the solution does not work as foreseen.

If the solution is complex, ANSPs should consider how risk can be reduced, perhaps by implementing the solution in stages, or by introducing it at a smaller ATC centre first for a trial period.

4.4 Guidelines for Improving the Alerting Performance of MSAW

The most important step is to identify and fully understand the nature of any deficiencies with MSAW. Figure 4-2, below is an idealised troubleshooting process that shows the steps that should be taken when trying to solve problems related to MSAW performance. The feedback loop in the process ensures that if the system is changed (parameters, algorithms or external systems modified), then the problem is re-reviewed and other changes made as necessary. For example, having modified the algorithms, it may be necessary to re-evaluate the MSAW parameter settings.

It is not always necessary for MSAW to be technically enhanced. Many problems can be overcome or reduced by changing the MSAW parameters. Further, making parameter changes might provide a temporary solution to a problem, whilst a better long-term solution is being investigated.

Similarly, some problems could be resolved simply by updating a list of SSR “controlled” codes. It is important to review these codes regularly and make sure they are up to date. It should be considered that specific SSR codes may be assigned to aircraft that are intentionally close to the terrain, such as police helicopters, air ambulances, pipeline/power line inspection flights, survey helicopters, military exercise/low level flights, aerobatic displays and other special events. These SSR codes should be inhibited from MSAW processing in order to prevent continuous nuisance alerts.

Sometimes, a very simple solution may be found which can make a significant contribution to the performance of MSAW. In particular, some deficiencies may be discovered by carefully inspecting the code or the specification. For instance, some things to check for are:

- Check that the eligibility criteria are finding all the aircraft of interest (i.e. they are not removing relevant aircraft from MSAW processing)

- If using a step-wise prediction method, check that the step time is sufficiently short so that no conflicts are missed

- Make sure that the alert confirmation stage gives priority to alerting when the situation is imminent. (Any tests for imminent conditions must not wait for a count of conflict hits to build up)

Certain problems, such as erroneous tracks (due to tracking blunders, radar reflections or erroneous transponders) are not usually solved by tuning the MSAW parameters and are likely to need specific enhancements to the tracker, or identification and correction of offending transponders. For example, trying to avoid alerts from tracking blunders by increasing the conflict count would be inappropriate, because it would reduce the overall performance of MSAW. Instead, problems with the tracks introduced to MSAW should be solved within the wider surveillance system.

Furthermore, MSAW performance may be masked if there are an overwhelming number of false alerts from erroneous tracks. Therefore it is best to deal with these types of unwanted alerts before trying to tune the parameters for optimum alerting performance.

Once most of the problems have been resolved, further improvements to MSAW may be made, for example, by the introduction of new algorithms or the use of digital terrain data.

ANSPs should select enhancements that are in accordance with how aircraft behave in the airspace and local operational procedures. For example, use of CFL or SFL is best considered only if the CFL is input as part of normal ATC procedures or if SFL is available from mode S enhanced surveillance.

The ANSP should review the overall effect of any changes to the MSAW system on alerting performance, and should consider whether some of the other parameters need re-tuning to redress the balance between warning time and nuisance alert rate. For example, if CFL or SFL is used, some parameters may be increased, since there may be more scope to increase the warning time with little effect on the nuisance alert rate.

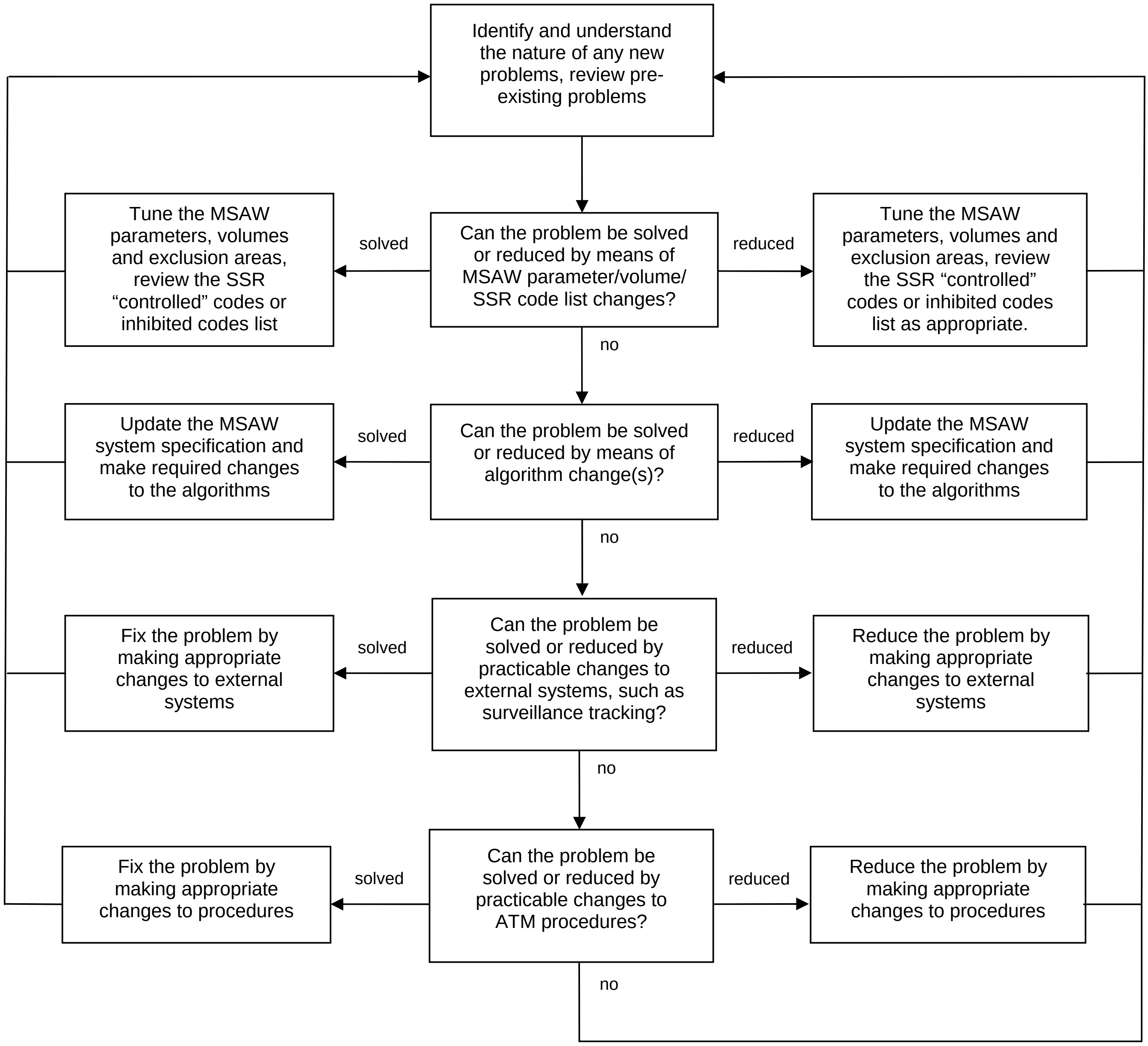

Figure 4-2 Idealised Troubleshooting Chart for MSAW

4.5 HMI Options for MSAW

4.5.1.1 Introduction

Controller's displays vary between the ECAC states, and likewise so does the presentation of MSAW alerts, and MSAW related information.

The purpose of this section is not to promote one type of presentation over another, but to describe a number of options and explain what needs to be considered when deciding on an appropriate HMI.

The most important aspect of an alert is that is should be clear and unambiguous. Even if MSAW is the only source of alerts, the HMI should be designed bearing in mind that other sources may be added in the future.

4.5.1.2 Requirement for Presentation of Alerts

The EUROCONTROL Specification for Minimum Safe Altitude Warning requires that:

MSAW-09 MSAW alerts ***shall*** attract the controller's attention and identify the aircraft involved in the situation; MSAW alerts ***shall*** be at least visual.

It continues:

An audible element ***should*** be included to improve the systems ability to draw the controller's attention to the alert as appropriate (e.g. in Control Towers). If a continuous audible element is included, an acknowledgement mechanism ***may*** be provided to silence an alert.

4.5.1.3 Visual Presentation

An alert is usually indicated visually either by the addition of a short coloured string ("MSAW", "T" or "LA") in the track label, a change of colour or a flashing of part of the track label, or a change in the track symbol colour.

4.5.1.4 Audible Presentation

An audible element to the alert can help draw the controller's attention to a conflict.

The alarm should be clear and unambiguous, and should be audible to the relevant controller.

On the other hand, alarms that are too frequent, too loud or unpleasant will become a nuisance. Continuous alarms may also be a nuisance, and furthermore may overlap with controller's RT instructions to pilot, causing alarm and confusion in the cockpit.

The precise characteristics of the audible alarm must be carefully engineered, taking into consideration other competing noises in the control room and the frequency of MSAW alerts.

4.5.1.5 Alert Inhibition

Alert inhibition can be applied to one or more aircraft, not necessarily those that are currently alerting, and suppress them from alerting.

Tracks are selected for inhibition by the controller on his display, usually based upon SSR codes or call signs.

Note the requirement from the EUROCONTROL Specification for Minimum Safe Altitude Warning:

MSAW-15 Alert inhibitions ***shall*** be made known to all controllers concerned.

4.5.1.6 Controller Inputs

The HMI for controller inputs should be as user-friendly and efficient as possible.

4.5.1.7 MSAW Status Information

MSAW-16 Status information ***shall*** be presented to supervisor and controller working positions in case MSAW is not available.

It should be immediately clear to controllers and supervisors when MSAW is not fully functioning.

4.6 MSAW Verification

4.6.1 Verification Methods

The aim of verification is to check that MSAW is behaving as described in the specification. Therefore, verification relies on the availability of a detailed and accurate specification.

The level of verification that can be done will also depend fundamentally on the data recording capabilities of the system. Guidelines for recording MSAW data are described in detail in chapter 5 of *appendix A: Reference MSAW System*.

It is normally the responsibility of the manufacturer to make sure that MSAW is working as specified. Nevertheless, it is likely that the purchaser will want to check the same, and may either require evidence of verification, or the facility to make their own checks.

4.6.2 Verification Using an MSAW Model

A model of MSAW (written to the same specification) can be an invaluable tool for verification.

For an accurate MSAW model to be produced, it is absolutely essential that the specification is complete and unambiguous. The specification should include the algorithms, parameters, trace message formats, and timing characteristics of MSAW.

When using an MSAW model, the steps that should be followed are:

- Produce or acquire a detailed and accurate specification of the MSAW algorithms.

- Produce the operational MSAW – the operational MSAW should be made capable of outputting trace (or debug) messages containing pertinent internal values, and flags at decision points

- At the same time as the operational MSAW is under production, other engineers should produce an MSAW model to the same specification. The MSAW model should be made capable of producing the same trace messages.

- Design and produce test scenarios to exercise all aspects of the MSAW logic. All essential information, such as parameter values MSAW surface definitions and QNH must also be specified as part of each test. A number of example test scenarios are given in *appendix A: Reference MSAW System*.

  (Note that for test scenarios, the terrain and obstacle model, parameters and QNH values do not have to be realistic, or even close to those that will be used operationally. The purpose of the tests is to ensure that all aspects of the MSAW logic are provoked. For some tests it may be convenient to use extreme parameter values).

- Input the test scenarios into the operational MSAW, recording the surveillance data used by MSAW, the alerts and trace messages.

- Input the same test scenarios into the MSAW model, recording the alerts and trace messages. To ensure the surveillance data are identical to those used by the operational MSAW, it may be necessary to use the surveillance data recorded from the operational MSAW in the previous step.

- Compare the alerts and trace messages from the operational system and the model. In principle, this could be done manually – however, if there are a number of tests, automatic comparison tools will be invaluable at this stage. Any differences between the two must be investigated to check the reason for the difference. If the model is incorrect, this can be quickly fixed.

If the operational system is incorrect it will have to be fixed and the tests rerun. Note that it is also possible that a difference between MSAW system the model highlights an ambiguity in the specification, which should be corrected

- Repeat the previous three steps until all the differences have been resolved.

- Input operational traffic into the operational MSAW, recording the surveillance data used, the alerts and trace messages.

  (Operational traffic is useful because it contains aircraft geometries and conditions that may have been overlooked in the design of the test scenarios)

- Input the same opportunity traffic into the MSAW model, recording the alerts and trace messages. Again, to ensure the surveillance data are identical to those used by the operational MSAW, it may be necessary to use the surveillance data recorded from the operational MSAW in the previous step

- Compare the alerts and trace messages from the operational MSAW and the model, resolving any differences.

- Repeat the previous three steps until all the differences have been resolved.

4.6.3 Verification without an MSAW Model

The use of an MSAW model for verification requires a significant investment of time and resources. If such investments are prohibitive, verification can be done without an MSAW model. However, the level of verification does still rely very much on a detailed specification and sufficient recording capabilities of the operational MSAW.

Without an MSAW model, one approach to verification is:

- Produce or acquire a detailed and accurate specification of the MSAW algorithms.

- Produce the operational MSAW – the operational MSAW should be able to produce trace (or debug) messages containing pertinent internal values, and flags at decision points.

- Design and produce test scenarios to exercise all aspects of the MSAW logic. The terrain and obstacle model, parameter values and QNH required must also be specified as part of each test. (Note that some tests, can be designed such that the passing of the test is indicated by the presence or absence of an alert)

- Input the test scenarios into the operational MSAW, recording the surveillance data used, the alerts and trace messages.
- Check that the expected alerts are present, and there are none that are not expected.
- For a selection of the tests, manually check that pertinent values (e.g. time of violation) are correctly computed.
- For a selection of the tests, manually check the alerts and trace messages against the specification. It should be possible to follow the logical path by comparing the computed values and flags to the algorithms in the specification.
- Repeat the previous four steps (as necessary) until all issues have been resolved.

5. OPTIMISING MSAW

5.1 Introduction

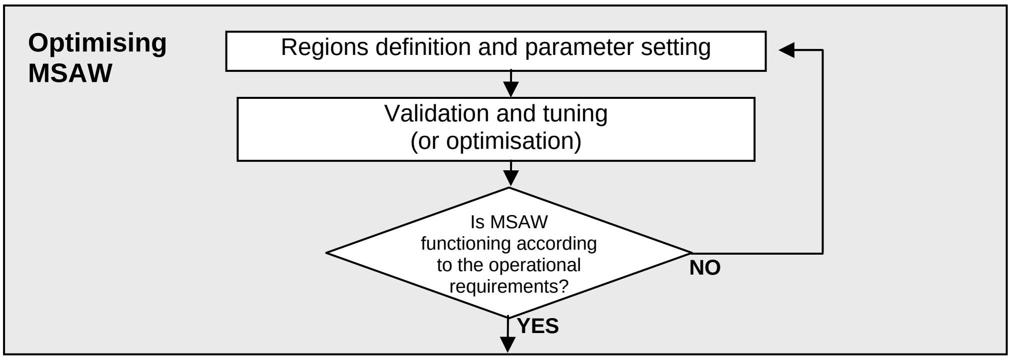

Figure 5-1: Phase 3 of the MSAW Lifecycle

The objective of optimisation is tuning of the MSAW parameters to meet the requirements laid out in the EUROCONTROL Specification for Minimum Safe Altitude Warning:

MSAW-07 MSAW ***shall*** detect operationally relevant situations for eligible aircraft.

MSAW-08 MSAW ***shall*** alert operationally relevant situations for eligible aircraft.

MSAW-10 The number of nuisance alerts produced by MSAW ***shall*** be kept to an effective minimum.

Note.– Human factors and local circumstances determine what constitutes an effective minimum.

MSAW-12 When the geometry of the situation permits, the warning time ***shall*** be sufficient for all necessary steps to be taken from the controller recognising the alert to the aircraft successfully executing an appropriate manoeuvre.

Note.– Insufficient warning time may be provided in cases of sudden, unexpected manoeuvres.

MSAW-13 MSAW ***shall*** continue to provide alert(s) as long as the alert conditions exist.

Meeting such requirements also means optimising the MSAW for the specific needs of the local environment and trying to achieve the best balance between warning time and nuisance alert rate. It is not a one-off activity but a recurring activity throughout the operational life of MSAW in order to keep MSAW optimised for the ever changing operational environment.

Essential elements of this process are: (a) the Definition of the MSAW parameter setting and (b) the Validation and Tuning. The two activities are repeated iteratively several times in order to provide as much warning time as possible, whilst keeping the number of unwanted alerts to an acceptable level and maximising the number of wanted alerts.

Comprehensive Guidance to appropriate parameter values is given in *appendix A: Reference MSAW System*, with suggestions on how to define parameters.

The material includes guidance to parameter optimisation for the reference MSAW system, optimisation concepts, and the optimisation procedure.

5.2 Overview of Parameter Optimisation

At the most basic level, parameter optimisation requires two things:

1. The capability to quantitatively measure the performance of MSAW, given certain surveillance data as input.

2. The capability to alter the parameter settings, so the results of various parameter values can be compared.

The method presented in *appendix A* is highly recommended because it includes quantitative measures of MSAW performance, and once in place is fast and efficient. Unfortunately, the method does also require the use of large samples of recorded data, the use of various tools for MSAW modelling, visualisation and encounter classification. All in all, the process requires a significant commitment of resources to the task.

The tuning process is greatly enhanced by the participation of controllers. Only staff with operational experience can provide guidance on wanted and unwanted alerts, the desired warning time and tolerable nuisance alert rates in the local airspace.

In addition to introducing the recommended parameter optimisation method (section 5.3), this section also describes some alternative methods (section 5.4) that would reduce the amount of expended effort.

5.2.1 Overview of Parameter Optimisation Tools and Files

The diagram below shows the tools and data files that are appropriate for MSAW parameter optimisation. Tools are indicated in bold type, files are shown in normal type.

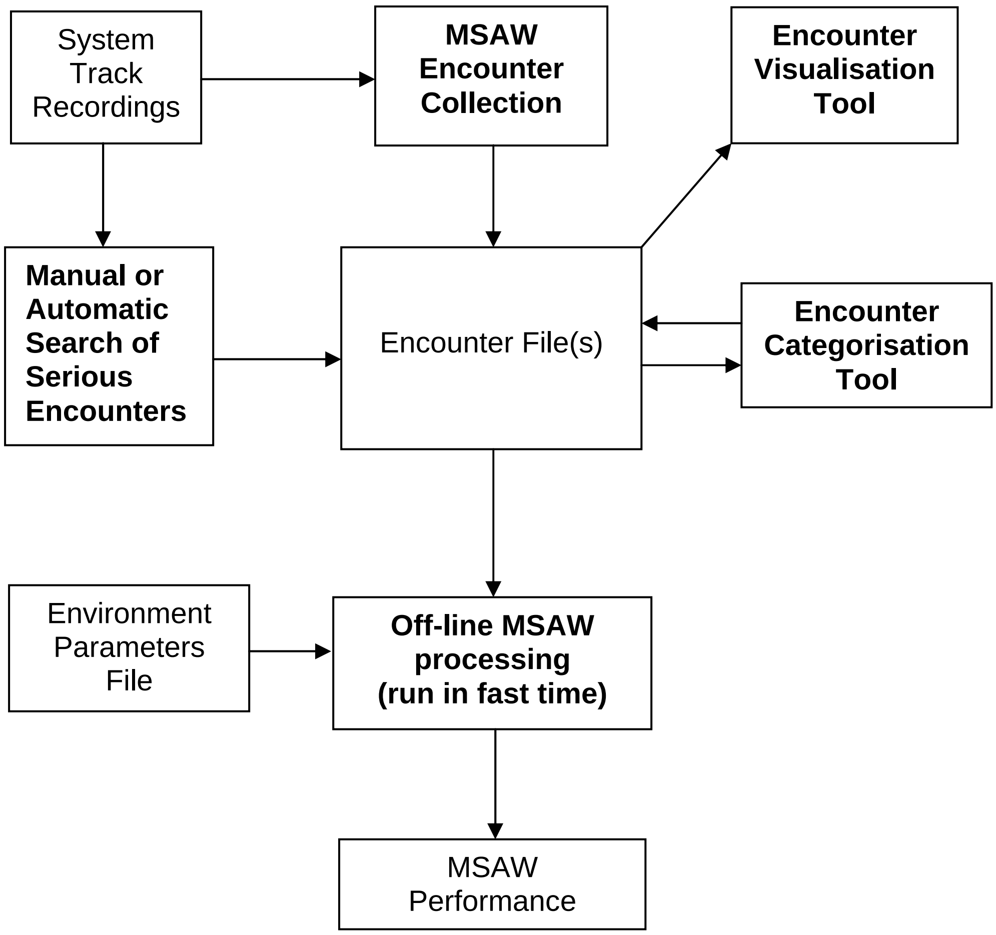

Figure 5-2 Tools and Files Required for Parameter Optimisation

5.2.2 Encounter Collection

The first stage of the optimisation process is the collection of situations of interest in one or more “encounter files”. The purpose is to compose a set of situations suitable for MSAW performance analysis. To this end, the encounter file must contain situations that give rise to both “wanted” and “unwanted” alerts. The unwanted alerts are relatively simple to find, since these will occur in any sample of general traffic system tracks. However, the wanted alert encounters are less common and may need to be extracted from historical system track recordings.

5.2.3 Encounter Files

The encounter files comprise the system tracks that are of potential concern for MSAW.

5.2.4 Encounter Categorisation Process

The purpose of encounter categorisation is to classify each situation in the encounter file into one of the following categories:

Category 1	ALERT NECESSARY – the situation involved a serious deviation below safe altitude or avoided terrain by a late manoeuvre.
Category 2	ALERT DESIRABLE – although there was no serious deviation below safe altitude, an alert would have been useful in drawing the attention of the controller to the situation.
Category 3	ALERT UNNECESSARY – An alert was unnecessary for the satisfactory resolution of the situation but would be “predictable” or understandable by the controller.
Category 4	ALERT UNDESIRABLE – the situation presented little threat of deviation below safe altitude and an alert would be distracting or unhelpful.
Category 5	VOID – This situation is not to be used for optimisation. For example. It may be a false situation caused by erroneous track data, or it may occur in a region of airspace not covered by MSAW.

Table 5-1 Definition of Encounter Categories

The encounter categorisation process needs to be done before inputting the encounter file into the MSAW model.

5.2.5 Encounter Visualisation and Manual Categorisation

Because the encounter categorisation process is somewhat subjective, some means of examining individual encounters will be required, in order to do a manual categorisation. Software that generates a printed diagram showing the situation in lateral and vertical view is recommended. The diagram should also show pertinent data such as minimum altitudes (MVA, MOCA, MSA) and the terrain and obstacles model. An assessment may then be made of the borderline situations to assign an appropriate category. For manual categorisation, it may also be useful to take advice from controllers as to whether an MSAW alert is desirable for particular borderline situations.

5.2.6 The Off-Line MSAW processing

Having categorised all the encounters, they are input into an off-line MSAW process.

The off-line MSAW process must be functionally identical to the operational system. Also, the process should be able to run in fast time, so that several weeks worth of traffic may be processed very quickly; during optimisation the same data sets will need to be processed by the model many times with varying environment parameter sets.

The off-line MSAW process will record various data, such as described in *appendix A*.

5.2.7 MSAW Performance Results

The MSAW performance results file contains details of the performance test run, overall performance statistics as well as the timing and details of each of the alerts.

The test run details must include:

- The names of all environment and encounter files input into the model.
- Identification of encounters that have been processed.

The overall statistics must include the following measures:

- The number of encounters of each category
- The number and percentage of alerts of each category
- The mean warning times for wanted alerts

The details of each alert must include:

- Identification of the aircraft encounter
- The time and duration of the alert
- The polygon volume or cell that was predicted to be penetrated (as relevant)

5.2.8 Requirements for MSAW Performance

In essence, the purpose of the optimisation process is to maximise the number of wanted alerts, providing as much warning time as possible whilst keeping the number of unwanted alerts to an acceptable level.

Possible requirements for MSAW performance are listed in Table 5-2, below:

Performance Indicator	Maximise / Minimise	Required Performance	Preferred Performance
% of Category 1 encounters alerted	Maximise	≥95%	100%
% of Category 2 encounters alerted	Maximise	≥80%	≥90%
% of alerted encounters which are Category 3, 4 & 5	Minimise	≤75%	≤50%
% of Category 3 encounters alerted	Minimise	-	≤30%
% of Category 4 encounters alerted	Minimise	-	≤1%
% of Category 5 encounters alerted	Minimise	-	-
% of Category 1 and 2 encounters where adequate warning time exists which give less than adequate warning time	Minimise	≤45%	≤35%
Mean warning time achieved for Category 1 and 2 encounters where adequate warning time exists	Maximise	≥90% of adequate	≥95% of adequate
Mean achieved warning time for Category 1 and 2 encounters where adequate warning time does not exist	Maximise	≥70% of mean objective warning time	≥75% of mean objective warning time

Table 5-2 Possible MSAW Performance Requirements

In order to maximise performance, repeated runs with different MSAW parameters are generally required. Guidance for parameter settings is given in *appendix A*.

5.3 Alternative Parameter Optimisation Strategies

There are a number of strategies that may be adopted by ANSPs to ease the burden of full parameter optimisation.

5.3.1 Using Artificial Scenarios

Firstly, it may be possible to generate a large number of artificial scenarios, including wanted alerts and unwanted alerts. This would avoid the need to collect real data, or search for serious encounters. Suitable encounter models exist for the generation of many thousands of scenarios that could be used for MSAW parameter optimisation.

Scenario generators may also be available for producing individual encounters, using track script files (These scripts include track start positions, turns, climbs etc). If scenarios are generated individually, then encounters can be designed that are either definitely “wanted alerts” or definitely “unwanted alerts”. This approach would avoid the need for an encounter categorisation tool.

No matter how the scenarios are generated, they will need to include a large variety of different geometries and manoeuvres in all the airspace of interest.

Ultimately, the success of this approach will depend on how well the scenarios simulate the real traffic.

5.3.2 Adapting Existing Visualisation Tools

Visualisation tools that allow tracks and MSAW alerts to be displayed are already available to ANSPs.

With a small amount of effort it may be possible to modify other track display tools to include MSAW alerts. If this is not possible, the timing of each alert could still be marked on a picture using off the shelf software.

5.3.3 Using Real MSAW Systems

If a version of MSAW is available that isn’t running on the operational partition of the ATC system, then this could be used, instead of producing an MSAW model. This MSAW must be functionally the same as the operational one.

For example, in some ATC systems, MSAW is available in a test partition.

Whereas a model can run in fast time, a test MSAW will be limited to (more or less) real time. To save manual effort, all the encounters may be best injected into MSAW as surveillance data in one large data sample. There is no reason why a large number of aircraft encounters could not be compressed into a fairly short timeframe, reducing the time between each test run to a tolerable level.

The MSAW must be capable of taking user-defined parameters and recording the alerts that are produced, and these alerts must be attributable to each encounter for later analysis.

As part of the optimisation, it is essential that the recorded alerts can be presented in a form that allows the user to assess the performance of MSAW. It may be necessary to produce a tool that takes the recorded alert file and summarises the results in a text file. The information presented should include as a minimum the identity of each encounter, whether the encounter has alerted and the time and duration of each alert. Other useful information would include, positions and heights of the aircraft at the start of the alert, the MSAW surface (polygon) or terrain cell relevant to the alert, and if possible, an identification of whether the alert is wanted.

5.3.4 Identifying Alert Hotspots

Identifying the geographical locations where the alerts tend to happen can be very informative, and can help the user to optimise the MSAW volumes, exclusion areas and general parameters. The user is also able to assess whether particular sectors would see more alerts than others.

A plan view presentation is required upon which the start point of each MSAW alert is depicted. The data used to show the alert positions should be taken from an extensive period of real data (recorded MSAW alerts), or alerts from an off line MSAW model.

5.3.5 Warning Time Measures for MSAW

Appendix A: reference MSAW System describes the calculation of warning time for measuring MSAW performance. This is quite a complex process requiring calculation of the point of risk, as well as an analysis of the situation to determine the maximum possible warning time.

As a simple alternative, it is often sufficient to compare the timing of the alerts between different runs (of the MSAW model or the test MSAW). Although this will not give an absolute measure, it will provide a very useful comparative measure of the warning time performance, allowing the system to be optimised.

6. OPERATING MSAW

6.1 Introduction

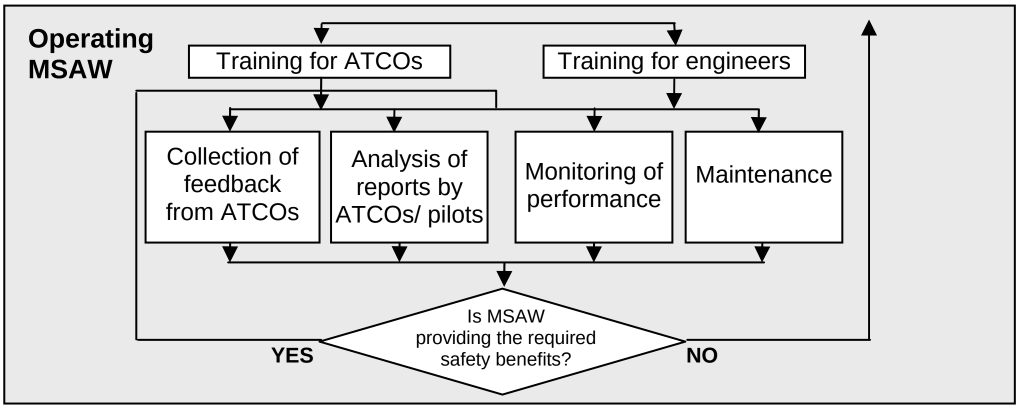

Figure 6-1: Phase 4 of the MSAW Lifecycle

This chapter provides guidance to ANSPs in the operation and monitoring of MSAW, and also in appropriate training.

6.2 Training for ATCOs

MSAW-03 The ANSP ***shall*** ensure that all controllers concerned are given specific MSAW training and are assessed as competent for the use of the relevant MSAW system.

Note.– The primary goal of the training is to develop and maintain an appropriate level of trust in MSAW, i.e. to make controllers aware of the likely situations where MSAW will be effective and, more importantly, situations in which MSAW will not be so effective (e.g. sudden, unexpected manoeuvres).

Training should be designed to promote appropriate operational use of MSAW and to prevent misuse. Training should include, amongst other things:

- The role of MSAW in the provision of ATS
- Differentiation between safety nets and controller's tools
- The difference between airborne safety nets (GPWS) and ground-based safety nets (MSAW)
- How MSAW detects conflicts (indicating the main features of MSAW)
- Differentiation between desired and undesired alerts
- Which aircraft are eligible for MSAW

- The airspace in which MSAW is active
- The use of flight data in MSAW processing and the consequences
- How MSAW alerts are displayed and acknowledged
- How MSAW performs in various situations (play back of MSAW situations helps here)
- What action to take in the event of an alert
- What action to take in the case that MSAW is not available
- Procedures for feedback of MSAW performance (this helps further optimisation)

Controller training on MSAW should be given before using MSAW, and again after significant changes to MSAW. Refresher training after a certain time is recommended.

A number of tools, such as ATC test partitions, ATC simulators, MSAW models or various types of situation replay media (e.g. video) are all relevant, and may be used to show example situations to controllers.

6.3 Skill Development for Engineers / Operational Analysts

In this context, engineers are the operational analysts responsible for the setting up, optimisation and maintenance of MSAW.

Most importantly, engineers should understand how MSAW works; requiring that they become familiar with the MSAW specification. If no specification is immediately available, then the manufacturer should be able to supply one.

Some description of algorithms is essential for teaching new technical staff about MSAW. Therefore, if the specification is of poor quality, or is not available from the manufacturer, then it may be necessary for an engineer to examine the source code, and to precisely document the MSAW algorithms.

Engineers should then be provided with the tools and take time to become skilled in MSAW alert analysis and parameter optimisation.

It is a useful exercise to collect and analyse all MSAW alert situations, not only to aid parameter tuning, but to provide informative examples than can be shown to engineers, ATCOs and other staff.

The more the engineer analyses alerts, the more the engineer will understand the specification, and how the MSAW parameters affect performance.

It is a useful exercise to compare the specific MSAW system with the reference MSAW System in *appendix A*, and furthermore *appendix A* provides detailed advice on parameter setting, and optimisation.

6.4 Analysis of Pilot/ATCO reports

It is good practice to analyse the performance of MSAW for all reported incidents and safety significant events. The analysis of individual situations can help the user to choose suitable parameters and identify potential improvements to the MSAW algorithms.

Furthermore, it is useful to keep as large a sample as possible of historical incidents for parameter optimisation.

6.5 Monitoring of MSAW Performance

It is good practice to analyse all safety significant events regardless of whether they result in an MSAW alert. During an analysis of such events, MSAW parameters and regions (and if necessary, algorithms) should be carefully considered, since it may be that some changes to the MSAW settings are identified that could potentially improve MSAW performance. Nevertheless, any changes to the settings are best tested with an off-line MSAW model before implementation in the operational system.

Monthly alert rate figures over the course of a year can help ensure that the alert rate stays within a tolerable level. Additionally, occasional analysis of the alert hotspots on an appropriate display may help to ensure that MSAW remains relevant to the airspace and the traffic environment.

6.6 Maintenance

MSAW SSR code files should be updated to reflect changes in SSR code allocations, otherwise MSAW performance is likely to gradually degrade. It may be necessary to update these files several times a year.

Regular parameter optimisation is recommended to ensure that the MSAW performance improves rather than degrades following changes to airspace.

Note: Appendices are contained in separate documents.

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