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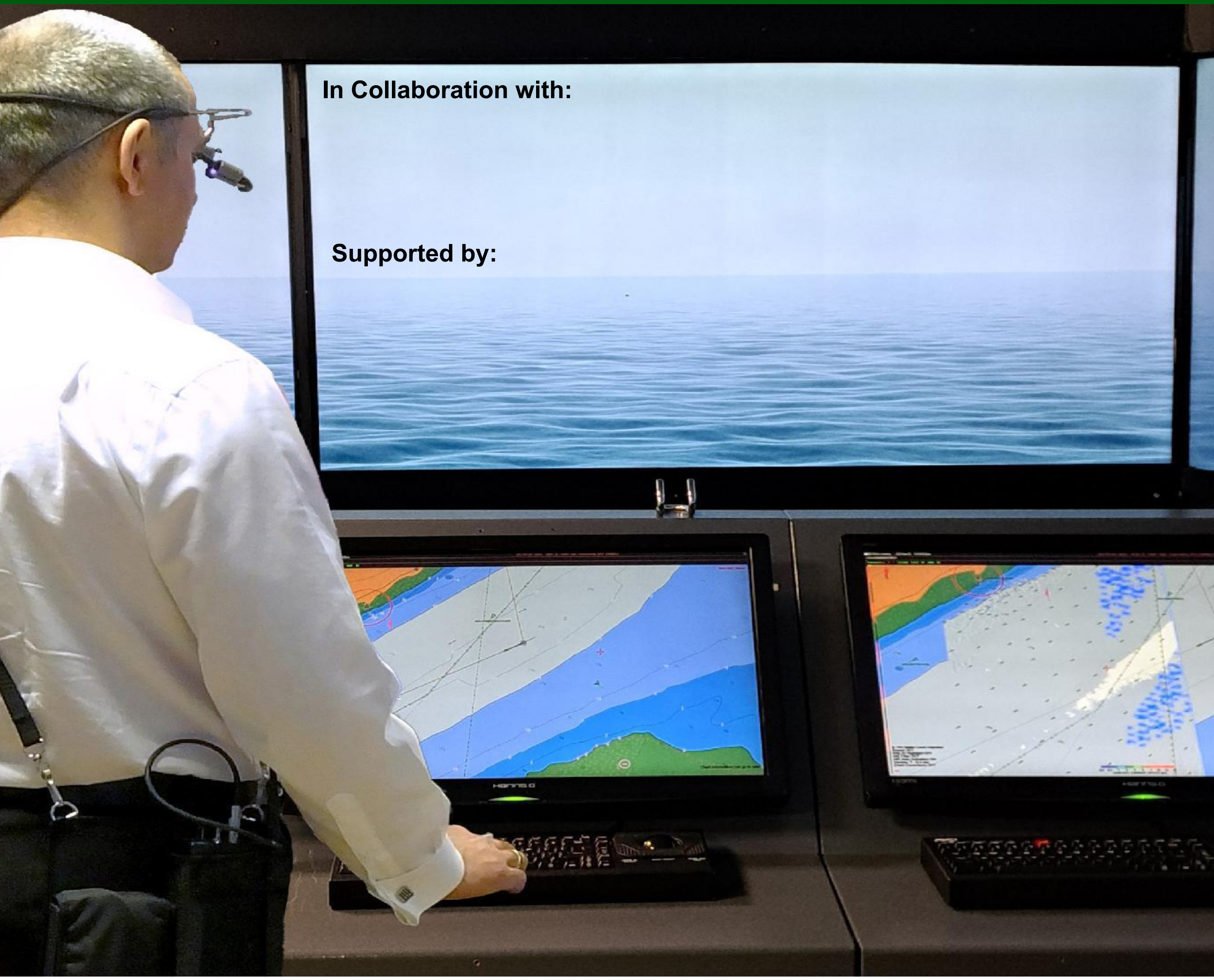
In Collaboration with the ECDIS Simulation Department
10 ECDIS Manufacturers
100 Seafarers of Various Rank and Experience



Operational Evaluation of S-100 Products and Industry Recommendations

1000 Hours Assessed Pilotage/Coastal 20 Comprehensive BRM/BTM Scenarios Comparing S-100 and S-57

Acknowledgements

ECDIS Ltd gratefully acknowledges the contribution of the participating Masters, Deck Officers, Pilots, Maritime Instructors and technical specialists who contributed their knowledge and operational experience during the simulator evaluation programme. The authors also acknowledge the support provided by the participating simulator centre, technology partners and maritime organisations whose collaboration made the research programme possible. Without the willingness of experienced mariners to evaluate emerging navigation technologies in realistic operational environments, this research would not have been possible.

Disclaimer

This report presents the findings of simulator-based research undertaken to evaluate operational aspects of selected International Hydrographic Organization (IHO) S-100 product specifications. The findings contained within this publication represent observations made during controlled simulator exercises and should not be interpreted as formal approval, certification or endorsement of any individual navigation system, manufacturer or software implementation. ECDIS Ltd accepts no responsibility for operational decisions made using the information contained within this report.

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Foreword

The maritime industry is entering a period of significant technological transformation. Advances in hydrographic surveying, environmental modelling and digital communications are changing not only the information available to mariners but also the way in which navigational decisions are made on the bridge.

The International Hydrographic Organization's S-100 Universal Hydrographic Data Model represents the foundation of this transformation. Unlike previous chart standards, S-100 enables the integration of multiple interoperable maritime datasets within a common framework, providing bridge teams with access to richer and more dynamic navigational information than has previously been possible.

Recognising the importance of understanding how these developments affect practical bridge operations, ECDIS Ltd undertook a structured programme of simulator trials involving experienced maritime professionals operating within realistic navigation scenarios.

This publication documents the methodology, findings and recommendations arising from that programme. In understanding both the opportunities and challenges associated with the implementation of S-100 products. While technology continues to evolve rapidly, one conclusion remains constant throughout this report.

The purpose of technology is not to replace the professional navigator, but to provide better information that supports safer navigational decision-making. ECDIS Ltd hopes that the findings presented within this report will contribute to the continued development of practical, user-focused electronic navigation systems that enhance safety, efficiency and environmental protection across the global maritime industry.

Debbie Hull

Managing Director, ECDIS Ltd

Table 4.11: Participants ratings per questionnaire section

Background

Electronic navigation has undergone significant development since the introduction of Electronic Chart Display and Information Systems (ECDIS) and S-57 Electronic Navigational Charts (ENCs). Although these systems have substantially improved navigational safety, advances in hydrographic surveying, environmental modelling and digital information management have highlighted the need for a more flexible framework capable of integrating a wider range of maritime information products.

The International Hydrographic Organization (IHO) developed the S-100 Universal Hydrographic Data Model to address this requirement. S-100 provides the foundation for a family of interoperable product specifications capable of delivering hydrographic, oceanographic and navigational information through compatible ECDIS platforms.

Research Objectives

The simulator programme sought to evaluate the operational performance of selected S-100 products within realistic bridge environments.

The principal objectives were to determine:

- Whether S-100 improves situational awareness.
- The effect of integrated datasets on bridge team workload.
- The usefulness of dynamic environmental information during passage planning.
- Human-factor implications associated with increased information availability.
- Training requirements for future implementation.

Methodology

One hundred experienced maritime professionals completed structured simulator exercises using the ECDIS Ltd Simulator integrated within a full mission bridge simulator. Participants undertook identical navigation scenarios using both traditional S-57 Electronic Navigational Charts and selected S-100 products.

Data collection combined:

- Structured questionnaires.
- Instructor observations.
- Simulator performance metrics.
- Facilitated debrief sessions.

This mixed-method approach enabled both quantitative and qualitative assessment of operational performance.

Introduction

The maritime industry is undergoing a fundamental transformation in the way navigational information is created, distributed and presented on the bridge. Advances in hydrographic surveying, real-time environmental monitoring and digital communications have created opportunities to provide mariners with far richer information than was possible when the S-57 ENC standard was first introduced.

Recognising these developments, the International Hydrographic Organization (IHO) developed the S-100 Universal Hydrographic Data Model to provide a common framework capable of supporting a family of interoperable maritime data products. Unlike S-57, which was designed specifically for electronic navigational charts, S-100 enables multiple datasets—including bathymetry, water levels, surface currents and navigational warnings—to be integrated within a compatible ECDIS.

The purpose of this report is to evaluate the practical implications of these developments through structured simulator trials involving experienced seafarers and maritime instructors. By examining how bridge teams interact with the new datasets during realistic navigation scenarios, the study provides insight into the operational benefits, human factors and training requirements associated with the transition to S-100.

Objectives of the Trials

The simulator trials were designed to investigate several key questions:

- Does S-100 improve situational awareness compared with S-57?
- Can integrated datasets reduce bridge team workload during passage planning?
- How do dynamic water levels and bathymetric surfaces influence Under Keel Clearance (UKC) assessments?
- Do surface current datasets improve route optimisation and ETA prediction?
- How do navigators perceive machine-readable navigational warnings?
- What additional training will be required before widespread implementation?
- What human-factor risks emerge when multiple dynamic data layers are presented simultaneously?

Contents

Chapter 1 — BACKGROUND

Electronic navigation has undergone continuous development over the past three decades. The introduction of Electronic Chart Display and Information Systems (ECDIS) fundamentally changed bridge operations by replacing paper chart navigation with official vector-based Electronic Navigational Charts (ENCs). This transition improved route planning, monitoring, chart updating and navigational safety while reducing the administrative burden associated with maintaining paper charts.

Although the S-57 ENC standard has served the maritime industry well since its adoption, advances in hydrographic surveying, environmental modelling and digital communications have highlighted limitations in its ability to support modern navigation. Mariners increasingly require access not only to chart information but also to dynamic environmental data such as high-resolution bathymetry, water levels, surface currents and digital navigational warnings.

To address these emerging requirements, the International Hydrographic Organization developed the S-100 Universal Hydrographic Data Model, providing a flexible framework capable of supporting a family of interoperable maritime information products.

Unlike S-57, which focuses solely on electronic navigational charts, S-100 enables multiple product specifications to operate together within a compatible ECDIS, allowing navigators to build a richer and more comprehensive picture of the operating environment.

1.1 Evolution of Electronic Navigation

The development of Electronic Chart Display and Information Systems (ECDIS) has been one of the most significant advances in marine navigation since the introduction of radar. Over the last three decades, navigational practices have evolved from paper-based chartwork to fully integrated digital navigation systems capable of combining positioning, chart information and sensor data into a single operational display.

The introduction of the S-100 Universal Hydrographic Data Model represents the next stage in this evolution. Unlike previous developments, S-100 extends beyond electronic charts and provides a framework for integrating a wide range of hydrographic and maritime information products into a common operating environment.

Understanding this evolution provides important context for evaluating the operational benefits identified during the simulator trials.

Figure 1.1: Evolution from paper charts to integrated digital navigation

1.2 Development Timeline

Period	Development	Operational Significance
Before 1990	Paper Charts	Manual navigation and chart correction
1990 - 2000	Raster Charts (RNC)	Digital display of paper charts
1995 - 2025	S-57 Electronic Navigational Charts	Vector-based ECDIS navigation
2020 onwards	S-100 Framework	Integrated hydrographic data services
Future	Digital Maritime Services	Dynamic decision-support environment

Table 1.1: Development timeline of electronic navigation systems

1.2.1 Paper Chart Navigation

For centuries, paper charts formed the foundation of marine navigation. Navigators combined charted information with visual observations, radar, celestial navigation and pilotage to determine the vessel's position and plan safe routes.

Paper charts remain an official means of navigation in many circumstances and continue to provide an important reference. However, they require:

- Manual correction.
- Manual route planning.
- Manual danger assessment.
- Continuous chart inventory management.

These processes are labour intensive and susceptible to human error if not performed correctly.

1.2.2 Raster Navigational Charts (RNC)

Raster charts represented the first significant step towards digital navigation. These charts are scanned images of traditional paper charts and preserve the appearance of their paper counterparts.

Although RNCs provide familiar presentation, they have several limitations:

- No object intelligence.
- Limited automatic safety checking.
- No route validation.
- Limited interaction with onboard sensors.

Consequently, raster charts were viewed as an intermediate technology rather than a long-term solution.

1.2.3 S-57 Electronic Navigational Charts

The introduction of vector-based Electronic Navigational Charts transformed bridge operations by enabling navigators to interact directly with chart objects.

S-57 introduced:

- Intelligent chart features.
- Automatic safety contour monitoring.
- Route checking.
- Anti-grounding alarms.
- Electronic chart updates.
- Sensor integration.

These capabilities significantly improved navigational safety and became the basis for mandatory ECDIS carriage under SOLAS.

Operational Benefits of S-57:

- Reduced chart correction workload.
- Improved positional awareness.
- Automated route monitoring.
- Standardised international chart format.
- Enhanced integration with GPS and radar.

Key Observation: The simulator participants universally recognised the importance of S-57 in modern navigation. However, they also acknowledged that increasing operational complexity requires information beyond that available from a traditional Electronic Navigational Chart.

1.2.4 Limitations of S-57

Despite its success, S-57 has several inherent limitations arising from the period in which it was developed.

Static Information:

Traditional ENCs primarily contain static hydrographic information.

Dynamic Environmental Data:

This is generally obtained from separate publications and systems and includes:

- Tidal water levels.
- Surface currents.
- Dynamic UKC.
- Temporary navigational warnings.

Limited Product Scope:

S-57 was designed specifically for Electronic Navigational Charts. It was not intended to support:

- Bathymetric surfaces.
- Water level models.
- Dynamic environmental services.
- Future digital maritime products.

Display Limitations:

Although S-57 supports extensive chart functionality, portrayal rules are comparatively rigid when compared with the flexibility offered by S-100. Participants in the simulator trials commented that:

- Busy harbour areas occasionally appeared cluttered.
- Bathymetric interpretation required considerable experience.
- Additional environmental information would improve planning confidence.

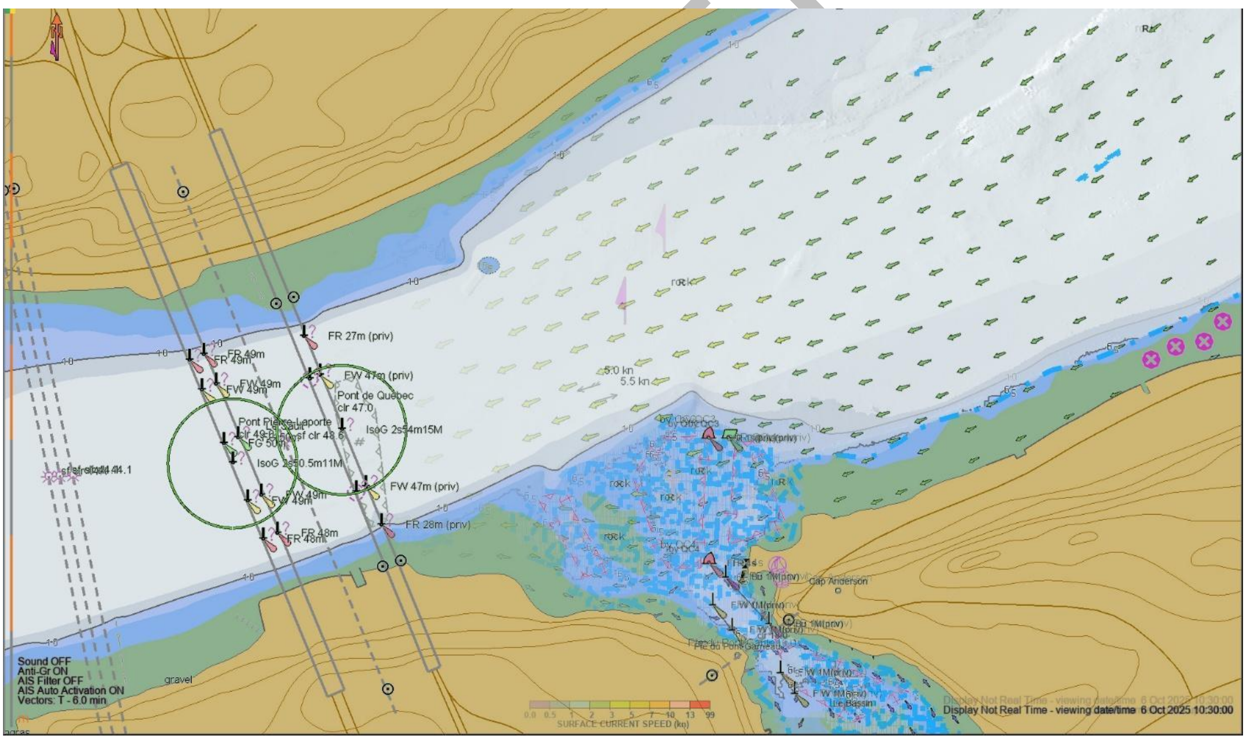

Image 1.1: Example of a merged S-57 and several S-100 Layers taken from the ECDIS Procedures Guide 2026 – 2027 Volume 2 published by Witherbys

Feature	S-57	S-100
Electronic Chart	✓	✓
Bathymetric Surface	✗	✓
Dynamic Water Levels	✗	✓
Surface Currents	✗	✓
Machine Readable Warnings	✗	✓
Under Keel Clearance	Manual	Integrated
Future Expansion	Limited	Extensive

Table 1.2: Comparison of capabilities available in S-57 and S-100 environments

Key Point: S-100 should not be viewed as a replacement for S-57 alone. It represents a broader framework designed to integrate multiple maritime information services into a single interoperable environment.

1.3 Why was S-100 Developed?

The International Hydrographic Organization recognised that future navigation would require more than electronic charts. Modern bridge teams increasingly rely upon:

- High-resolution seabed information.
- Dynamic tidal information.
- Surface current predictions.
- Digital navigational warnings.
- Real-time environmental services.

Rather than creating separate standards for each new product, the IHO developed the S-100 Universal Hydrographic Data Model to provide a common framework supporting interoperability between products. This approach allows individual product specifications—such as S-101, S-102 and S-104—to be developed independently while remaining compatible within a common ECDIS environment.

Key Finding: The move from S-57 to S-100 is not simply a change in chart format. It is a transition from a single-product navigation system to a digital maritime information ecosystem capable of integrating multiple operational data sources.

1.4 Chapter 1 Summary

This chapter has described the historical evolution of electronic navigation and explained why the S-100 framework was developed. Understanding these developments provides the foundation for the simulator evaluation presented in the following chapters.

Chapter Highlights

- Electronic navigation has evolved from paper charts to integrated digital information systems.
- S-57 transformed chart navigation but was not designed for modern environmental datasets.
- S-100 provides a common framework supporting interoperable hydrographic products.
- The simulator programme was established to evaluate how these products perform in realistic bridge operations.
- Future navigation will increasingly depend upon integrated digital maritime services rather than standalone chart products.

The operational evidence generated during the trials, including participant ratings, instructor assessments and qualitative feedback, is presented in Chapters 4-7.

Chapter 2 — Research Objectives and Study Design

This chapter defines the objectives of the research programme and explains the methodology used to evaluate S-100 products within a full mission bridge simulator. It describes the research questions, participant selection, simulator environment and data collection techniques that formed the basis of the operational evaluation.

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2.1 Research Background

The introduction of S-100 product specifications has created significant opportunities for improving the presentation and use of hydrographic information. While technical development has progressed rapidly, comparatively little operational evidence has been published regarding how professional mariners interact with these products during realistic bridge operations.

The purpose of this research was therefore not to verify software functionality but to examine how S-100 products influence navigational performance, situational awareness and bridge team decision-making.

Unlike laboratory testing or software validation, the study placed experienced mariners in operationally realistic scenarios where they were required to make navigational decisions using either conventional S-57 ENCs or integrated S-100 products.

2.2 Research Aim

The primary aim of the project was:

To evaluate whether the integration of S-100 products within an ECDIS environment improves navigational safety, operational efficiency and situational awareness when compared with traditional S-57 Electronic Navigational Charts.

This overarching aim guided the design of each simulator exercise and the collection of both quantitative and qualitative data.

2.3 Research Questions

The study was structured around a series of key research questions.

RQ1:

Does S-101 improve chart interpretation and route planning compared with S-57?

RQ2:

Does S-102 improve understanding of seabed morphology during pilotage and harbour approaches?

RQ3:

Can S-104 reduce the workload associated with tidal calculations and under-keel clearance assessments?

RQ4:

Does S-111 improve awareness of environmental forces affecting vessel movement?

RQ5:

Can S-124 improve the identification and management of temporary navigational hazards?

RQ6:

How do bridge teams perceive the integration of multiple S-100 products within a single ECDIS display?

RQ7:

What human-factor considerations should influence future implementation and training?

Ref	Research Question	Product(s)
RQ1	Chart portrayal	**S-101**
RQ2	Bathymetry	**S-102**
RQ3	Water levels	**S-104**
RQ4	Surface currents	**S-111**
RQ5	Navigational warnings	**S-124**
RQ6	Integrated navigation	**Multiple**
RQ7	Human factors	**All**

Table 2.1: Research questions and corresponding S-100 products

2.4 Operational Objectives

The research was designed to address a number of practical operational objectives including determining whether S-100 products could:

- Reduce navigational workload.
- Improve route planning efficiency.
- Enhance route monitoring.
- Improve understanding of the surrounding environment.
- Support safer under-keel clearance assessment.
- Improve pilotage.
- Increase confidence during harbour approaches.
- Reduce manual calculations.
- Improve bridge resource management.

The emphasis throughout was on operational usefulness rather than technological novelty.

2.5 Human Factors Objectives

In addition to technical performance, the study sought to understand how S-100 products influence human performance on the bridge.

The following themes were evaluated:

- Situational Awareness
  - Do integrated datasets provide a clearer understanding of the operational environment?
- Cognitive Workload
  - Does additional information reduce workload by supporting decision-making, or increase workload by introducing unnecessary complexity?
- Display Management
  - Can multiple data layers be presented without creating excessive clutter?
- Automation Bias
  - Does the availability of advanced decision-support tools encourage over-reliance on automation?
- Bridge Resource Management
  - Do integrated displays improve communication and shared understanding among bridge team members?

Human Factors Assessment Framework:

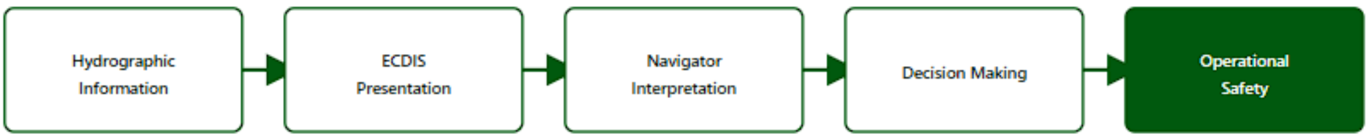

Figure 2.1: Human-factors assessment pathway from hydrographic information to operational safety

2.6 Research Design

The study adopted a mixed-methods research design, combining quantitative and qualitative approaches.

Quantitative Data

Collected through:

- Structured questionnaires.
- Likert-scale responses.
- Scenario completion times.
- Route planning performance.
- Operational observations.

Qualitative Data

Collected through:

- Facilitated debrief sessions.
- Instructor observations.
- Participant comments.
- Operational discussions.

This combination allowed statistical trends to be interpreted alongside the experiences and opinions of professional mariners.

2.7 Study Limitations

All research programmes have limitations, and these should be acknowledged.

The principal limitations of this study include:

- Simulator exercises cannot replicate every aspect of real-world operations.
- Participants had limited previous exposure to S-100 products.
- The evaluation focused on selected product specifications rather than the complete S-100 ecosystem.
- Operational procedures may vary between shipping companies.

Despite these limitations, simulator-based research provides a safe, repeatable and controlled environment in which emerging technologies can be evaluated before widespread operational deployment.

2.8 Ethical Considerations

Participation in the study was voluntary.

Participants were informed that:

- Responses would be anonymised.
- Individual comments would not be attributed without permission.

- Results would be presented in aggregated form.
- The purpose of the study was to evaluate technology rather than individual performance.

This approach encouraged open and constructive feedback throughout the programme.

2.9 Success Criteria

To determine whether the evaluation had achieved its objectives, several success criteria were established.

The project would be considered successful if it:

- Identified measurable operational benefits.
- Highlighted areas requiring improvement.
- Generated practical recommendations for implementation.
- Provided evidence to support future training programmes.
- Improved understanding of human-factor considerations.
- Contributed to ongoing development of S-100 products.

2.10 Chapter 2 Summary

This chapter has defined the objectives and methodology underpinning the simulator evaluation programme. By adopting a structured mixed-methods approach, the study combined operational performance data with participant feedback to provide a balanced assessment of both the technical capabilities and practical usability of the S-100 framework.

Key Findings

- The research focused on operational performance rather than software compliance.
- Seven core research questions guided the simulator programme.
- Both technical and human-factor objectives were considered equally important.
- A mixed-methods approach provided a robust evidence base for analysis.
- The methodology was designed to be repeatable, transparent and suitable for future comparative studies.

Chapter 3 — Simulator Facilities and Trial Environment

This chapter describes the simulator facilities, ECDIS configuration, hardware, software architecture and environmental modelling used throughout the evaluation programme. It also explains the rationale for selecting a simulator-based methodology and describes how repeatable operating conditions were maintained throughout the research.

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3.1 Introduction

Modern bridge simulators provide an ideal environment for evaluating emerging navigation technologies before they are introduced into operational service.

Unlike live ship trials, simulator exercises allow identical scenarios to be repeated under controlled conditions while eliminating the safety risks associated with experimental procedures at sea.

For this project, the ECDIS Ltd Simulator was integrated within a Full Mission Bridge Simulator to provide a realistic operating environment representative of a modern SOLAS-compliant merchant vessel.

Participants completed realistic navigation exercises using operational bridge procedures while instructors monitored performance and collected research data.

3.2 Why Simulator-Based Research?

Conducting evaluations within a simulator provides several significant advantages over onboard trials.

Safety:

Complex navigation scenarios can be reproduced without exposing personnel, vessels or the environment to unnecessary risk.

Repeatability:

Every participant can complete exactly the same voyage under identical:

- Weather
- Traffic
- Visibility
- Tidal conditions
- Vessel loading
- Equipment configuration

This repeatability ensures that differences in performance are attributable to the navigation products being evaluated rather than external variables.

Flexibility:

The simulator allows researchers to introduce:

- Equipment failures
- Changing weather
- Machinery defects
- Restricted visibility
- Emergency situations
- Traffic conflicts

without compromising safety.

Data Collection:

Every aspect of vessel operation can be recorded, including:

- Vessel track
- Speed
- Heading
- Rudder orders
- Engine movements
- Alarm acknowledgements
- ECDIS interaction
- Route amendments

This provides a level of detail that would be extremely difficult to obtain during routine commercial operations.

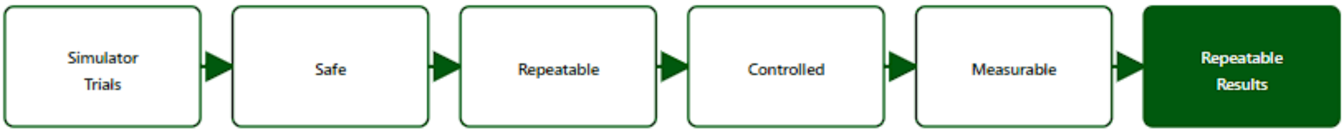

Figure 3.1: Benefits of simulator-based research for controlled and repeatable evaluation

3.3 Simulator Configuration

The research programme used the ECDIS Ltd Simulator integrated into a Full Mission Bridge Simulator configured to replicate the bridge of a contemporary merchant vessel.

The simulator incorporated representative navigation equipment, including:

- Primary ECDIS workstation.
- Secondary ECDIS workstation.
- X-band radar.
- S-band radar.
- Automatic Identification System (AIS).
- Global Navigation Satellite System (GNSS).

- Gyrocompass.
- Speed log.
- Echo sounder.
- Conning display.
- Autopilot.
- Steering controls.
- Engine telegraph.
- VHF communications.

The bridge layout was designed to replicate operational working conditions and support realistic Bridge Resource Management (BRM).

Equipment	Function
ECDIS Ltd Simulator	Primary navigation display
Radar (X-Band)	Collision avoidance
Radar (S-Band)	Long-range surveillance
AIS	Vessel identification
GNSS	Position fixing
Gyrocompass	Heading reference
Echo Sounder	Depth monitoring
Conning Display	Integrated navigation data
Engine Controls	Propulsion management

Table 3.1: Navigation equipment and operational functions within the simulator environment

3.4 ECDIS Configuration

The ECDIS Ltd Simulator was configured to allow participants to compare traditional S-57 Electronic Navigational Charts with selected S-100 products under identical operational conditions.

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Available products included:

- S-57 ENC.
- S-101 Electronic Navigational Chart.
- S-102 Bathymetric Surface.
- S-104 Water Level Information.
- S-111 Surface Currents.
- S-124 Navigational Warnings.

Where available, participants could enable and disable individual layers to observe how different combinations influenced decision-making.

3.5 Environment Modelling

To ensure operational realism, the simulator modelled a range of environmental conditions.

These included:

Wind:

- Calm
- Moderate
- Strong crosswind

Visibility:

- Daylight
- Twilight
- Night
- Restricted visibility

Sea State:

- Calm
- Moderate swell
- Heavy swell

Tidal Conditions:

- Flood tide
- Ebb tide
- High water
- Low water

Traffic Density:

- Open sea
- Coastal traffic
- Harbour traffic
- Traffic Separation Scheme

The ability to reproduce identical conditions for every participant ensured consistency throughout the evaluation.

3.6 Vessel Models

Several representative vessel types were selected to reflect the diversity of modern commercial shipping.

Vessel Type	Typical Length	Draught	Operational Focus
Container Ship	**330 m**	**14.5 m**	Schedule-driven operations
Bulk Carrier	**225 m**	**15.2 m**	UKC and tidal access
LNG Carrier	**295 m**	**11.8 m**	High-consequence navigation
Product Tanker	**185 m**	**10.5 m**	Coastal navigation
General Cargo	**140 m**	**7.0 m**	Port operations

Table 3.2: Vessel models used during the simulator trials

This variety ensured that the findings were applicable across a broad range of vessel types.

3.7 Trial Routes

The simulator scenarios included a representative selection of operational environments:

Open Ocean Passage:

To evaluate route planning and monitoring.

Coastal Navigation:

To assess chart portrayal and route optimisation.

Harbour Approach:

To evaluate bathymetric interpretation and tidal awareness.

Restricted Channel:

To assess Under Keel Clearance and pilotage.

Traffic Separation Scheme:

To examine the interaction between route monitoring, traffic awareness and navigational warnings.

3.8 Instructor Control Station

An instructor workstation monitored every simulator exercise.

The instructor could:

- Modify environmental conditions.
- Introduce failures.
- Create traffic conflicts.
- Inject navigational warnings.
- Record participant performance.
- Pause and replay exercises.

This capability allowed detailed analysis of bridge team performance during post-exercise debriefs.

3.9 Data Recording

Throughout each exercise, the simulator automatically recorded:

- Vessel track.
- Position.
- Speed.
- Heading.
- Helm orders.
- Engine movements.
- Alarm acknowledgements.
- ECDIS interactions.
- Route amendments.

These objective data were supplemented by instructor observations and participant questionnaires to provide a comprehensive evidence base.

3.10 Quality Assurance

To ensure consistency and reliability, each scenario was validated before participant trials commenced.

Quality assurance included:

- Verification of chart data.
- Confirmation of environmental settings.
- Repeatability testing.
- Equipment functionality checks.
- Standardised instructor briefing.

This ensured that all participants completed comparable exercises under equivalent conditions.

3.11 Chapter 3 Summary

The simulator facilities provided a realistic and repeatable environment in which emerging S-100 products could be evaluated safely and systematically.

The use of identical scenarios, representative bridge equipment and comprehensive data recording ensured that the findings presented in subsequent chapters are based on consistent operational conditions rather than anecdotal observations.

Simulator-based evaluation provides a safe, controlled and repeatable method of assessing emerging navigation technologies before operational deployment.

The integration of the ECDIS Ltd Simulator within a Full Mission Bridge Simulator allowed participants to evaluate S-100 products under realistic bridge conditions while enabling detailed performance analysis and structured debriefing.

Chapter 4 — Operational Trials and Research Findings

This chapter presents the operational findings from the simulator evaluation programme. It examines participant performance during a series of structured navigation exercises and compares the use of traditional S-57 Electronic Navigational Charts with selected S-100 product specifications.

The findings are based on simulator observations, structured questionnaires, instructor assessments and participant debrief sessions.

Rather than considering each product in isolation, this chapter explores how integrated hydrographic information influenced navigation, workload and bridge team performance.

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4.1 Introduction

The introduction of S-100 products has the potential to change the way navigators interact with hydrographic information. However, technological capability alone is not sufficient to justify operational adoption. New products must demonstrate measurable improvements in safety, efficiency or situational awareness while avoiding unnecessary increases in complexity or workload.

The simulator programme therefore focused on the perceived operational usability and human factor implications of S-100, rather than evaluating software functionality alone.

Participants completed identical navigation scenarios using:

- Traditional S-57 Electronic Navigational Charts.
- Integrated S-100 products.

The resulting comparisons provided valuable insight into the practical advantages and limitations of the emerging framework.

Participant questionnaire items were assessed using a five-point Likert scale, where a score of 1 represented “Strongly Disagree” or “Very Poor”, a score of 3 represented “Neutral” or “Acceptable”, and a score of 5 represented “Strongly Agree” or “Excellent”. To make results easier to interpret and compare, responses were consolidated into three reporting categories. Scores of 1 and 2 were classified as negative, score 3 as neutral and scores of 4 and 5 as positive. These categories describe participants’ responses to each statement in the questionnaire and should not be interpreted as pass or fail thresholds.

Alongside the grouped percentages, the arithmetic mean score (M) is reported using the original 1-5 responses. A mean score above 3 indicates that responses tended towards the positive end of the scale, while a mean below a 3 indicates that responses tended towards the negative end. A mean close to 3 indicates a broadly neutral or mixed result.

All participant questionnaire items received 100 responses. Consequently, each participant represents one percentage point. Instructor assessments are reported separately because they were based upon ten observations, meaning each instructor response represents ten percentage points.

The statistical analysis is descriptive. Differences between products or sections within the questionnaire are discussed as patterns within the recorded responses by participants, rather than statistically significant.

4.2 Trial Structure

Each participant completed a sequence of simulator exercises designed to replicate the principal phases of a commercial voyage.

The sequence included:

Exercise 1 – Passage Planning

Preparation of a coastal voyage using official electronic chart information.

Objectives:

- Route planning.
- Safety contour verification.
- Hazard identification.
- Route validation.

Exercise 2 – Coastal Navigation

Monitoring progress along a coastal route.

Objectives:

- Situational awareness.
- Chart interpretation.
- Route monitoring.
- Alarm management.

Exercise 3 – Harbour Approach

Navigation through restricted waters under tidal conditions.

Objectives:

- Bathymetric interpretation.
- Water level assessment.
- Under-keel clearance.
- Pilotage.

Exercise 4 – Dynamic Environmental Information

Evaluation of:

- Surface currents.
- Water levels.
- Temporary navigational warnings.

Objectives:

- Decision support.
- Display interpretation.
- Information management.

Exercise 5 – Integrated Navigation

Participants completed the same route using all available S-100 products simultaneously.

This final exercise examined:

- Information integration.
- Display management.
- Cognitive workload.
- Overall operational acceptance.

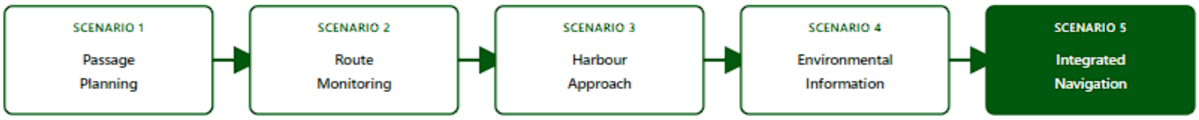

Figure 4.1: Sequence of the five operational trial scenarios

4.3 Participant Demographics

One hundred experienced maritime professionals participated in the evaluation.

The participant group represented a broad range of experience across the commercial shipping industry.

Experience	Percentage
Less than 5 years	15%
5–10 years	28%
10–20 years	33%
More than 20 years	24%

Table 4.1: Distribution of participants by maritime experience

Most participants therefore had extensive operational experience using Electronic Chart Display and Information Systems, as 57% had at least ten years' experience and 85% had at least five years.

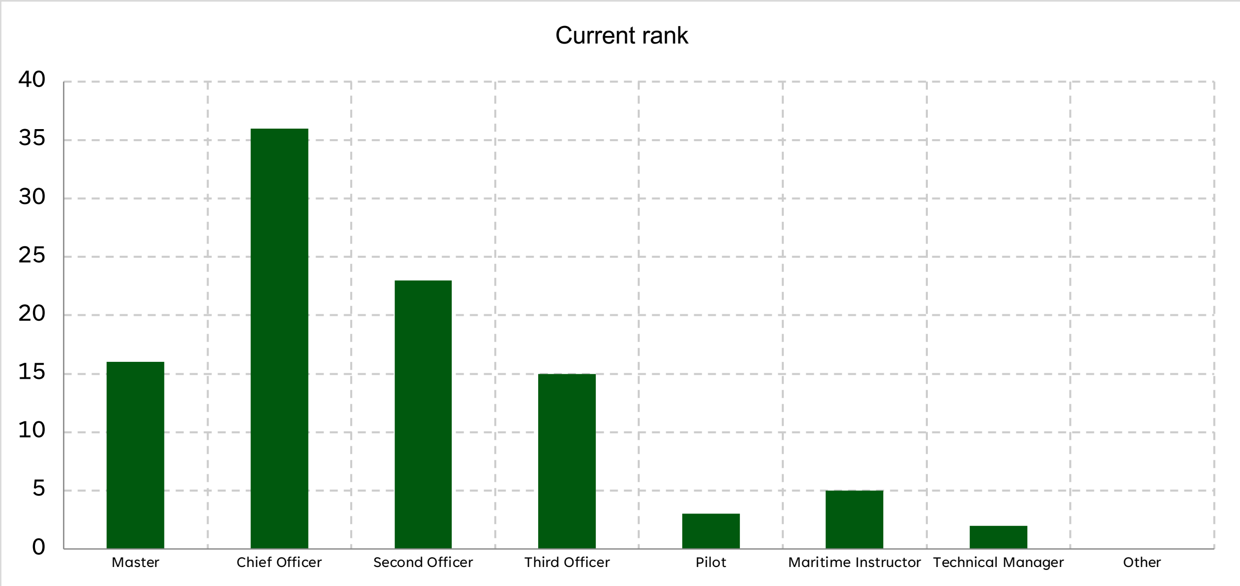

Figure 4.2: Participants' seafaring rank

Chief Officers formed the largest rank group at 36%, followed by Second Officers at 23%, Masters at 16% and Third Officers at 15%. Pilots represented 3%, maritime instructors 5% and technical managers 2%. Overall, 90% of participants held ranks from Third Officer to Master.

Participants had experience serving on:

- Container ships
- LNG carriers
- Oil tankers
- Chemical tankers
- Bulk carriers
- Offshore vessels
- Passenger vessels

This diversity ensured that the findings reflected a wide range of navigational practices.

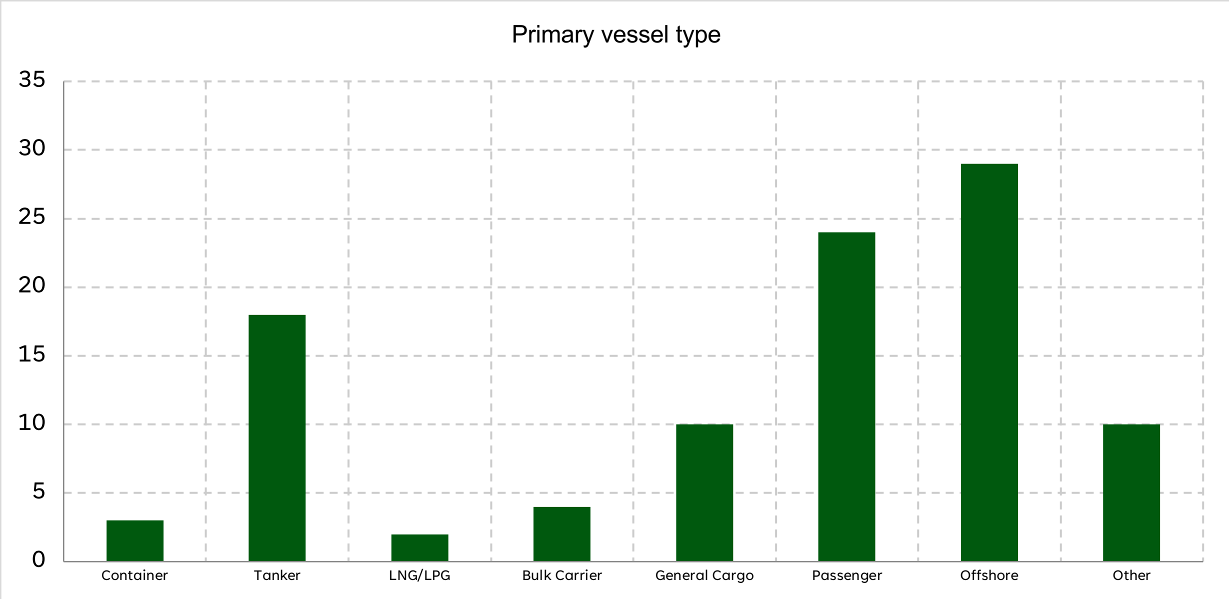

Figure 4.3: Participants' primary vessel type

Offshore operations formed the largest vessel background at 29%, followed by passenger shipping at 24% and tanker operations at 18%. Together, these sectors accounted for 71% of the sample. The remaining participants represented general cargo, bulk carrier, container, LNG/LPG and other vessel sectors.

4.4 Familiarity with S-100

Prior to the trials, participants were asked to assess their familiarity with S-100.

Figure 4.4: Participants' previous experience with S-100

Previous operational exposure to S-100 was extremely limited. 48% of participants reported no previous exposure, while 47% reported awareness only and 5% reported limited practical experience. No participant reported regular operational use. Consequently, 95% entered the trials with no more than an awareness level knowledge of S-100.

The general familiarisation with S-100 results were predominantly negative, with one important exception. Negative responses were recorded for ease of understanding (93%; M = 1.48), interface intuitiveness (72%; M = 1.48), straightforward menu navigation (71%; M = 2.33) and becoming confident quickly (89%; M = 1.59). However, 78% of participants responded positively to the ease of recognising display symbols (M = 4.25).

Therefore, the findings do not demonstrate rapid independent adaptation by participants to S-100. While symbol recognition was comparatively strong, system comprehension, interface navigation and early confidence remained difficult. As such, the results support sufficiently detailed and structured practical familiarisation before operational implementation.

Participants' Comments:

"I have never used this ECDIS before and find the menu structure confusing, although the display was very clear."

"I needed time to understand how the layers work together."

4.5 Passage Planning Performance

The first exercise compared route planning using S-57 and S-101.

Participants were asked to:

- Plan a coastal voyage.
- Establish safety contours.
- Identify hazards.
- Validate the route.
- Record planning time.

Operational Observations:

Most participants completed the task successfully using both systems.

However, instructors noted several differences.

Using S-57:

Participants frequently referred to additional publications when considering:

- Tidal conditions.
- Under-keel clearance.
- Temporary navigational warnings.

Planning involved a greater degree of manual interpretation.

Using S-101:

Participants generally reported:

- Improved chart readability.
- Easier identification of chart objects.
- Better text placement.

- Increased confidence during route validation.

S-101 received particularly strong ratings for symbol interpretation and route planning.

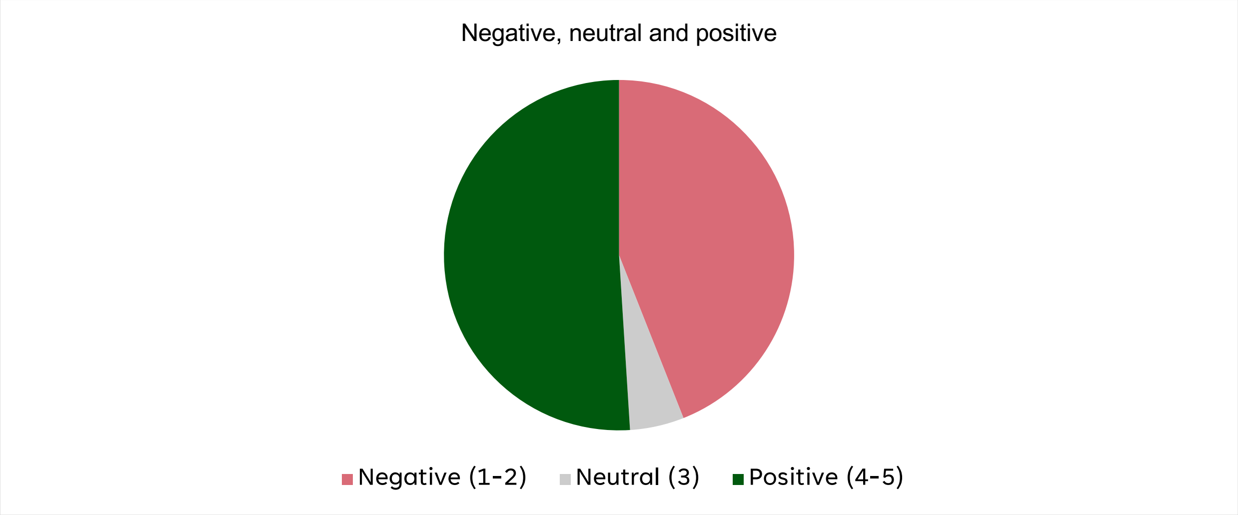

Figure 4.5: Participants ratings of route planning with S-101

Symbol interpretation was the most positive S-101 result, receiving 97% positive responses (M = 4.64). Route planning was also rated positively by 74% of participants (M = 3.81), while general chart clarity produced a more moderate result, with 57% positive and 38% negative responses (M = 2.44).

However, the remaining results were less favourable. Only 15% rated text placement positively, while 52% were neutral and 33% negative (M = 2.78). 60% responded negatively to the statement: “Harbour areas were easier to interpret than S-57” (M = 2.44).

Participants’ Comments:

"The route planning process felt familiar, but the chart was easier to read."

“It did not change the way I planned my route but the chart display is much clearer.”

4.6 Harbour Approach

The harbour approach generated some of the most valuable findings.

Participants approached a tidal harbour using:

- S-57 only.

and subsequently repeated the exercise using:

- S-101.
- S-102.
- S-104.

Traditional Method

Participants were required to:

- Review charted depths.
- Consult tide tables.
- Calculate UKC manually.
- Confirm safety margins.

Integrated Method

Participants were provided with:

- Dynamic bathymetry.
- Water level information.
- Enhanced chart portrayal.

S-102 Bathymetry:

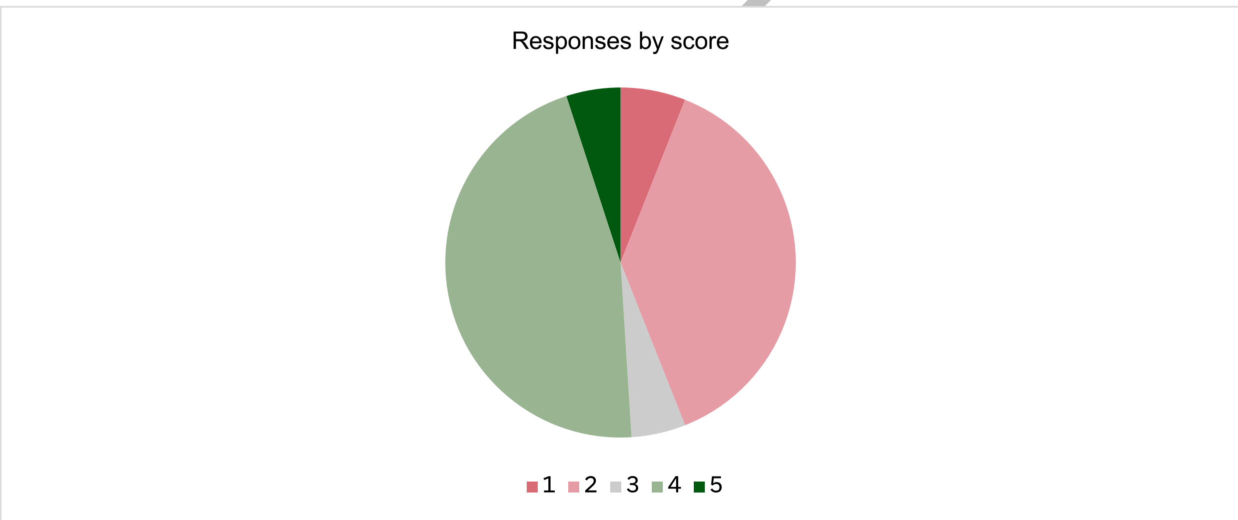

Figure 4.6: Responses ranking S-102 overall operational usefulness

S-102 received strong ratings for seabed understanding and overall usefulness. 81% responded positively to easier understanding of seabed shape (M = 4.30), and 81% also rated its overall usefulness positively (M = 4.42). Improved under-keel awareness was rated positively at 63% (M = 3.66).

However, only 14% stated that harbour approaches were easier to interpret, with most rating this as neutral (M = 2.47). Display quality was the clearest concern among S-102 ratings, receiving 71% negative responses and only 12% positive responses (M = 2.10).

S-104 Water Levels:

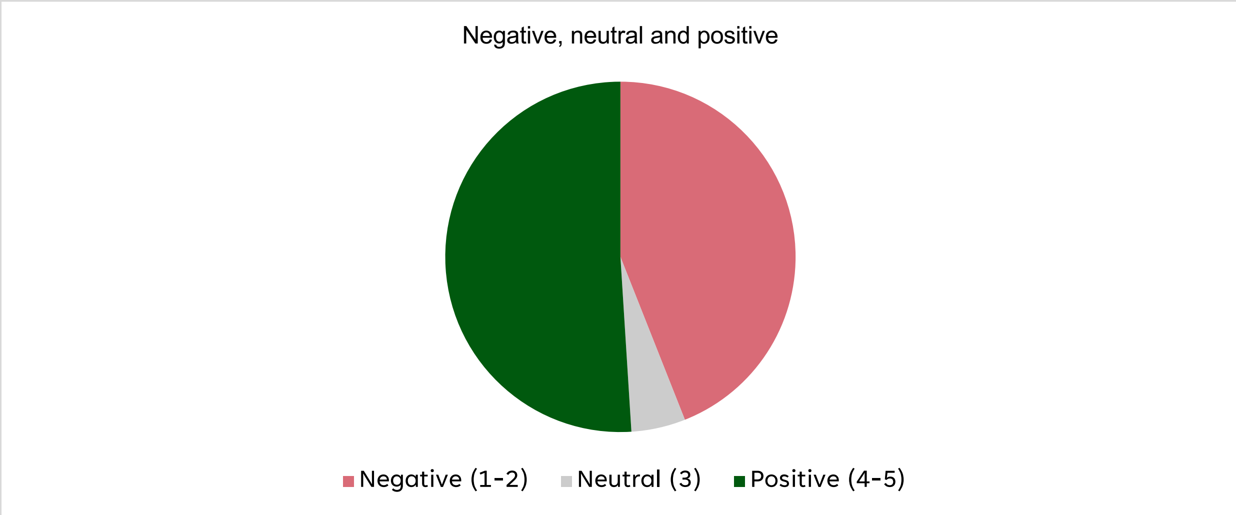

Figure 4.7: Responses ranking if S-104 reduced manual calculations

S-104 generated strong confidence and presentation results. 86% responded positively to increased confidence during tidal navigation (M = 4.33), while 78% rated the information as clearly presented (M = 3.88). However, ease of interpretation was more varied, receiving 42% positive, 25% neutral and 33% negative responses (M = 3.14).

The manual calculation result was substantially less favourable. 82% of respondents recorded a negative rating to the statement that S-104 improved confidence during tidal navigations (M = 1.59).

Participants' Comments:

"I liked that it changed the safety contour automatically for me between high and low water."

"It gave me confidence that more safe water was available."

"I couldn't tell which spot soundings had been changed for the height of tide and this made me uncomfortable so I still had to do a manual calculation."

4.7 Situational Awareness

Participants consistently rated integrated S-100 products highly for improving situational awareness.

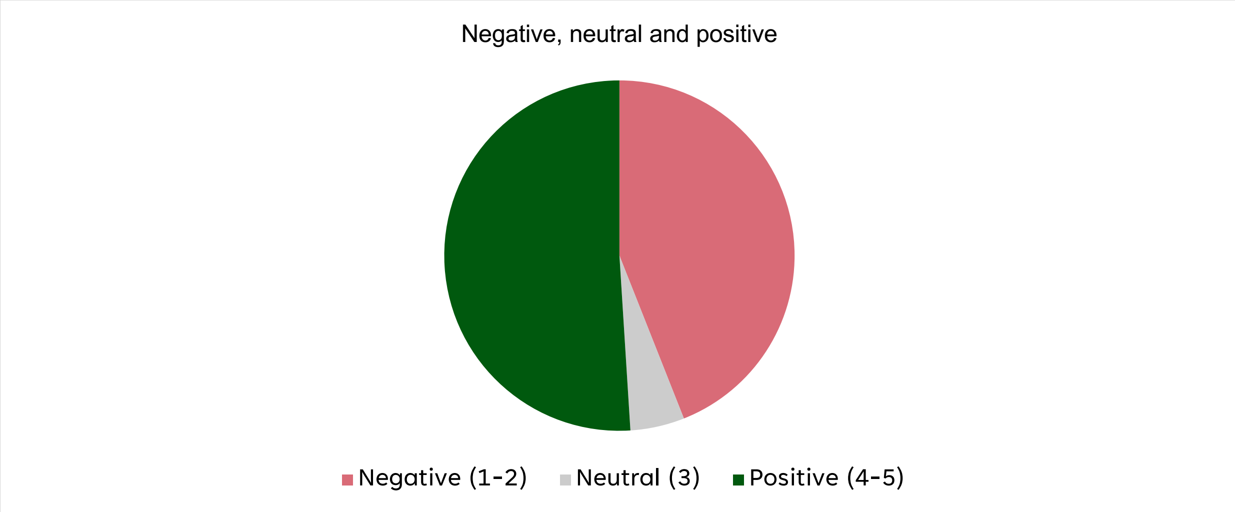

Figure 4.8: Responses ranking situational awareness

Situational awareness was the strongest and most consistent human factors outcome. 93% responded positively to the statement that situational awareness was improved, compared to 3% neutral and 4% negative responses (M = 4.63). Instructor assessments were closely aligned with this, with nine out of ten observations being positive and one being neutral (M = 4.60).

Product specific findings support this outcome with S-111 receiving 81% positive responses for environmental awareness, S-124 received 84% positive responses for hazard awareness, and S-102 received 63% positive ratings for improved under-keel awareness.

Contributing factors included:

- Improved chart presentation.
- Better understanding of seabed shape.
- Easier interpretation of tidal effects.
- Visualisation of environmental conditions.

Key Finding:

Participants reported that S-100 products helped them understand the operational environment more quickly than when using traditional chart products alone.

4.8 Workload

One of the principal concerns before the trials was that additional information might increase workload.

Participants reported a strong overall workload benefit during:

- Passage planning.
- Harbour approaches.
- UKC assessment.

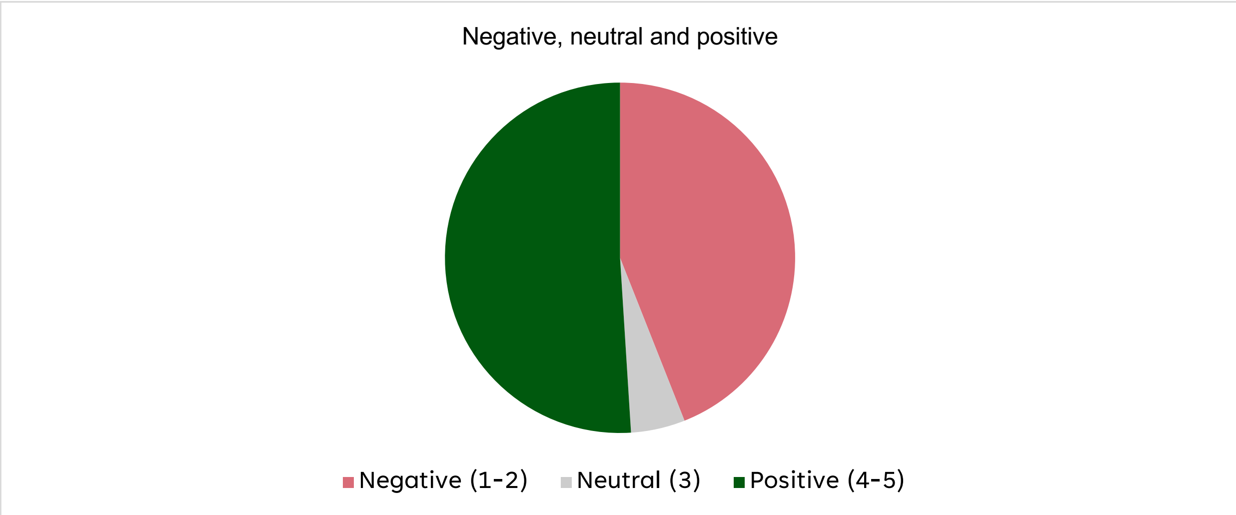

Figure 4.9: Responses to the statement that workload decreased

85% of responses gave a positive rating to the statement that workload decreased (M = 4.37). S-124 also received 68% positive responses for reduced workload (M = 4.10). Instructor assessments were more moderate, with 50% positive and 50% neutral workload ratings (M = 3.90).

These favourable results must be considered alongside task specific concerns. 65% responded negatively to the statement that information overload was avoided, while only 23% responded positively (M = 2.14). The S-104 manual calculation result was also predominantly negative.

Therefore, increased workload was observed during:

- Initial familiarisation.
- Display customisation.
- Learning new presentation methods.

Workload should not be described as uniformly reduced and this finding highlights the importance of structured training before operational implementation.

4.9 Confidence in Decision-Making

Participants were asked whether integrated S-100 information increased their confidence during navigation.

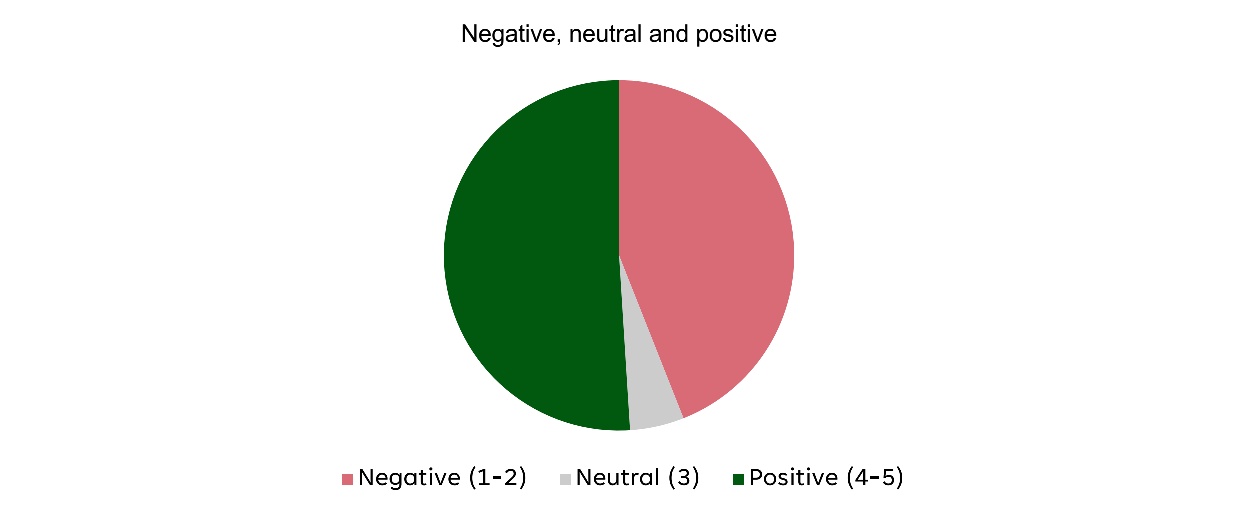

Figure 4.10: Ratings to the statement asking responders if they would be comfortable using S-100 operationally

Confidence varied according to the product and question assessed. S-104 produced the strongest result, with 86% responding positively to increased confidence during tidal navigation (M = 4.33). While S-129 produced a more mixed result: 50% rating positively, 30% were neutral and 20% negative (M = 3.46).

The broader operational result was closely divided. 51% stated that they would be comfortable using S-100 operationally, while 44% responded negatively and 5% were neutral (M = 3.06). Operational confidence therefore cannot be described as uniform.

Reasons included:

- Better environmental awareness.
- Improved chart interpretation.
- Reduced uncertainty.
- Easier hazard identification.

However, several participants stressed that electronic information should always be verified using established navigational practices.

4.10 Summary of Operational Findings

The questionnaire results demonstrate that the perceived operational benefits of S-100 were common environment.

4.11 Chapter 4 Summary

The operational trials demonstrated that bridge teams can successfully integrate S-100 products into familiar navigation workflows. Improvements were observed in route planning, harbour approaches, situational awareness and under-keel clearance assessment, while initial increases in workload were largely confined to the familiarisation period.

Key Findings:

Integrated S-100 products improved the quality of navigational information without requiring fundamental changes to bridge procedures.

The greatest operational benefit was achieved when multiple products—particularly S-101, S-102 and S-104—were used together to support decision-making during complex navigation tasks.

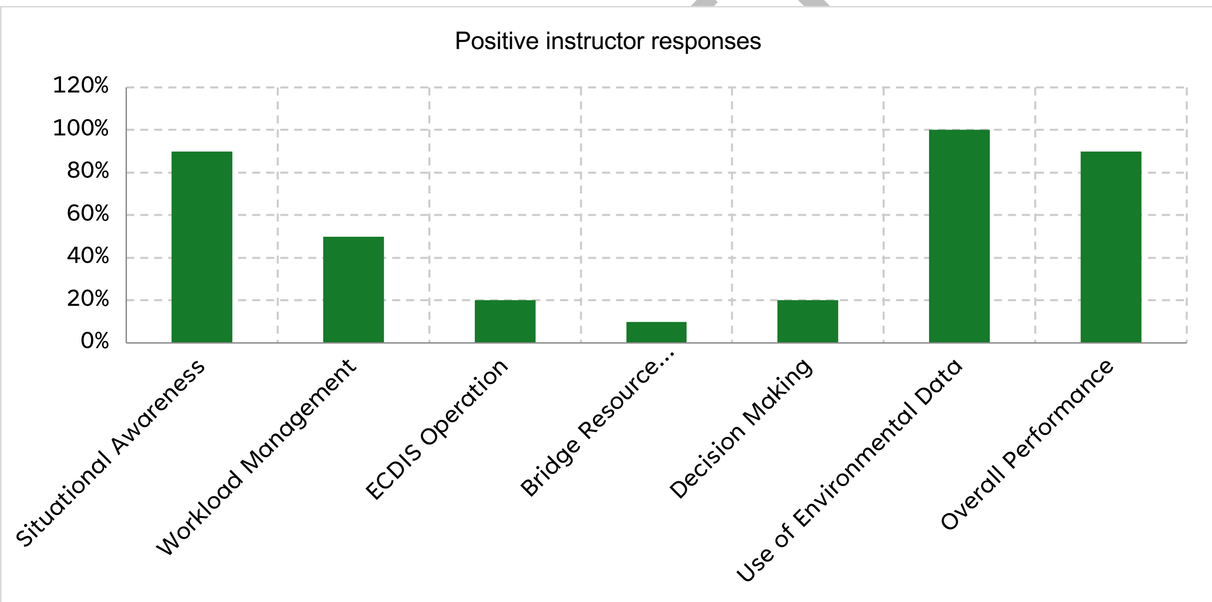

Table 4.11: Distribution of instructor assessment ratings based on ten observations

Instructor assessments were strongest for the use of environmental data, which received 100% positive ratings and the highest mean score of 4.80. Situational awareness was also strongly rated, with 90% positive ratings (M = 4.60), while overall performance received the same positive proportion and a mean of 4.50. These results provide instructor support for the participant finding that improved environmental information was one of the principal benefits of the integrated S-100 environment.

Instructor assessments were more cautions in relation to workload management, ECDIS operation, Bridge Resource Management and decision making. Workload management received 50% positive and 50% neutral ratings (M = 3.90), while 70% of ECDIS operation ratings were neutral (M = 3.20). Bridge resource management also received 70% neutral responses and only 10% positive responses (M = 2.90). Decision making was the lowest rated area, with 40% negative, 40% neutral and only 20% positive ratings (M = 2.70).

Ultimately, the instructor evidence indicates that improved situational awareness did not automatically result in stronger decision making or bridge team performance. Participants may have had access to better environmental information while still requiring additional familiarisation to interpret, prioritise and communicate that information effectively.

There was strong agreement between participants and instructors regarding situational awareness. However, instructors were more cautious concerning workload and operational performance. While 85% of participants reported reduced workload, instructors divided evenly between positive and neutral workload ratings. This may reflect the distinction between participants' immediate perceptions and instructors' wider observation of task execution.

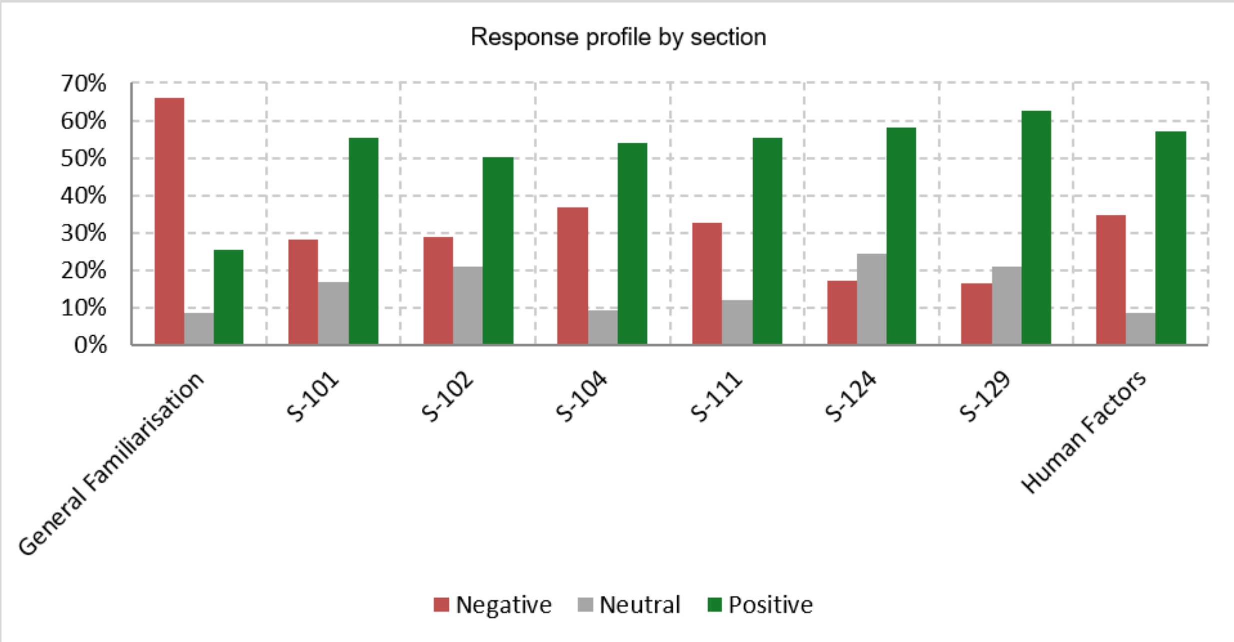

Table 4.12: Participants ratings per questionnaire section

Note: Percentages represent the average distribution of responses across all questions within each section. They should not be interpreted as the percentage of participants giving an overall approval rating to each product.

The section level results show that S-129 produced the highest overall mean score (M = 3.86) and the largest average proportion of positive responses at 62.5%. S-124 followed with a mean of 3.66 and 58.3% positive responses. S-111 and S-101 produced similar means of 3.43 and 3.42 respectively, while S-102 recorded a mean of 3.39. The small differences between these middle ranking sections should not be treated as statistically significant.

General familiarisation was the only section with overall negative responses at 66.2% and a mean below the neutral midpoint at 2.33. This reinforces the conclusion that initial usability and familiarisation represented the principal weakness of S-100. The more favourable product results therefore emerged despite substantial early difficulty in understanding and navigating the interface.

The aggregated figures also conceal substantial variation between individual questions. For example, S-102 received strong ratings for seabed understanding and overall usefulness, but poor ratings for display quality and harbour area interpretation. Similarly, S-104 received strong confidence and presentation ratings, but an overwhelming negative result for reduced manual calculation. Section means (M) should therefore be used as an overview and interpreted alongside the individual item results.

The human factors section produced 57% positive responses overall, but this average combined highly favourable results for situational awareness and workload with negative results concerning information overload and bridge team communication. The section result therefore represents a mixture of strong operational benefits and continuing implementation concerns rather than a consistently positive outcome.

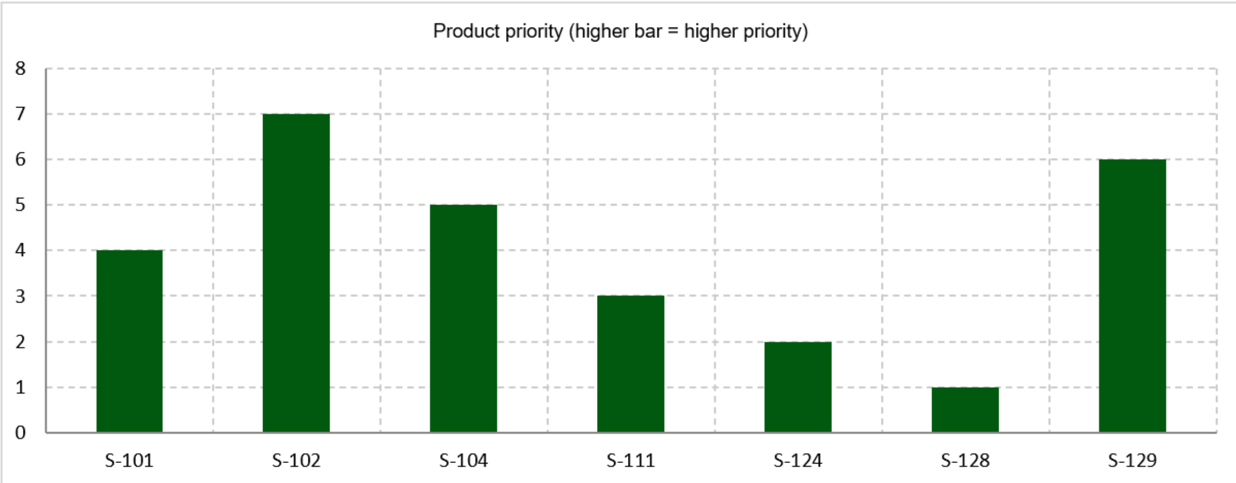

Table 4.13: Overall group ranking of the evaluated S-100 products

Note: The product ranking represents the single overall group ordering supplied in the questionnaire responses.

The overall product ranking placed S-102 first, followed by S-129 and S-104. However, S-101 was identified as the preferred product for initial implementation because of its similarity to existing S-57 practice. This distinction demonstrates that the product offering the greatest perceived operational benefit was not necessarily the product considered easiest to introduce. Participants also emphasised that products should be introduced individually because simultaneous familiarisation with multiple products could become overwhelming.

Taken together, the findings support a phased introduction and human centred transition to S-100. Initial implementation should build upon familiar S-101 functions before progressively introducing specialised environment, bathymetric, tidal and under keel products. Training should focus not only on operating each product but also on prioritising information, configuring displays and integrating new data into bridge team decision making.

The results provide evidence of perceived operational benefits, particularly in situational awareness, environmental understanding and access to integrated navigational information. However, they do not establish objective reductions in planning time, navigational error or calculation time.

Chapter 5 — Product Evaluation and Comparative Analysis from Maritime Instructors' Perspective

This chapter presents a detailed evaluation of each S-100 product specification included within the simulator trials. It examines participant feedback, instructor observations and operational performance, before comparing each product against equivalent S-57 functionality where appropriate.

The objective is to identify not only whether participants preferred the S-100 products, but also to understand why they preferred them and how those preferences may influence future implementation.

The main purpose of Chapter 5 is to draw from the instructors' experience by reflecting on the transition of teaching S-57 to 'new to' ECDIS students, to then teaching S-100.

5.1 Introduction

Although S-100 is often discussed as a single standard, it is more accurately described as a framework supporting multiple interoperable product specifications.

During the simulator programme, participants evaluated the following products:

- S-101 Electronic Navigational Charts
- S-102 Bathymetric Surface
- S-104 Water Level Information

Each product was assessed independently before considering the operational benefits of integrating them into a single navigation display.

5.2 Evaluation Criteria

To ensure consistency, each product was assessed using common evaluation criteria.

Criterion	Description
Ease of Use	How quickly users understood and operated the product
Situational Awareness	Contribution to understanding the operational environment
Decision Support	Extent to which the product supported safe navigation
Display Quality	Clarity of graphical presentation
Operational Benefit	Practical value during routine navigation
Training Requirement	Level of additional familiarisation required

Table 5.1: Criteria used to evaluate each S-100 product

Participants scored each criterion using a five-point scale ranging from Very Poor to Excellent.

5.3 S-101 Electronic Navigational Chart

S-101 is the successor to the S-57 Electronic Navigational Chart Product Specification. It retains the core principles of vector chart navigation while introducing a more flexible data model, enhanced feature catalogues and improved portrayal capabilities.

The intention is not to fundamentally change the navigator's workflow, but to improve the quality, consistency and future extensibility of electronic chart information.

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5.3.1 Operational Findings

Participants adapted to S-101 rapidly.

Several commented that route planning procedures remained familiar, reducing the amount of retraining required.

The principal improvements identified were:

- Improved chart clarity.
- Better colour management.
- Enhanced text placement.
- More intuitive presentation of complex harbour areas.
- Improved consistency between zoom levels.

5.3.2 Instructor Observations

Instructors noted that participants spent less time interpreting chart symbols and more time discussing navigation strategies.

This suggests that improved portrayal reduced the cognitive effort required to understand the chart.

5.3.3 Comparison with S-57

Characteristic	S-57	S-101
Data Model	Fixed	Flexible
Feature Catalogue	Limited	Expanded
Portrayal	Static	Dynamic
Future Development	Restricted	Extensible
User Experience	Familiar	Familiar with enhancements

Table 5.2: Comparison of S-57 and S-101 chart characteristics

5.3.4 Key Finding

S-101 was viewed as a natural evolution of S-57 rather than a replacement requiring entirely new operational procedures.

5.4 S-102 Bathymetric Surface

S-102 provides a high-resolution bathymetric surface representing the seabed as a continuous digital model rather than a series of discrete contour lines and spot soundings.

This enables navigators to visualise seabed morphology more intuitively.

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5.4.1 Participant Feedback

S-102 consistently received the highest ratings of all products evaluated.

Participants particularly valued:

- Smooth depth transitions.
- Clear visualisation of dredged channels.
- Improved identification of shoals.
- Easier interpretation of underwater terrain.

Masters and Pilots commented that S-102 would be particularly beneficial when navigating unfamiliar ports or tidal approaches.

5.4.2 Operational Benefits

Compared with S-57, participants reported:

- Faster identification of navigable water.
- Greater confidence during pilotage.
- Improved understanding of under-keel clearance.
- Reduced reliance on mental interpretation of contour spacing.

5.4.3 Other Observations

The use of S-102 changed the nature of bridge discussions.

Instead of interpreting individual depth contours, participants focused on route safety, vessel manoeuvring and environmental conditions.

5.4.4 Comparison with S-57

Characteristic	S-57	S-102
Contours	Yes	Optional
Spot Soundings	Yes	Supplementary
Continuous Surface	No	Yes
Terrain Visualisation	Limited	Excellent
Pilotage Support	Moderate	High

Table 5.3: Comparison of S-57 and S-102 bathymetric presentation

5.4.5 Key Finding

S-102 provided the greatest measurable improvement in situational awareness during restricted-water navigation.

5.5 S-104 Water Level Information

S-104 introduces dynamic water level information directly into the ECDIS environment.

Rather than consulting separate tide tables, users can visualise predicted water levels in relation to charted depths.

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5.5.1 Participant Feedback

Deep-draught operators regarded S-104 as particularly valuable.

The product reduced the need to perform repetitive manual calculations during passage planning and tidal port approaches.

5.5.2 Operational Benefits

Participants reported:

- Improved confidence.
- Reduced planning time.
- Better understanding of tidal windows.
- Enhanced UKC assessment.

5.5.3 Considerations

Several respondents emphasised that S-104 should complement, rather than replace:

- Tide tables.
- Pilot advice.
- Company procedures.
- Professional judgement.

5.5.4 Comparison with Traditional Practice

Traditional Method	S-104
Tide Tables	Integrated
Manual Calculation	Automated Support
Multiple Sources	Single Display
Static Information	Time-dependent

Table 5.4: Comparison of traditional tidal planning and S-104 water-level integration

5.5.5 Key Findings

S-104 significantly reduced the administrative effort associated with tidal planning while improving confidence in navigational decision-making.

5.6 Interim Discussion

The first three products evaluated—S-101, S-102 and S-104—demonstrated a common theme.

Rather than changing the principles of navigation, they improved the quality, accessibility and interpretation of information already used by professional mariners.

Participants consistently stated that these products supported existing bridge procedures instead of replacing them.

This finding is important because successful adoption of new technology depends upon enhancing established practices rather than introducing unnecessary complexity.

5.6.1 Emerging Themes

Across all exercises involving S-101, S-102 and S-104, four recurring themes were identified.

- Improved Information Quality
- Participants consistently reported that information was easier to interpret.
- Reduced Cognitive Effort
- Less time was spent interpreting hydrographic information.
- Better Decision Support
- Bridge teams focused more on navigational decisions than on manual calculations.
- Need for Familiarisation
- Although the products were generally intuitive, structured training remained essential to ensure consistent operational use.

5.7 Chapter 5 Summary

The evaluation of S-101, S-102 and S-104 demonstrated clear operational benefits across a range of navigation tasks. Participants particularly valued, improved chart portrayal, enhanced bathymetric visualisation and the integration of dynamic water level information.

The findings indicate that the greatest value of these products lies not in replacing traditional navigational principles but in improving the presentation and usability of hydrographic information, thereby allowing bridge teams to concentrate on safe navigation rather than data interpretation.

5.7.1 Key Findings

S-101 improves the presentation of official Electronic Navigational Charts while maintaining familiar operational workflows.

S-102 was consistently identified as the most valuable enhancement to situational awareness, particularly during pilotage and harbour approaches.

S-104 reduces the workload associated with tidal planning by integrating water level information directly into the ECDIS environment.

Chapter 6 — Advanced S-100 Products and Integrated Navigation

This chapter examines the remaining S-100 product specifications evaluated during the simulator programme and assesses their contribution to an integrated navigation environment.

Attention is given to:

- S-111 Surface Currents
- S-124 Navigational Warnings
- S-128 Catalogue of Nautical Products
- S-129 Under Keel Clearance

The chapter also considers how these products interact with one another to support bridge team decision-making throughout different phases of a voyage.

6.1 Introduction

One of the principal advantages of the S-100 framework is that it enables multiple hydrographic products to operate together within a common data model.

Unlike traditional navigation, where information is often gathered from numerous independent sources, S-100 allows navigators to access complementary datasets through a single ECDIS interface.

The simulator exercises demonstrated that the greatest operational benefits were achieved when products were viewed as an integrated ecosystem rather than as individual services.

6.2 Evaluation of S-111 Surface Currents

Surface currents influence virtually every phase of navigation.

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They affect:

- Fuel consumption.
- ETA calculations.
- Pilotage.
- Turning circles.
- Track control.
- Berthing.
- Tug operations.

Historically, this information has been obtained from current atlases, pilot books and local knowledge.

S-111 enables the data to be displayed dynamically within the ECDIS.

6.2.1 Simulator Findings

Participants quickly recognised the practical value of current vectors.

Most reported that they could immediately understand:

- Why the vessel was setting off track.
- How currents influenced turning behaviour.
- Where speed reductions would occur.
- The likely effect of tidal streams during harbour approaches.

6.2.2 Operational Example

During one restricted-water scenario, participants observed that a strong crosscurrent was pushing the vessel towards the edge of the dredged channel.

Using traditional navigation:

- Current predictions were consulted separately.
- The bridge team mentally estimated drift.
- Helm adjustments were based on experience.

6.2.3 Using S-111

- The current vector was visible directly on the ECDIS.
- Drift was anticipated earlier.
- Smaller helm corrections were required.
- Participants reported greater confidence throughout the manoeuvre.

6.2.4 Advantages

Participants highlighted several benefits:

- Improved route optimisation.
- Better fuel management.
- Increased awareness of environmental forces.
- More effective pilot–bridge communication.
- Improved ETA prediction.

6.2.5 Potential Risks

Several participants cautioned against displaying excessive vector density.

Recommended improvements included:

- Adjustable display density.
- Time animation.
- User-defined filters.
- Automatic decluttering at small scales.

6.2.6 Key Findings

S-111 enhances understanding of vessel behaviour by making environmental influences immediately visible within the navigation display.

6.3 Evaluation of S-124 Navigational Warnings

Maritime Safety Information (MSI) is traditionally disseminated through NAVTEX, SafetyNET and NAVAREA warnings.

While effective, these systems require bridge teams to manually interpret text messages and determine whether the warnings affect the planned voyage.

S-124 transforms this process by providing machine-readable, geographically referenced warnings.

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6.3.1 Simulator Findings

Participants responded very positively.

Rather than reading lengthy textual messages, they immediately identified affected areas on the chart display.

The visual presentation significantly reduced the time required to understand the operational implications of each warning.

6.3.2 Case Study

A temporary dredging operation was introduced midway through a harbour approach.

Using conventional procedures:

- The warning was read.
- The location was identified.
- The route was checked manually.

Using S-124:

- The affected area appeared directly on the ECDIS.
- The route conflict was immediately apparent.
- Participants amended the route with minimal delay.

6.3.3 Human Factors

Participants noted that:

- Relevant warnings were easier to identify.
- Geographical presentation reduced misunderstanding.
- Alert fatigue could become a concern if filtering was not available.

6.3.4 Recommendations

ECDIS manufacturers should provide:

- Severity filtering.
- User-defined categories.
- Automatic expiry.
- Clear graphical differentiation between advisory and critical warnings.

6.3.5 Key Finding

Graphically integrated navigational warnings significantly reduced the time required to assess the operational relevance of Maritime Safety Information.

6.4 Evaluation of S-128 Catalogue of Nautical Products

S-128 is often overlooked because it operates largely behind the scenes.

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However, it provides an essential function by allowing ECDIS systems to identify:

- Available products.
- Dataset coverage.
- Product versions.
- Update status.
- Compatibility.

6.4.1 Participant Perception

Initially, most bridge teams regarded S-128 as having little operational relevance.

However, instructors recognised its importance for fleet-wide data management.

6.4.2 Long-Term Significance

As additional S-100 products become operational, S-128 will become increasingly important in ensuring:

- Complete product coverage.
- Consistent updates.
- Reduced administrative workload.
- Improved configuration management.

6.4.3 Key Finding

Although largely invisible to bridge teams, S-128 provides the foundation for reliable management of future S-100 services.

6.5 Evaluation of S-129 Under Keel Clearance

Safe Under Keel Clearance (UKC) assessment is one of the most critical tasks undertaken during restricted-water navigation.

Traditionally, bridge teams calculate UKC using:

- Charted depth.
- Height of tide.
- Vessel draught.
- Dynamic allowances.
- Company safety margins.

This process requires considerable experience and is prone to calculation errors if undertaken under pressure.

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6.5.1 Simulator Findings

S-129 consistently received the highest operational ratings alongside S-102.

Participants appreciated that:

- Calculations were simplified.
- Information was integrated.
- Dynamic updates were available.
- Confidence increased during tidal navigation.

6.5.2 Case Study

Participants completed a tidal harbour approach using both traditional and integrated methods.

Traditional Method:

- S-57.
- Tide tables.
- Company UKC worksheet.
- Manual calculations.

Average preparation time was noticeably longer, and participants frequently cross-checked multiple information sources.

Integrated Method:

- Using S-101, S-102, S-104 and S-129.
- Dynamic UKC information was presented directly within the ECDIS.
- Manual calculations were reduced.
- Participants focused on vessel monitoring rather than arithmetic.
- Confidence during the approach increased.

6.5.3 Instructor Observations

Instructors emphasised that S-129 should be viewed as decision support, not decision replacement.

Professional judgement remained essential, particularly when considering:

- Squat.
- Heel.
- Weather.
- Survey uncertainty.
- Local operating procedures.

6.5.4 Key Finding

S-129 reduced administrative workload while improving confidence, but participants unanimously agreed that final responsibility must remain with the bridge team.

6.6 Integrated Navigation

One of the most significant findings of the research was that the value of S-100 products increased when used together.

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Participants consistently reported that the combination of:

- S-101.
- S-102.
- S-104.
- S-111.
- S-124.
- S-129.

provided far greater operational benefit than any single product alone.

6.7 Overall Product Rankings

Based on participant feedback, instructor observations and operational usefulness, the products were ranked as follows:

Rank	Product	Overall Operational Benefit
1	**S-102 Bathymetric Surface**	**Outstanding**
2	**S-129 Under Keel Clearance**	**Outstanding**
3	**S-104 Water Level Information**	**Excellent**

Rank	Product	Overall Operational Benefit
4	S-101 Electronic Navigational Chart	Excellent
5	S-124 Navigational Warnings	Very Good
6	S-111 Surface Currents	Very Good
7	S-128 Catalogue of Nautical Products	Good (strategic importance)

Table 6.1: Overall ranking of evaluated S-100 products by perceived operational benefit

6.8 Chapter 6 Summary

The advanced S-100 products demonstrated that the framework is considerably more than a successor to S-57. Participants consistently recognised the operational advantages of integrating hydrographic, environmental and navigational information into a single decision-support environment.

The strongest benefits were observed when multiple datasets were combined to support complex tasks such as harbour approaches, tidal navigation and under-keel clearance assessment.

6.8.1 Key Findings

The true strength of S-100 lies not in individual product specifications, but in the integration of complementary datasets that collectively enhance navigational decision-making.

Participants consistently favoured an integrated approach over separate information sources, provided that displays remained uncluttered and users retained control over information presentation.

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Chapter 7 — Human Factors and Bridge Team Performance

This chapter examines the human-factor considerations identified during the simulator evaluation programme. It explores how professional mariners interacted with the S-100 products, the impact on situational awareness and cognitive workload, and the implications for Bridge Resource Management (BRM), training and future ECDIS design.

The objective is to ensure that technological advancement is accompanied by improvements in human performance, rather than introducing unnecessary complexity or new operational risks.

7.1 Introduction

Navigation is ultimately a human-centred activity. Regardless of the sophistication of onboard systems, responsibility for the safe conduct of the vessel remains with the Master and bridge team.

The introduction of S-100 products therefore raises an important question:

Can additional information improve decision-making without increasing cognitive workload?

The simulator programme demonstrated that the answer depends less on the quantity of information available and more on how that information is presented, prioritised and used.

7.2 Situational Awareness

Situational awareness is commonly described as a three-stage process:

Perception – noticing relevant information.

Comprehension – understanding what it means.

Projection – anticipating what will happen next.

The simulator trials assessed all three stages.

7.2.1 Traditional Navigation

Using S-57, officers often needed to combine information from:

- Electronic charts
- Tide tables
- Sailing directions
- Current atlases
- Local notices
- Pilot information

This required significant mental effort to build a complete operational picture.

7.2.2 Integrated Navigation

Using S-100 products, much of this information was available within the ECDIS, allowing bridge teams to focus on interpretation rather than information gathering.

Participants consistently reported:

- Faster understanding of developing situations.
- Improved anticipation of environmental effects.
- Better awareness of navigational hazards.
- Increased confidence during restricted-water navigation.

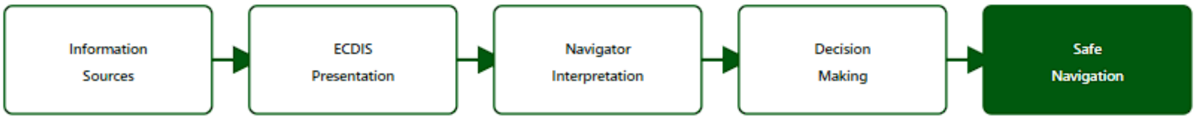

Figure 7.1: Development of situational awareness from information sources to safe navigation

7.3 Cognitive Workload

Before the trials commenced, one concern expressed by several stakeholders was that the introduction of multiple S-100 products might overload bridge teams with information.

The findings suggest a more nuanced picture.

7.3.1 During Familiarisation

Participants experienced a temporary increase in workload while becoming familiar with:

- New symbols.
- Display layers.
- Product interactions.
- Configuration options.

7.3.2 During Operational Use

Once familiar with the interface, most participants reported that workload decreased because:

- Manual calculations were reduced.
- Environmental information was integrated.
- Fewer external publications were required.
- Information was easier to interpret.

7.3.3 Instructor Observation

An experienced bridge team adapted rapidly when information was introduced progressively.

Conversely, participants presented with all available S-100 layers immediately after the briefing often spent excessive time adjusting display settings rather than monitoring the navigation task.

7.3.4 Key Recommendation

Future training should introduce products sequentially rather than simultaneously.

7.4 Information Overload

Although participants welcomed additional information, nearly every debrief included discussion about display clutter.

- Common concerns included:
- Too many active layers.
- Excessive warning symbols.
- Dense current vectors.
- Reduced chart readability.

<image being optimised by graphics>

The majority recommended that ECDIS systems should allow users to tailor the display to the current phase of navigation.

Navigation Phase	Suggested Products
Ocean Passage	S-101, S-111
Coastal Passage	S-101, S-111, S-124
Harbour Approach	S-101, S-102, S-104
Tidal Port Entry	S-101, S-102, S-104, S-129
Pilotage	All relevant products, agreed with the Pilot

Table 7.1: Recommended S-100 products by phase of navigation

7.5 Automation Bias

Automation bias is the tendency to place excessive trust in computer-generated outputs.

Participants recognised this risk, particularly when using advanced decision-support tools such as S-129.

Several masters emphasised that:

"The software supports the decision, but it must never make the decision."

Professional judgement remained central to safe navigation.

Bridge teams continued to verify:

- Under-keel clearance.
- Chart quality.

- Environmental conditions.
- Company procedures.
- Pilot advice.

This demonstrates that experienced mariners viewed S-100 as an aid rather than a substitute for professional expertise.

7.6 Bridge Resource Management

The simulator trials also explored how S-100 influenced communication and teamwork on the bridge.

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Positive Observations

Participants reported:

- More effective discussions during passage planning.
- Improved shared understanding of environmental conditions.
- Better communication with Pilots.
- Easier explanation of navigational decisions to other bridge team members.

Instructors observed that the integrated display encouraged collaborative decision-making because all members of the bridge team were referring to the same information source.

Areas Requiring Attention

However, participants also noted the importance of:

- Clearly assigning monitoring responsibilities.
- Avoiding duplication of tasks.
- Ensuring that no information layer was assumed to be monitored by someone else.

7.7 User Interface Design

The simulator programme generated valuable feedback on interface design.

Participants preferred interfaces that were:

- Clean.
- Consistent.
- Configurable.
- Uncluttered.
- Familiar.

They particularly valued:

- Adjustable transparency.
- Simple layer controls.

- Consistent colour schemes.
- Context-sensitive information.
- Minimal menu depth.

Design Principles for Future ECDIS

Based on participant feedback, the following principles are recommended:

1. Present only relevant information.
2. Minimise unnecessary alarms.
3. Allow rapid access to environmental layers.
4. Maintain consistency with existing ECDIS workflows.
5. Support customisation without excessive complexity.

7.8 Training Implications

Participants unanimously agreed that successful implementation depends upon structured training.

Recommended training should include:

Stage 1 – Awareness

- Introduction to S-100.
- Product overview.
- Operational benefits.

Stage 2 – Familiarisation

- ECDIS interface.
- Product selection.
- Display management.

Stage 3 – Practical Application

- Passage planning.
- Route monitoring.
- Harbour approaches.
- Tidal navigation.
- Under-keel clearance.

Stage 4 – Assessment

- Simulator exercises.
- Instructor observation.
- Scenario-based assessment.
- Operational debrief.

7.9 Lessons Learned

The simulator programme identified several important lessons.

Lesson 1:

Technology should simplify navigation rather than complicate it.

Lesson 2:

Progressive familiarisation is more effective than introducing all products simultaneously.

Lesson 3:

Bridge teams value integrated information when it supports existing workflows.

Lesson 4:

Professional judgement remains the most important safety barrier.

Lesson 5:

Human-centred interface design is as important as technical capability.

7.10 Chapter 7 Summary

The simulator trials confirmed that the successful implementation of S-100 depends not only on technical performance but also on the way information is presented to the bridge team.

Participants consistently recognised the operational benefits of integrated hydrographic information, provided that interfaces remained intuitive, displays were configurable and training was structured around realistic operational scenarios.

The findings reinforce a key principle that underpins this report:

The objective of S-100 is not to replace the navigator, but to enhance the navigator's ability to make safe, informed and timely decisions.

7.10.1 Key Findings

Human performance remains the critical factor in the successful implementation of S-100.

Well-designed interfaces, effective training and disciplined Bridge Resource Management are essential if the full benefits of integrated digital navigation are to be realised.

7.10.2 Recommendations for the Industry

Based on the human factors evaluation, ECDIS Ltd recommends:

1. Adopt a phased implementation strategy for S-100 products to minimise cognitive overload.
2. Develop standardised simulator training programmes that introduce products progressively.
3. Implement configurable display profiles tailored to different phases of navigation.
4. Maintain the navigator as the final decision-maker, ensuring decision-support tools complement rather than replace professional judgement.
5. Continue user-centred design and operational trials, incorporating feedback from Masters, Officers, Pilots and instructors into future software development.

Chapter 8 — Implementation Strategy and Future Roadmap

This chapter provides a structured roadmap for the implementation of S-100 products within the maritime industry. Drawing upon the findings of the simulator evaluation programme, it outlines recommended actions for shipping companies, hydrographic offices, ECDIS manufacturers, training providers and regulatory organisations.

The objective is to support a safe, consistent and internationally harmonised transition from S-57 to the S-100 framework.

8.1 Introduction

The simulator programme demonstrated that the S-100 framework has the potential to significantly improve the availability and usability of navigational information. However, the introduction of new technology into safety-critical environments requires careful planning, effective governance and comprehensive training.

The maritime industry has experienced similar transitions before, including:

- Paper charts to Raster Navigational Charts (RNCs).
- RNCs to vector Electronic Navigational Charts (S-57).
- Conventional navigation to mandatory ECDIS carriage.

Each transition required a period of coexistence, familiarisation and refinement before becoming accepted operational practice.

The move to S-100 should follow the same disciplined approach.

8.2 Principles of Implementation

The findings of this study support five fundamental implementation principles.

Principle 1 – Safety First

The introduction of S-100 must enhance navigational safety without introducing unacceptable operational risk.

Technology should support existing navigational practices rather than replace them.

Principle 2 – Progressive Introduction

Products should be introduced gradually.

Participants consistently adapted more effectively when new capabilities were added sequentially rather than simultaneously.

Principle 3 – User-Centred Design

Bridge teams should remain at the centre of ECDIS design.

Products must support operational workflows rather than requiring navigators to adapt to technology.

Principle 4 – Interoperability

The principal strength of S-100 lies in the ability of products to operate together.

Future implementation should therefore prioritise interoperability between hydrographic, oceanographic and navigational datasets.

Principle 5 – Continuous Improvement

Implementation should be viewed as an ongoing process rather than a single deployment.

Feedback from operational users should continue to influence future product development.

Figure 8.1: Recommended pathway from simulator evaluation to fleet development

8.3 Recommendations for Shipping Companies

Shipping companies should begin preparing for S-100 implementation well before mandatory operational use.

Recommended actions include:

- Policy Development
- Review bridge procedures.
- Update voyage planning guidance.
- Revise UKC procedures where appropriate.
- Develop company-specific familiarisation material.

Training

Provide structured training covering:

- S-100 architecture.
- Product specifications.
- Human factors.
- Display management.
- Practical simulator exercises.

Fleet Preparation

Shipping companies should:

- Assess ECDIS compatibility.
- Review hardware requirements.
- Plan software upgrades.

- Develop implementation schedules.

Operational Monitoring

Following implementation, companies should:

- Monitor user feedback.
- Review incident reports.
- Conduct refresher training.
- Update procedures based on operational experience.

8.4 Recommendations for Hydrographic Offices

Hydrographic Offices play a central role in the successful implementation of S-100.

Recommendations include:

Data Quality

Continue investment in:

- Modern hydrographic surveying.
- High-resolution bathymetry.
- Data validation.
- Metadata quality.

Product Consistency

Ensure that:

- Product specifications are applied consistently.
- Neighbouring regions provide compatible datasets.
- Updates are distributed efficiently.

User Engagement

Maintain dialogue with:

- Mariners.
- Shipping companies.
- Equipment manufacturers.
- Maritime academies.

Operational feedback should continue to inform future product development.

8.5 Recommendations for ECDIS Manufacturers

The simulator programme identified several priorities for future ECDIS development.

Interface Design

Develop interfaces that are:

- Simple.
- Configurable.
- Consistent.
- Uncluttered.

Information Management

Provide:

- Intelligent layer management.
- Automatic decluttering.
- Context-sensitive displays.
- User-defined profiles.

Decision Support

Continue developing tools that:

- Support navigators.
- Reduce manual calculations.
- Improve situational awareness.

Avoid replacing professional judgement with automated decision-making.

8.6 Recommendations for Maritime Training Organisations

Training providers should begin preparing for S-100 implementation by updating existing ECDIS programmes.

Recommended course structure:

- Module 1
  - Introduction to S-100.
- Module 2
  - Individual Product Specifications.
- Module 3
  - Integrated Navigation.
- Module 4
  - Simulator Exercises.
- Module 5
  - Assessment.
- Module 6
  - Operational Familiarisation.

Simulator-based learning should remain the principal method of developing practical competence.

8.7 Recommendations for Regulators

International regulators should continue supporting harmonised implementation through:

- Common technical standards.
- Consistent training requirements.
- International guidance.
- Collaboration with Hydrographic Offices and industry.

The findings of this research support continued cooperation between the International Maritime Organization (IMO), the International Hydrographic Organization (IHO) and the International Electrotechnical Commission (IEC) to ensure consistent implementation across manufacturers and flag states.

8.8 Looking Beyond the Current Product Set

The products evaluated during this programme represent only the first stage of the S-100 ecosystem.

Future product specifications are expected to expand the range of information available to bridge teams.

Product	Purpose	Potential Operational Benefit
S-121	Maritime Limits and Boundaries	Improved jurisdictional awareness
S-122	Marine Protected Areas	Environmental compliance
S-123	Marine Radio Services	Integrated communication planning
S-127	Marine Traffic Management	Enhanced traffic awareness
S-131	Harbour Infrastructure	Improved port operations
S-164	Test Data Sets	Validation and interoperability testing

Table 8.1: Future S-100 product specifications and their potential operational benefits

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As these products mature, ECDIS will continue to evolve into a comprehensive maritime information platform.

8.9 A Vision for Digital Navigation

The transition to S-100 is not simply about introducing additional datasets. It represents a shift towards digital maritime services, where information is continuously updated, interoperable and delivered in a form that supports real-time operational decision-making.

Future developments may include:

- Live environmental updates.
- Dynamic route optimisation.
- Predictive under-keel clearance.
- Enhanced port information services.
- Integration with voyage optimisation systems.
- Improved decision support through advanced analytics.

While these developments are promising, participants consistently emphasised that technology must remain transparent, understandable and under the control of the bridge team.

8.10 Chapter 8 Summary

The implementation of S-100 should be viewed as a managed transition rather than a single technical upgrade. Successful adoption depends upon collaboration between regulators, hydrographic offices, equipment manufacturers, shipping companies and training providers.

The simulator programme demonstrated that the technology is capable of delivering meaningful operational benefits. The challenge now lies in ensuring that implementation is supported by consistent standards, high-quality training and continued engagement with end users.

8.10.1 Key Findings

The transition to S-100 should be phased, user-centred and supported by structured training programmes.

Interoperability, data quality and human-centred design will be the principal factors determining the long-term success of the S-100 framework.

8.10.2 Strategic Recommendations

- Adopt phased implementation programmes rather than fleet-wide deployment without familiarisation.
- Invest in simulator-based training as the primary method of building operational competence.
- Maintain collaboration between industry and regulators to ensure consistent interpretation of S-100 standards.
- Prioritise user-centred ECDIS design, ensuring that additional information improves rather than hinders situational awareness.
- Continue operational research as new S-100 product specifications become available.

Chapter 9 — Conclusions and Future Research

This chapter presents the overall conclusions arising from the simulator evaluation programme. It considers the significance of the findings, identifies areas requiring further investigation and provides a long-term vision for the development of S-100-based navigation systems.

The conclusions are intended to support decision-makers within Hydrographic Offices, shipping companies, equipment manufacturers, maritime training organisations and regulatory bodies.

9.1 Introduction

The introduction of the S-100 Universal Hydrographic Data Model marks one of the most significant developments in marine navigation since the widespread adoption of Electronic Chart Display and Information Systems (ECDIS).

Unlike previous advances, which focused primarily on improving chart presentation, S-100 introduces a common framework capable of integrating multiple hydrographic, oceanographic and navigational information products into a single operational environment.

The simulator programme described in this report sought to determine whether this additional capability translates into measurable operational benefits for professional mariners.

The findings indicate that it does.

9.2 Achievement of Research Objectives

The study was designed around seven principal research questions.

The evaluation demonstrated that these objectives were successfully addressed through a combination of simulator observations, participant questionnaires and structured debrief sessions.

Objective 1:

- Evaluate S-101 chart portrayal
- Finding: Participants consistently preferred the improved presentation and readability of S-101 compared with S-57.

Objective 2:

- Evaluate S-102 Bathymetric Surface
- Finding: S-102 received the highest operational ratings, particularly during pilotage and harbour approaches.

Objective 3:

- Assess S-104 Water Levels
- Finding: Dynamic water level information reduced manual calculations and improved confidence during tidal navigation.

Objective 4:

- Evaluate S-111 Surface Currents
- Finding: Participants reported improved understanding of environmental forces affecting vessel behaviour.

Objective 5:

- Evaluate S-124 Navigational Warnings
- Finding: Graphical presentation reduced the time required to identify hazards and assess route impacts.

Objective 6:

- Assess integrated S-100 navigation
- Finding: The combined use of multiple products produced greater operational benefits than any individual product alone.

Objective 7:

- Investigate Human Factors
- Finding: Success depends upon interface design, structured training and effective Bridge Resource Management rather than technology alone.

Objective	Outcome	Status
S-101 Evaluation	Improved chart portrayal	Achieved
S-102 Evaluation	Enhanced seabed awareness	Achieved
S-104 Evaluation	Reduced planning workload	Achieved
S-111 Evaluation	Better current awareness	Achieved
S-124 Evaluation	Improved warning management	Achieved
Integrated Navigation	Greater operational benefit	Achieved
Human Factors	Key implementation considerations identified	Achieved

Table 9.1: Achievement of the research objectives and principal outcomes

9.3 Principal Conclusions

The simulator programme produced five principal conclusions.

Conclusion 1:

- S-100 represents an evolution rather than a revolution.
- Participants adapted quickly because the framework builds upon familiar ECDIS principles while introducing richer information and improved flexibility.

Conclusion 2:

- Integrated information improves decision-making.
- The greatest operational benefit was observed when multiple S-100 products were used together, enabling bridge teams to access a comprehensive picture of the navigational environment.

Conclusion 3:

- Human-centred design is essential.
- The value of additional information depends upon effective presentation, sensible prioritisation and the ability for users to customise the display.

Conclusion 4:

- Professional judgement remains fundamental.
- Participants consistently regarded S-100 products as decision-support tools rather than automated decision-makers.

Conclusion 5:

- Training is the key to successful implementation.
- Simulator-based familiarisation should form the foundation of future S-100 training programmes.

Figure 9.1: Relationship between S-100 products, improved information, decision-making and safe navigation

9.4 Implications for the Maritime Industry

The findings have implications across several sectors.

Shipping Companies:

- Review bridge procedures.
- Plan software/hardware upgrades.
- Invest in simulator training.
- Monitor operational experience.

Hydrographic Offices:

- Continue developing interoperable S-100 datasets.
- Improve metadata quality.
- Support international harmonisation.

Equipment Manufacturers:

- Focus on intuitive interface design.
- Continue user-centred development.
- Improve display management.
- Improve speed of software.

Training Organisations:

- Develop practical simulator courses.
- Integrate S-100 into existing ECDIS curricula.
- Assess operational competence rather than theoretical knowledge alone.

Regulators:

- Promote international consistency.
- Publish implementation guidance.
- Encourage operational research.
- Support harmonised competency requirements.

9.5 Future Research Priorities

The simulator programme represents an important step in evaluating S-100, but additional research is recommended.

Priority topics include:

- Operational Trials
- Long-term evaluation aboard commercial vessels.
- Seasonal environmental variations.
- Multi-voyage performance studies.

Human Factors:

- Fatigue.
- Alarm management.
- Information prioritisation.
- Bridge team communication.

Emerging Technologies:

- Artificial Intelligence decision support.
- Predictive voyage optimisation.
- Digital twins.
- Autonomous and remotely operated vessels.

Cybersecurity:

As navigation becomes increasingly dependent on digital services, future research should also examine:

- Data integrity.
- Authentication of hydrographic information.
- Resilience against cyber threats.
- Continuity of navigation services during system failures.

9.6 A Vision for the Future

The maritime industry is moving towards an increasingly connected operational environment.

Future bridge systems may integrate:

- Hydrographic information.
- Meteorological forecasts.
- Oceanographic models.
- Traffic management services.
- Port information.
- Environmental restrictions.
- Voyage optimisation tools.

S-100 provides the framework capable of supporting this evolution.

However, the technology will only achieve its full potential if development continues to place the needs of the navigator at its centre.

9.7 Final Statement

Throughout the simulator programme, one message emerged consistently from participants.

Technology should reduce complexity, not create it.

The introduction of S-100 products offers a significant opportunity to improve navigational safety by presenting richer, more integrated information within a familiar ECDIS environment. Participants demonstrated that these products could improve situational awareness, reduce routine workload and support more informed operational decisions.

At the same time, the research reinforces a fundamental principle of safe navigation:

No technology can replace the knowledge, experience and professional judgement of a competent bridge team.

The future of digital navigation will therefore depend not only on advances in hydrographic data but also on the continued partnership between mariners, Hydrographic Offices, equipment manufacturers, training providers and international regulatory organisations.

9.7.1 Final Recommendations

Based on the evidence gathered during this study, ECDIS Ltd recommends that organisations preparing for S-100 implementation should:

- Adopt a phased transition from S-57 to S-100.
- Invest in simulator-based familiarisation before operational deployment.
- Develop user-centred ECDIS interfaces that minimise unnecessary complexity.
- Promote international harmonisation of standards, training and implementation.
- Continue collaborative operational research as additional S-100 product specifications become available.

9.7.2 Closing Remarks

This report has demonstrated that the transition to S-100 is not merely a technical upgrade but a significant step towards a more integrated, information-rich approach to maritime navigation.

With careful implementation, continued collaboration and a strong emphasis on human-centred design, the S-100 framework has the potential to become the foundation of the next generation of safe, efficient and resilient navigation systems.

Appendix A – Participant Questionnaire and Evaluation Forms

This appendix contains the questionnaires, evaluation forms and structured debrief templates used during the operational assessment of selected S-100 product specifications.

The purpose of these questionnaires was to gather consistent feedback from experienced maritime professionals regarding the operational usability, effectiveness and perceived benefits of S-100 products when compared with traditional S-57 Electronic Navigational Charts.

Responses were collected immediately following each simulator exercise to minimise recall bias and ensure observations reflected participants' experiences during the scenarios.

Unless otherwise stated, responses were recorded using a five-point Likert scale, as seen below.

1	2	3	4	5
Strongly Disagree / Very Poor	Disagree / Poor	Neutral / Acceptable	Agree / Good	Strongly Agree / Excellent

A1 Questionnaire Respondent Details

PARTICIPANT NUMBER	DATE	SIMULATOR SESSION
____________	____________	____________

Current Rank

- ☐ Master
- ☐ Chief Officer
- ☐ Second Officer
- ☐ Third Officer
- ☐ Pilot
- ☐ Maritime Instructor
- ☐ Technical Manager
- ☐ Other: ____________

Years of Experience

- ☐ Less than 5
- ☐ 5–10
- ☐ 10–20
- ☐ More than 20

Primary Vessel Type

- ☐ Container
- ☐ Tanker
- ☐ LNG/LPG
- ☐ Bulk Carrier
- ☐ General Cargo
- ☐ Passenger
- ☐ Offshore
- ☐ Other: ____________

Previous Experience with S-100

- ☐ None
- ☐ Awareness only
- ☐ Limited practical use
- ☐ Regular operational use

A2 General Familiarisation

Please rate the following statements.

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Statement	1	2	3	4	5
The system was easy to understand	☐	☐	☐	☐	☐
The interface was intuitive	☐	☐	☐	☐	☐
Display symbols were easy to recognise	☐	☐	☐	☐	☐
Menu navigation was straightforward	☐	☐	☐	☐	☐
I became confident using the system quickly	☐	☐	☐	☐	☐

Comments:

A3 S-101 Electronic Navigational Charts

Please assess S-101.

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Question	1	2	3	4	5
Chart presentation was clear	☐	☐	☐	☐	☐
Symbols were easy to interpret	☐	☐	☐	☐	☐

Question	1	2	3	4	5
Text placement was effective	☐	☐	☐	☐	☐
Harbour areas were easier to interpret than S-57	☐	☐	☐	☐	☐
Route planning was easier	☐	☐	☐	☐	☐

Which feature did you find most useful?

What improvements would you recommend?

A4 S-102 Bathymetric Surface

Rate the usefulness of S-102.

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Question	1	2	3	4	5
Seabed shape was easier to understand	☐	☐	☐	☐	☐
Harbour approaches were easier to interpret	☐	☐	☐	☐	☐
Under-keel awareness improved	☐	☐	☐	☐	☐
Display quality was appropriate	☐	☐	☐	☐	☐

Question	1	2	3	4	5
Overall operational usefulness	☐	☐	☐	☐	☐

Comments

A5 S-104 Water Levels

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Statement	1	2	3	4	5
Water level information was easy to interpret	☐	☐	☐	☐	☐
Reduced manual calculations	☐	☐	☐	☐	☐
Improved confidence during tidal navigation	☐	☐	☐	☐	☐
Information was presented clearly	☐	☐	☐	☐	☐

Comments

A6 S-111 Surface Currents

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Statement	1	2	3	4	5
Current vectors were easy to interpret	☐	☐	☐	☐	☐
Improved awareness of environmental forces	☐	☐	☐	☐	☐
Useful during pilotage	☐	☐	☐	☐	☐
Improved route monitoring	☐	☐	☐	☐	☐

A7 S-124 Navigational Warnings

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Statement	1	2	3	4	5
Warnings were easy to identify	☐	☐	☐	☐	☐
Display location was clear	☐	☐	☐	☐	☐
Improved hazard awareness	☐	☐	☐	☐	☐
Reduced workload	☐	☐	☐	☐	☐

A8 S-129 Under Keel Clearance

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Statement	1	2	3	4	5
UKC information was easy to understand	☐	☐	☐	☐	☐
Improved confidence	☐	☐	☐	☐	☐
Reduced manual calculations	☐	☐	☐	☐	☐

Statement	1	2	3	4	5
Suitable for operational use	☐	☐	☐	☐	☐

A9 Human Factors

1 = Strongly Disagree / Very Poor | 5 = Strongly Agree / Excellent

Statement	1	2	3	4	5
Situational awareness improved	☐	☐	☐	☐	☐
Workload decreased	☐	☐	☐	☐	☐
Information overload was avoided	☐	☐	☐	☐	☐
Bridge team communication improved	☐	☐	☐	☐	☐
I would be comfortable using S-100 operationally	☐	☐	☐	☐	☐

A10 Overall Evaluation

Rank the products:

Product	Rank
S-101	_____
S-102	_____
S-104	_____
S-111	_____
S-124	_____
S-128	_____
S-129	_____

Which product provided the greatest operational benefit?

Which product requires the most additional training?

Which product would you implement first?

A11 Open Discussion

What was the greatest advantage of S-100?

What concerns remain?

What improvements would you recommend?

A12 Instructor Observation Form

(Completed by the observing instructor)

Assessment Area	Rating (1–5)	Comments
Situational Awareness	______	
Workload Management	______	
ECDIS Operation	______	
Bridge Resource Management	______	
Decision Making	______	

Assessment Area	Rating (1–5)	Comments
Use of Environmental Data	_____	
Overall Performance	_____	

A13 Debrief Guide

The facilitator should explore the following topics during the structured debrief:

☐ **First impressions of the S-100 interface.**

☐ **Comparison between S-57 and S-100.**

☐ **Products that most influenced decision-making.**

☐ **Display clutter and information management.**

☐ **Training requirements.**

☐ **Bridge Resource Management implications.**

☐ **Recommendations for ECDIS manufacturers.**

☐ **Recommendations for Hydrographic Offices.**

☐ **Recommendations for future simulator evaluations.**

Appendix B - Technical Specification of the Simulator Environment

This appendix provides a technical description of the Full Mission Bridge Simulator and the ECDIS Ltd navigation system used throughout the S-100 evaluation programme.

The purpose is to:

- Document the simulator configuration.
- Describe the equipment used during the trials.
- Support repeatability of future research.
- Provide transparency regarding the operational environment.

B1 Simulator Overview

The research programme was conducted using a Full Mission Bridge Simulator representative of a modern SOLAS-compliant merchant vessel.

The simulator replicated the bridge environment of a deep-sea trading vessel and included integrated navigation equipment operating under realistic environmental conditions.

The bridge simulator supported:

- 240° visual system
- Real-time hydrodynamic modelling
- Environmental simulation
- Radar simulation
- AIS simulation
- ECDIS integration
- Engine controls
- Steering systems
- Bridge alarms
- Communications

The simulator allowed participants to operate using normal bridge procedures throughout each exercise.

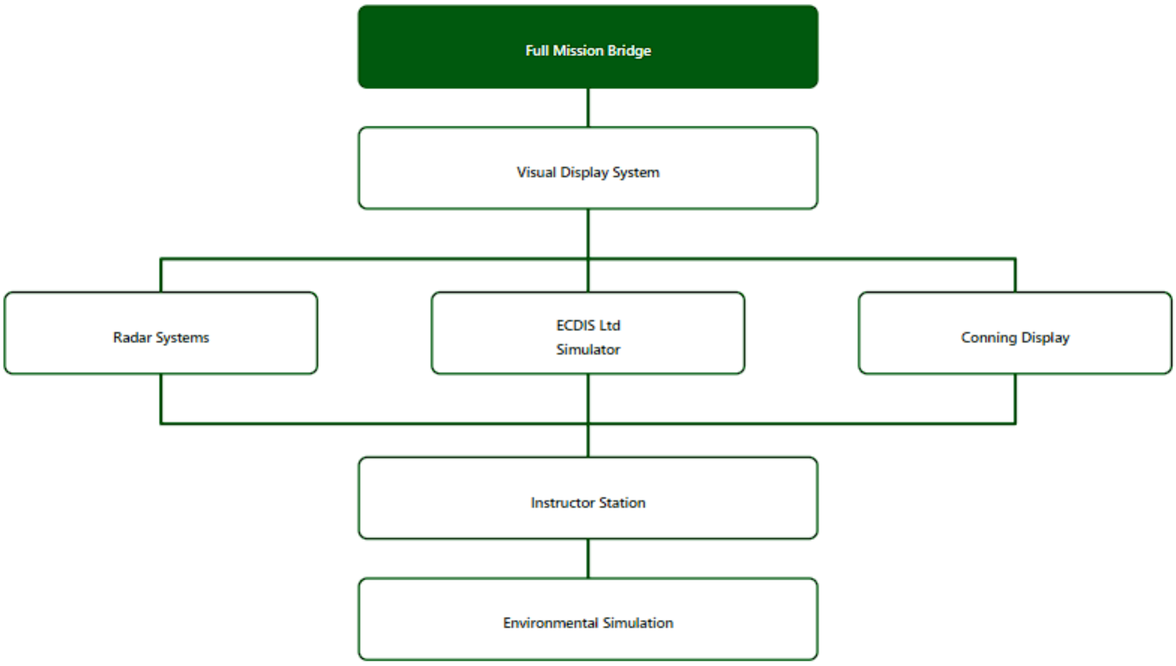

Figure B.1: Full-mission bridge simulator system architecture

B2 ECDIS Configuration

The ECDIS Ltd Simulator was configured to support both legacy S-57 Electronic Navigational Charts and selected S-100 products.

Product	Status
S-57 ENC	Operational
S-101 ENC	Operational
S-102 Bathymetry	Operational
S-104 Water Levels	Operational
S-111 Surface Currents	Operational
S-124 Navigational Warnings	Operational
S-128 Catalogue	Demonstration
S-129 UKC	Demonstration

Table B.1: Operational status of S-57 and S-100 products within the trial simulator

Note: Status refers to functional availability within the trial simulator at time of evaluation.

The simulator enabled participants to activate or deactivate individual products to compare operational performance under identical conditions.

B3 Navigation Equipment

The simulated bridge incorporated equipment commonly found aboard modern merchant vessels.

Equipment	Function
Primary ECDIS	Route Planning and Monitoring
Secondary ECDIS	Redundancy
X-Band Radar	Collision Avoidance
S-Band Radar	Long-Range Navigation
AIS	Vessel Identification
GNSS Receiver	Position Fixing
Echo Sounder	Depth Monitoring
Gyrocompass	Heading Reference
Speed Log	Speed Through Water
Autopilot	Track Keeping
Steering Controls	Manual Navigation
Engine Telegraph	Propulsion Control
VHF Radio	Communications

Table B.2: Navigation equipment and functions within the simulated bridge

B4 Environmental Modelling

The simulator modelled realistic environmental conditions.

Wind:

- Calm
- Moderate
- Fresh Breeze
- Strong Crosswind

Sea State:

- Calm
- Moderate
- Heavy

Visibility:

- Daylight
- Twilight
- Night
- Fog

Current:

- Flood
- Ebb
- Variable

Tidal Conditions:

- Rising Tide
- Falling Tide
- High Water
- Low Water

Weather:

- Clear
- Rain
- Reduced Visibility
- Heavy Weather

Environmental parameters could be altered in real time by the instructor to create consistent or evolving scenarios.

B5 Vessel Models

Representative vessel models were selected to reflect the diversity of commercial shipping.

Vessel Type	Length	Beam	Draught
Container Ship	330 m	48 m	14.5 m
Bulk Carrier	225 m	32 m	15.0 m
LNG Carrier	295 m	46 m	11.8 m
Product Tanker	185 m	32 m	10.5 m
General Cargo	140 m	22 m	7.2 m

Table B.3: Principal dimensions of the vessel models used in the simulator trials

Each vessel incorporated realistic manoeuvring characteristics including:

- Turning circles
- Acceleration
- Deceleration
- Rudder response
- Hydrodynamic interaction
- Wind effects

B6 Instructor Control Station

A dedicated instructor workstation controlled all exercises.

Capabilities included:

- Scenario selection
- Weather changes
- Current changes
- Failure injection
- Traffic generation
- Alarm generation
- Replay facility
- Data recording

The instructor was able to pause, restart and repeat exercises to ensure consistency between participants.

B7 Data Recording

Throughout every exercise the simulator automatically recorded operational data.

Recorded parameters included:

- Vessel position
- Speed over ground
- Speed through water
- Heading
- Rudder angle
- Engine orders
- Track history
- Cross Track Error
- ECDIS interactions
- Alarm acknowledgements
- Route modifications

These objective data were correlated with questionnaire responses and instructor observations.

B8 Research Data Flow

Figure B.2: Research data flow from simulator exercise to research database

B9 Scenario Validation

Prior to participant trials every scenario underwent validation to ensure repeatability.

Validation included:

- Chart verification
- Environmental checks
- Route testing
- Equipment functionality
- Alarm verification
- Data recording verification

Only validated scenarios were included in the research programme.

B10 Quality Assurance

Quality assurance procedures included:

- Before Each Trial
- Equipment inspection
- Software verification
- Chart loading
- Environmental reset
- Instructor briefing

During Each Trial:

- Continuous monitoring
- Data recording
- Event logging
- Performance observation

After Each Trial:

- Participant questionnaire
- Structured debrief
- Data backup
- Scenario reset

B11 Repeatability

One of the principal strengths of simulator-based research is repeatability.

Every participant completed:

- Identical routes
- Identical environmental conditions
- Identical traffic situations
- Identical equipment configuration
- Identical briefing

This ensured that observed differences were attributable to the navigation products rather than external variables.

B12 Technical Limitations

Although the simulator provided a highly realistic environment, certain operational factors could not be fully replicated.

Examples include:

- Crew fatigue over extended voyages.
- Commercial schedule pressures.
- Real-world weather unpredictability.
- Equipment maintenance issues.
- Human behavioural differences over long periods.
- Company operating culture.

These limitations should be considered when interpreting the results.

Appendix B Summary

The Full Mission Bridge Simulator provided a realistic, repeatable and controlled environment for evaluating the operational use of S-100 products.

Its combination of integrated navigation systems, environmental modelling and comprehensive data recording enabled detailed analysis of bridge team performance while eliminating the risks associated with live operational trials.

The simulator therefore proved to be an effective platform for assessing the operational benefits, human-factor implications and implementation considerations associated with the next generation of digital maritime navigation.

Technical Specification Summary:

Parameter	Specification
Simulator Type	Full Mission Bridge Simulator
Navigation System	ECDIS Ltd Simulator
Chart Standards	S-57 and S-100
Products Evaluated	S-101, S-102, S-104, S-111, S-124, S-128, S-129
Participants	100 Professional Mariners
Research Method	Mixed Methods
Data Sources	Simulator logs, questionnaires, instructor observations, debriefs
Output	Operational and human-factor evaluation

Table B.4: Simulator trial configuration and research parameters

Appendix C – Simulator Scenarios and Operational Exercises

This appendix describes the simulator exercises used throughout the S-100 evaluation programme.

The scenarios were designed to:

- Evaluate individual S-100 products.
- Assess integrated navigation.
- Compare S-57 and S-100 performance.
- Investigate human factors.
- Support repeatable research.

Each scenario was validated before participant trials commenced to ensure consistency and repeatability.

C1 Overview of Trial Programme

The simulator programme consisted of five progressively more demanding navigation scenarios.

Scenario	Description	Primary Products
1	Passage Planning	S-57 / S-101
2	Coastal Navigation	S-101
3	Harbour Approach	S-101, S-102, S-104
4	Dynamic Environmental Navigation	S-111, S-124
5	Integrated Navigation	All Products

Table C.1: Operational trial scenarios and primary products evaluated

The scenarios were completed in sequence to allow participants to build confidence before evaluating the fully integrated S-100 environment.

C2 Scenario 1: Passage Planning

Comparing route planning using traditional S-57 Electronic Navigational Charts with the new S-101 Electronic Navigational Chart.

Learning Objectives

Participants should be able to:

- Create a safe route.
- Verify safety contours.
- Identify charted dangers.
- Configure ECDIS safety settings.
- Validate the planned route.

Scenario Description

The vessel is preparing for departure from a major commercial port.

Participants are required to produce a complete voyage plan using official Electronic Navigational Charts.

During the exercise they must:

- Select appropriate charts.
- Configure safety depth.
- Configure safety contour.
- Establish wheel-over positions.
- Validate the route.

Instructor Assessment

Assessment Area	Rating
Route Planning	_____
Safety Settings	_____
Chart Management	_____
ECDIS Operation	_____

Table C.2: Instructor assessment areas for Scenario 1: Passage Planning

Success Criteria

- Safe route completed.
- No unresolved route-check errors.
- Appropriate safety settings selected.
- Passage plan approved.

C3 Scenario 2: Coastal Navigation

Evaluating situational awareness during routine coastal navigation.

Operational Environment

- Moderate traffic
- Good visibility
- Daylight
- Moderate tidal stream

Tasks

Participants monitor:

- Position
- Cross Track Error
- Traffic
- Chart information
- Alarms

while maintaining the planned route.

Products Evaluated

- S-101
- Standard ECDIS functions

Instructor Observations

Focus on:

- Route monitoring
- Lookout
- Alarm management
- Situational awareness
- BRM

C4 Scenario 3: Harbour Approach

To assess S-102 Bathymetric Surface and S-104 Water Levels during restricted-water navigation.

Conditions

- Narrow channel
- Tidal port
- Deep-draught vessel
- Moderate crosswind

Navigation Tasks

Participants must:

- Monitor UKC.
- Interpret bathymetry.
- Assess tidal conditions.
- Maintain safe track.
- Communicate with the Pilot.

Products Used

Product	Purpose
S-101	ENC
S-102	Bathymetry
S-104	Water Levels

Table C.3: S-100 products used in Scenario 3: Harbour Approach

Assessment Criteria

- Safe speed
- UKC awareness
- Use of environmental data
- Communication
- Decision making

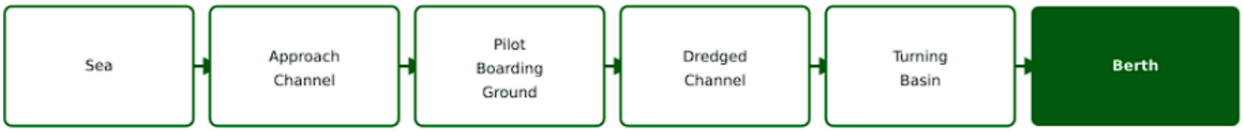

Figure C.1: Harbour-approach route from open sea to berth

C5 Scenario 4: Environmental Navigation

Evaluating dynamic environmental information.

Products

- S-111 Surface Currents
- S-124 Navigational Warnings

Exercise

Participants encounter:

- Changing tidal streams.
- Temporary navigation warnings.
- Increased traffic.
- Environmental restrictions.

They must determine:

- Whether the route remains safe.
- Whether speed should be altered.
- Whether ETA should be revised.

Instructor Measures

- Reaction time
- Route alterations
- Use of warnings
- Understanding of current effects

C6 Scenario 5: Integrated Navigation

Evaluating the complete S-100 environment.

Products Enabled

- S-101
- S-102
- S-104
- S-111
- S-124
- S-129

Navigation Situation

The vessel approaches a tidal port.

During the exercise the bridge team experiences:

- Cross current
- Falling tide
- Temporary dredging
- High traffic density
- Pilot boarding
- Dynamic UKC

Required Decisions

Participants must decide:

- Continue?
- Reduce speed?
- Alter route?
- Delay arrival?
- Request tug assistance?

Assessment Areas

Assessment	Score
Situational Awareness	_____
BRM	_____
Decision Making	_____
Use of S-100	_____
Workload Management	_____

Table C.4: Assessment areas for Scenario 5: Integrated Navigation

C7 Instructor Performance Matrix

Competency	Excellen t	Good	Satisfactory	Improvement Required
ECDIS Operation	☐	☐	☐	☐
Route Monitoring	☐	☐	☐	☐
Situational Awareness	☐	☐	☐	☐
BRM	☐	☐	☐	☐
Decision Making	☐	☐	☐	☐
Environmental Awareness	☐	☐	☐	☐

Table C.5: Instructor performance assessment matrix

C8 Debrief Questions

Following each exercise, instructors should discuss:

Navigation

- Which information was most useful?
- Which information was unnecessary?
- What influenced your decisions?

Human Factors

- Did workload increase or decrease?
- Was any information difficult to interpret?
- Were any displays confusing?

Product Evaluation

- Which product was most useful?
- Which requires improvement?
- Which products should be introduced first?

Future Development

- What additional information would be useful?
- How could the interface be improved?
- What training should future officers receive?

C9 Example Assessment Sheet

Exercise	Score
Passage Planning	_____
Route Monitoring	_____
Bathymetry	_____
Water Levels	_____
Surface Currents	_____
Warnings	_____
UKC	_____
Overall Performance	_____

Table C.6: Example simulator exercise assessment and scoring sheet

C10 Lessons Learned

Across all scenarios, several consistent observations emerged:

Operational

- Progressive familiarisation improved confidence.
- Integrated information supported decision-making.
- Participants valued graphical environmental information.

Human Factors

- Display clutter must be carefully managed.
- Bridge teams preferred configurable interfaces.
- Professional judgement remained central.

Training

Simulator-based learning proved highly effective.

Participants consistently recommended that future S-100 familiarisation should include practical bridge exercises rather than relying solely on classroom instruction.

Appendix C Summary

The simulator scenarios described in this appendix provide a structured framework for evaluating S-100 products under controlled and repeatable conditions. By documenting the objectives, environmental conditions, participant tasks and assessment criteria for each exercise, the appendix supports both transparency and repeatability, allowing other training organisations and research centres to replicate or adapt the programme.

Appendix D – Glossary, Acronyms and Technical Definitions

This appendix provides definitions of technical terms, abbreviations and concepts used throughout this report.

The terminology has been compiled from internationally recognized maritime publications, including IHO standards, IMO conventions and IEC documentation, to promote consistent interpretation of the S-100 framework.

D1 Acronyms

Acronym	Definition
AIS	Automatic Identification System
API	Application Programming Interface
BRM	Bridge Resource Management
CATZOC	Category Zone of Confidence
COLREGs	International Regulations for Preventing Collisions at Sea
DGPS	Differential Global Positioning System
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Navigational Chart
ETA	Estimated Time of Arrival
GNSS	Global Navigation Satellite System
HO	Hydrographic Office
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organization
IMO	International Maritime Organization

Acronym	Definition
INS	Integrated Navigation System
MSI	Maritime Safety Information
NAVAREA	Navigational Area for MSI broadcasts
NAVTEX	Navigational Telex Service
OOW	Officer of the Watch
PPU	Portable Pilot Unit
RNC	Raster Navigational Chart
SOLAS	International Convention for the Safety of Life at Sea

Table D.1: Maritime, navigation and S-100 acronyms used in the report

D2 Product Specifications

S-100

Universal Hydrographic Data Model

The International Hydrographic Organization framework supporting interoperable hydrographic and maritime information products.

S-101

Electronic Navigational Chart Product Specification

The successor to S-57 Electronic Navigational Charts, providing enhanced flexibility, improved portrayal and future extensibility.

S-102

Bathymetric Surface Product Specification

Provides high-resolution bathymetric surfaces allowing continuous visualization of seabed morphology.

S-104

Water Level Information Product Specification

Provides dynamic tidal and water level information integrated directly within ECDIS.

S-111

Surface Currents Product Specification

Provides graphical representation of surface current direction and velocity.

S-124

Navigational Warnings Product Specification

Supports machine-readable navigational warnings referenced directly to geographic locations.

S-128

Catalogue of Nautical Products

Provides information describing the availability, compatibility and management of S-100 products.

S-129

Under Keel Clearance Management

Supports dynamic assessment of available under-keel clearance using integrated hydrographic and environmental data.

D3 Hydrographic Terminology

Bathymetry

Measurement and representation of water depth and seabed features.

Contour

A line joining points of equal depth.

Depth Area

An area bounded by depth contours within an Electronic Navigational Chart.

Depth Contour

A line connecting locations of equal water depth.

Dredged Channel

A channel maintained to a specified depth by dredging.

Safety Contour

The contour selected within ECDIS to distinguish safe from potentially unsafe water.

Safety Depth

A user-defined depth used by ECDIS to emphasize soundings that may present a danger.

Spot Sounding

An individual measured depth shown on a nautical chart.

D4 Navigation Terms

Cross Track Error (XTE)

The perpendicular distance between the vessel's current position and the planned route.

Wheel-Over Position

The calculated position at which a vessel should commence a turn to follow the planned route.

Pilotage

Navigation conducted with the assistance of a licensed maritime pilot.

Route Monitoring

Continuous assessment of vessel progress against the planned route.

Passage Planning

The process of preparing a safe voyage from berth to berth.

D5 Human Factors

Automation Bias

The tendency to place excessive trust in automated systems.

Cognitive Workload

The mental effort required to process information and make operational decisions.

Decision Support

Information provided to assist human decision-making without replacing professional judgement.

Human-Centred Design

A design philosophy that places the needs and capabilities of users at the centre of system development.

Situational Awareness

The perception, comprehension and projection of information relating to the operational environment.

D6 Environmental Terms

Dynamic Water Level

A water level that changes over time due to tidal and meteorological influences.

Flood Tide

The period during which water levels are rising.

Ebb Tide

The period during which water levels are falling.

Surface Current

The movement of water at or near the sea surface caused by tides, wind or ocean circulation.

Squat

The increase in vessel draught caused by movement through shallow water.

D7 Bridge Resource Management

Bridge Resource Management (BRM) is the effective management of all available resources, including:

- Personnel
- Equipment
- Information
- Procedures

to ensure safe navigation.

The simulator programme demonstrated that S-100 products have the potential to support BRM by improving the availability and consistency of navigational information.

D8 Symbols Used in This Report

Symbol	Meaning
✓	Recommended practice
⚠	Operational caution
ℹ	Additional information
★	Key finding
►	Recommendation

Table D.2: Symbols used in the report

D9 Reference Standards

The terminology and concepts used throughout this report are aligned, where applicable, with the following international standards and guidance:

- IHO S-100 Universal Hydrographic Data Model
- IHO S-101 Product Specification
- IHO S-102 Product Specification
- IHO S-104 Product Specification
- IHO S-111 Product Specification
- IHO S-124 Product Specification
- IHO S-129 Product Specification
- IMO SOLAS Convention, Chapter V
- IMO e-Navigation Strategy Implementation Plan
- IEC 61174 – Electronic Chart Display and Information Systems (ECDIS)
- STCW Convention and Code

D10 Glossary Index

Term	Page*
Automation Bias	**94**
Bathymetry	**93**
Bridge Resource Management	**95**
Cognitive Workload	**94**

Term	Page*
Decision Support	94
ECDIS	91
ENC	91
Human-Centred Design	94
S-100	92
S-101	92
S-102	92
S-104	92
S-111	93
S-124	93
S-128	93
S-129	93
Situational Awareness	95
Under Keel Clearance	93

Table D.3: Glossary terms and corresponding page references in Appendix D

Appendix D Summary

This glossary provides a consistent reference for the terminology used throughout the report and supports a common understanding of the S-100 framework. It is intended to assist readers from a wide range of maritime backgrounds, including navigators, instructors, software developers, hydrographic specialists and regulators.

Appendix E – References and Bibliography

This appendix lists the principal international standards, guidance documents, technical specifications and selected academic publications that informed the research described within this report.

The references have been organised by subject area to assist readers wishing to undertake further study of the S-100 framework, ECDIS implementation and digital maritime navigation.

Unless otherwise stated, readers should consult the latest published editions of the documents referenced below.

E1 International Hydrographic Organization (IHO)

The following IHO publications provide the technical foundation for the S-100 framework and associated product specifications.

Core Standards

- International Hydrographic Organization. S-100 – Universal Hydrographic Data Model.
- International Hydrographic Organization. S-97 – Guidance for Creating S-100 Product Specifications.
- International Hydrographic Organization. S-98 – Interoperability Specification for S-100 Navigation Products.

Product Specifications

- IHO S-101 – Electronic Navigational Chart Product Specification.
- IHO S-102 – Bathymetric Surface Product Specification.
- IHO S-104 – Water Level Information Product Specification.
- IHO S-111 – Surface Currents Product Specification.
- IHO S-122 – Marine Protected Areas Product Specification.
- IHO S-123 – Marine Radio Services Product Specification.
- IHO S-124 – Navigational Warnings Product Specification.
- IHO S-128 – Catalogue of Nautical Products Product Specification.
- IHO S-129 – Under Keel Clearance Management Product Specification.
- IHO S-131 – Marine Harbour Infrastructure Product Specification.
- IHO S-164 – Test Data Sets for S-100 ECDIS.

Supporting Standards

- IHO S-4 – Regulations for International Charts.
- IHO S-44 – Standards for Hydrographic Surveys.
- IHO S-52 – Specifications for Chart Content and Display Aspects of ECDIS.
- IHO S-57 – Transfer Standard for Digital Hydrographic Data.
- IHO S-58 – Validation Checks for ENCs.
- IHO S-63 – Data Protection Scheme.
- IHO S-65 – ENC Production Guidance.

E2 International Maritime Organization (IMO)

The following IMO publications provide the regulatory framework supporting electronic navigation and ECDIS.

Conventions

- International Convention for the Safety of Life at Sea (SOLAS), Chapter V – Safety of Navigation.
- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), as amended.

Performance Standards

- IMO Performance Standards for Electronic Chart Display and Information Systems (ECDIS).
- IMO Performance Standards for Integrated Navigation Systems (INS).

Guidance

- IMO e-Navigation Strategy Implementation Plan.
- IMO Guidelines on ECDIS Training.
- IMO Bridge Procedures Guide (where applicable through industry guidance).

E3 International Electrotechnical Commission (IEC)

Relevant IEC standards include:

- IEC 61174 – Electronic Chart Display and Information Systems (ECDIS).
- IEC 62288 – Presentation of Navigation Information on Shipborne Displays.
- IEC 60945 – Maritime Navigation and Radiocommunication Equipment.
- IEC 61924 – Integrated Navigation Systems.

E4 Hydrographic Offices

Readers are encouraged to consult publications from recognized Hydrographic Offices, including:

- United Kingdom Hydrographic Office (UKHO).
- Norwegian Hydrographic Service.
- Australian Hydrographic Office.
- NOAA Office of Coast Survey.
- Canadian Hydrographic Service.

These organisations continue to publish guidance and implementation material relating to S-100 products.

E5 Academic Literature

The following subject areas are recommended for further study.

Human Factors

- Human factors in bridge design.
- Cognitive workload in navigation.
- Situational awareness in maritime operations.
- Automation bias in safety-critical systems.

Electronic Navigation

- Development of ECDIS.
- Integrated bridge systems.
- Decision support in navigation.
- Digital hydrographic information.

Simulator Research

- Full Mission Bridge Simulator validation.
- Maritime simulation methodology.
- Training effectiveness.
- Competency assessment.

E6 Industry Publications

Readers may also find the following sources valuable:

- BIMCO Guidance.
- ICS publications.
- Nautical Institute reports.
- OCIMF guidance.
- IALA recommendations.
- EMSA technical studies.
- ECDIS Procedures Guide 2026-2027 Edition Volumes 1-6.

E7 Online Resources

For the latest versions of standards and guidance, consult the official websites of:

- International Hydrographic Organization (IHO)
- International Maritime Organization (IMO)
- International Electrotechnical Commission (IEC)
- European Maritime Safety Agency (EMSA)
- United Kingdom Hydrographic Office (UKHO)

Always verify that you are using the current published edition of any referenced document.

E8 Suggested Reading

For readers wishing to develop a broader understanding of digital maritime navigation, the following themes are recommended.

Electronic Navigation

- Evolution of ECDIS.
- ENC production.
- Chart portrayal.
- Sensor integration.

Hydrography

- Hydrographic surveying.
- Bathymetric modelling.
- Marine geospatial data.
- Data quality assessment.

Human Factors

- Bridge Resource Management.
- Decision making.
- Fatigue.
- Alarm management.
- Human-centred design.

Emerging Technologies

- Artificial Intelligence.
- Maritime autonomy.
- Voyage optimisation.
- Digital twins.
- Cybersecurity.
- Maritime cloud services.

E9 Citation Style

To maintain consistency throughout this publication, references should follow a recognized citation standard such as ISO 690 or APA 7th Edition.

Each reference cited in the text should correspond to an entry in this bibliography, and all figures, tables and diagrams adapted from external sources should include appropriate attribution.

E10 Document Cross-Reference Matrix

Chapter	Primary References
Chapter 1 – Introduction	IHO S-100, S-57, SOLAS V
Chapter 2 – Research Design	Human factors literature, simulator methodology
Chapter 3 – Simulator Facilities	IEC 61174, IEC 62288
Chapter 4 – Operational Findings	Survey data, simulator observations
Chapter 5 – Product Evaluation	S-101, S-102, S-104
Chapter 6 – Integrated Navigation	S-111, S-124, S-129
Chapter 7 – Human Factors	BRM, STCW, human factors research
Chapter 8 – Implementation	IMO, IHO, IEC guidance
Chapter 9 – Conclusions	All referenced publications

Table E.1: Cross-reference between report chapters and primary sources

Appendix E Summary

The publications listed in this appendix provide the technical, regulatory and operational foundation for the work presented in this report. Together they demonstrate that the evaluation has been conducted within the context of internationally recognised standards and established maritime best practice.

Future editions of this report should review and update the bibliography as new editions of S-100 product specifications, IMO guidance and IEC standards become available.

Appendix F – Executive Action Plan and Implementation Checklist

This appendix provides practical guidance for organisations preparing to implement the S-100 framework.

The recommendations contained within this appendix are based upon the findings of the simulator evaluation programme and are intended to support safe, structured and internationally consistent implementation.

The appendix is organised by stakeholder group, recognising that successful implementation depends upon collaboration between Hydrographic Offices, equipment manufacturers, shipping companies, maritime training providers and regulators.

F1 Executive Summary

The simulator programme identified three fundamental requirements for successful implementation.

Technology:

- Reliable S-100 products integrated within compliant ECDIS equipment.

Training:

- Competent bridge teams familiar with both the technology and its operational application.

Governance:

- Clear company procedures supported by internationally harmonised standards.

Only when these three elements are combined can the full operational benefits of S-100 be realised.

F2 Implementation Roadmap

Phase 1: Awareness

Objective:

- Develop organisational understanding of S-100.

Activities:

- Senior management briefing.
- Technical workshops.
- Review current ECDIS capability.
- Assess fleet readiness.
- Review manufacturer roadmaps.

Deliverables:

✓ Awareness established

✓ Project sponsor appointed

Phase 2: Preparation

Activities:

- Update navigation procedures.
- Review bridge checklists.
- Identify training requirements.
- Develop familiarisation programme.
- Plan software upgrades.

Deliverables:

✓ Procedures updated

✓ Training programme approved

✓ Fleet implementation schedule prepared

Phase 3: Training

Provide training covering:

- S-100 Framework
- S-101
- S-102
- S-104
- S-111
- S-124
- S-129
- Human Factors

Training should include classroom instruction followed by simulator exercises.

Phase 4: Operational Trials

Recommended approach:

- Begin with selected vessels.
- Collect user feedback.
- Refine procedures.
- Repeat.
- Expand.
- Avoid fleet-wide implementation without operational validation.

Phase 5: Fleet Rollout

Following successful evaluation:

- Install software.
- Verify configuration.
- Conduct onboard familiarization.
- Monitor performance.
- Record lessons learned.

Recommended S-100 Implementation Model

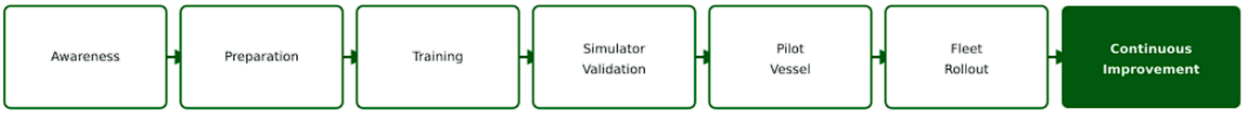

Figure F.1: Phased S-100 implementation pathway from awareness to continuous improvement

F3 Shipping Company Checklist

Management

☐ Appoint project manager

☐ Identify implementation budget

☐ Establish project timeline

☐ Review fleet compatibility

☐ Engage equipment manufacturer

Bridge Procedures

☐ Update Navigation Procedures

☐ Review Passage Planning

☐ Update UKC Policy

☐ Update BRM Procedures

☐ Update Emergency Procedures

Training

☐ Management briefing

☐ Instructor training

☐ Officer familiarisation

☐ Simulator assessment

☐ Refresher programme

F4 Training Provider Checklist

Training organisations should ensure that courses include:

☐ Introduction to S-100

☐ Product specifications

☐ Simulator familiarisation

☐ Human factors

☐ Practical pilotage

☐ UKC assessment

☐ Environmental information

☐ Assessment

F5 Hydrographic Office Checklist

Recommended priorities:

☐ Bathymetric quality assurance

☐ Product validation

☐ Metadata review

☐ Data harmonisation

☐ User feedback programme

☐ Interoperability testing

☐ Cross-border coordination

F6 ECDIS Manufacturer Checklist

Recommended development priorities:

☐ Improve interface consistency

☐ Reduce display clutter

☐ Improve layer management

☐ Context-sensitive displays

☐ Dynamic filtering

☐ Improve alarm management

☐ User testing

☐ Human-centred design

F7 Risk Register

Risk	Likelihood	Impact	Mitigation
Poor training	**Medium**	**High**	Simulator familiarisation
Display clutter	**Medium**	**High**	Improved interface design
Automation bias	**Low**	**High**	Human factors training
Software inconsistency	**Medium**	**Medium**	Compliance testing
Data quality issues	**Low**	**High**	Hydrographic QA processes
Resistance to change	**Medium**	**Medium**	Progressive implementation

Table F.1: S-100 implementation risk register

F8 Success Indicators

Implementation should be monitored using measurable performance indicators.

Suggested Key Performance Indicators include:

KPI	Target
Officers trained	**100%**
Simulator familiarization completed	**100%**
Bridge procedures updated	**100%**
Fleet software upgraded	**Planned schedule achieved**
User satisfaction	**>85%**
Operational incidents attributable to S-100	**Zero**

Table F.2: Key performance indicators for S-100 implementation

F9 Lessons for Future Projects

The simulator programme demonstrated several broader lessons that are applicable to future digital navigation initiatives.

Lesson 1

Technology should simplify operational tasks.

Lesson 2

Training should precede implementation.

Lesson 3

Users should remain involved throughout development.

Lesson 4

Operational trials provide valuable evidence before fleet-wide deployment.

Lesson 5

Continuous feedback improves long-term success.

F10 Final Statement

The successful implementation of S-100 is not simply a software upgrade.

It represents an organisational change affecting:

- Technology.
- Training.
- Procedures.
- Human performance.
- Safety management.

The findings of this research demonstrate that, when introduced in a structured and user-centred manner, the S-100 framework has the potential to improve navigational safety, operational efficiency and bridge team decision-making across the global maritime industry.