Paper for Consideration by [Council meeting]

[S-100 testbed project in 2022]

Submitted by:	KHOA, NOAA
Executive Summary:	By using the S-100 Testbed, this paper reports the technical details such as S-98/Dual Fuel concept/S-128 implementation and quantitative analysis results for the use of S-100 based product service.
Related Documents:	Roadmap for the S-100 Implementation Decade (2020–2030) C5-07.6A INF - KHOA (ROK) & NOAA (US) Information on S-100 Testbed Project, Decisions and Actions C5/60
Related Projects:	S-100 Testbed project of KHOA

Introduction / Background

1. The 5th IHO Council meeting noted the approach proposed by the S-100 Testbed project to quantitatively measure the efficiency of using the S-100 based product service. The Council invited the Member States to join the project and suggested other qualitative measures such as safety of navigation and efficiency as appropriate.

Analysis/Discussion

S-100 Testbed plan of KHOA

2. In consideration of the requirements for the S-100 development and Decision C5/60, KHOA tested the technical issues of S-100 and the usability and economic efficiency of the S-100 based product service.

Technical issues of S-100 (See Annex A for details)

3. The S-98 interoperability is essential for the integrated operation and harmonized display of S-10x data. The S-98 Edition 1.0.0 was released for testing in May 2022. Meanwhile, for the stable implementation of the S-10X product specifications, a Duel Fuel governance document has been published, and a technical guideline for Dual Fuel mode will be prepared.

4. The technical issues of S-100 are composed of the application of the S-98 interoperability catalogue, which is the core of the S-100 Implementation Roadmap, the Dual Fuel concept, and the up-to-dateness of navigation products using the S-128 Catalogue of Nautical Products.

(1) S-98 Interoperability

The S-100 Testbed successfully combined interoperability functions into S-100 ECDIS simulation system and the KHOA Viewer for testing according to S-98 Part A and Part B. The testbed applied interoperability catalogue from the ROK-USA joint project (from 2020 to 2021) and we checked S-101, S-102, S-111, S-124 and S-12X NPUB data overlays based on the Interoperability Catalogue.

Executive test summary and recommendation
- ROK-US joint project is improving the S-98 IC (Interoperability Catalogue) and it will be useful for OEMs and related stakeholders. - S-98 IC applied for harmonized display between S-10X data and scenario-based TDS for levels 1 and 2 are required. Current version of the draft IC needs to be refined. - We recommend taking S-98 IC as a part of S-164 TDS for type approval.

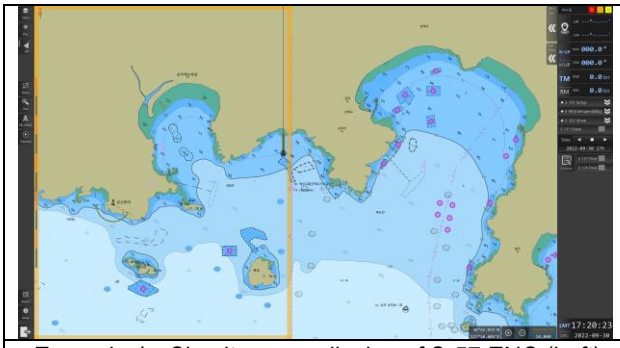
(2) DF-mode in S-100 testbed system

According to the Dual Fuel governance document, items below are applied to the S-100 ECDIS simulation system.

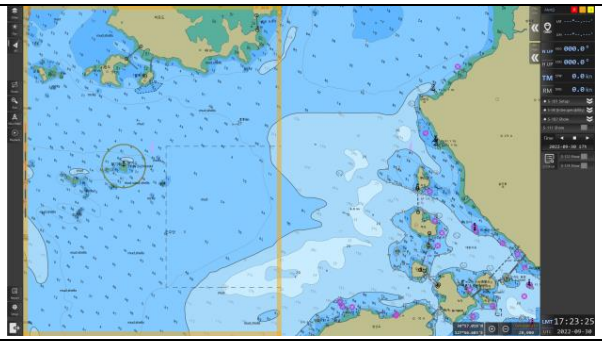
- S-101 ENC has priority over S-57 ENC
- Display of S-57 ENC in areas without S-101 ENC

- When S-57 ENC is displayed on screen, it is indicated that S-57 ENC is shown
- When S-57 ENC and S-101 ENC are displayed at the same time, the boundary between the datasets is displayed
- Ensure that the symbols and colours between S-57 ENC and S-101 ENC are the same

For other guidance, refer to the S-98 Annex.
Loading both S-57 and S-101 ENC went well. However, the symbol colours and chart display scale were different. You can see the adjacent area of two different types of chart very clearly. Therefore, we adjusted the colour table and chart display scale based on the Dual Fuel governance, and the boundary of S-57 has been added as well.

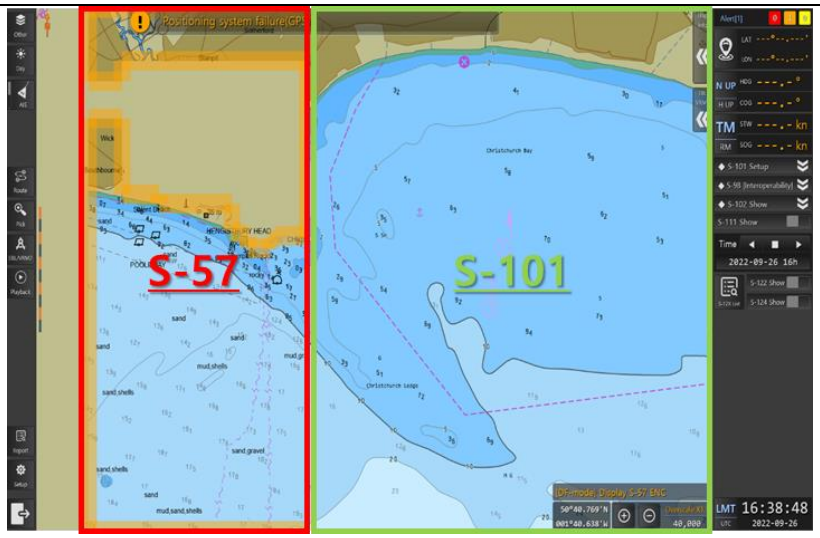


Example 1 - Simultaneous display of S-57 ENC (Left) and S-101 ENC (Right)



Example 2 - Simultaneous display of S-57 ENC (Left) and S-101 ENC (Right)

UKHO contributed their S-100 based data sets for Dual Fuel concept test. The picture below shows S-57 and S-101 ENC at the same time.

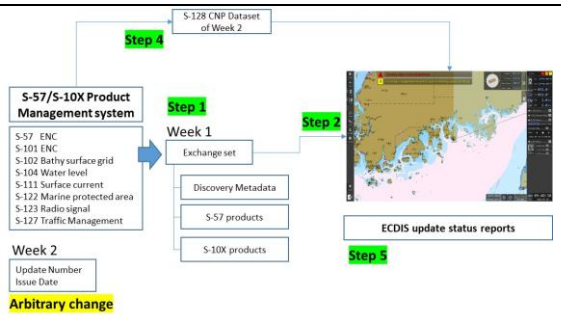


Simultaneous display of S-57 and S-101 ENC

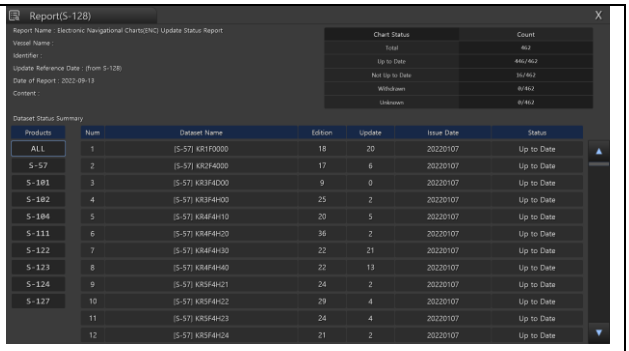
Executive test summary and recommendation
- The S-98 Annex C – Dual Fuel (DF) concept needs to be clearer to ensure that the industry can develop the DF mode of the S-100 navigation system consistently. - S-98 should include defined rules to display seamless portray of two different types of ENCs such as symbol color, connection of shoreline, display of specific feature types in curve and polygon - It is important to match S-52 PL 4.0 and S-101 PC so that colors and symbols are displayed not differently in the S-100 navigation system - S-98 needs to provide the technical guideline for indicating the boundaries between S-57 ENC and S-101 ENC when they are simultaneously on the screen

(3) Up-to-dateness of S-100 data using the S-128 CNP

The Testbed produced the S-128 TDS and checked the up-to-dateness of products on the S-100 navigation system. Through the chart manager function of the S-100 navigation system, checking and filtering products whether they are up-to-date or not can be distinguished. The figure below shows the process for verifying the up-to-dateness using the S-128 dataset and S-100 data update status report in the S-100 navigation system. The update status report was developed according to the S-98 Annex C guidelines.



Process for verifying the up-to-dateness using S-128



S-100 data update status report

Executive test summary and recommendation
- There was no issue for the S-128 data model while verifying the up-to-dateness - Detailed scenarios for short interval products S-104 and S-111 should be defined - S-98 Annex C guideline of S-100 data update status report for S-100 navigation system needs to be improved for its details - The test bed proposes the way to produce S-128 TDS by considering different S-100 products and occasions (new, re-issue, update and cancel), and to apply it as the S-164 TDS.

Usability test of S-100 service (See Annex B for details)

5. On the assumption that the amount of the distributed information to a mariner is 100, we compare the information that the mariner uses with S-57 ECDIS and other navigation purpose materials versus S-100 ECDIS to measure how much the usability of information increases.

6. The usability test quantitatively measures the improvement effect, advantage and utility that we expect using the S-100 based product service from the user's perspective. The research team evaluated the utility/usability using the S-100 based product service in the marine environment.

(1) Usability test background

- Purpose: Evaluate the usability of the newly introduced S-100 based product service compared to traditional hydrographic products
- Testing procedure: Assignment of voyage planning missions with different levels of difficulty between "Busan↔Jeju" and "Incheon↔Pyeongtaek" routes. (4 courses in total)
- Testing participants: 10 mariners (8 male and 2 female, average of 30 years old) with more than 3 years of navigation experience
- Measuring equipment: S-57 ECDIS, S-100 testbed system and eye tracker

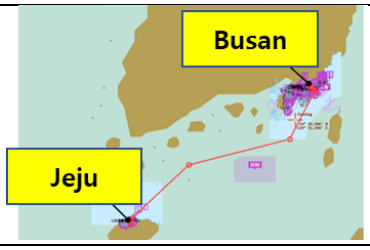
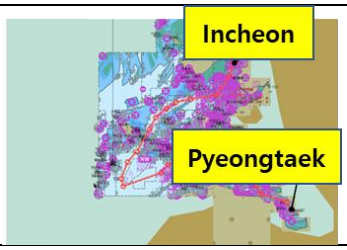
S-57 ECDIS

S-100 Testbed system

Eye tracker

Fig. 1 Usability testing procedure of S-100 based product service

- Testing scenario

Detailed scenario	Busan↔Jeju	Incheon↔Pyeongtaek
- Task 1. Update of nautical products - Task 2. Navigational warning - Task 3. Route planning - Task 4. Check the surface current of the arrival port - Task 5. Confirm route and save		

(2) Indicators

- Qualitative evaluation indicators: Questionnaire for subjective discomfort (visual, control, total), 7 points scale for visual and control discomfort (from 1 for very comfortable to 7 for very uncomfortable), 100 scores scale for total discomfort
- Quantitative evaluation indicators: Utilization of eye tracking data to track eye movements during conducting each task by participants.

(3) Test results

A. Qualitative evaluation results

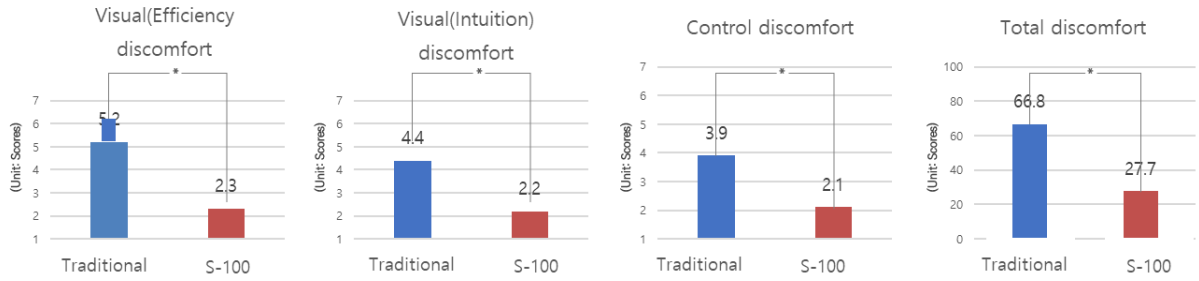


Fig. 2. Result of subjective comfort evaluation

- Visual (efficiency) discomfort: 5.2 for traditional products and 2.3 for S-100 based product service, more comfortable in the S-100 based product service
- Visual (intuition) discomfort: 4.4 for traditional products and 2.2 for S-100 based product service, more comfortable in the S-100 based product service
- Control discomfort: 3.9 for traditional products and 2.1 for S-100 based product service more comfortable in the S-100 based product service
- Total discomfort: 66.8 for traditional products and 27.7 for S-100 based product service, more comfortable in the S-100 based product service

B. Quantitative evaluation results (eye tracker measurement)

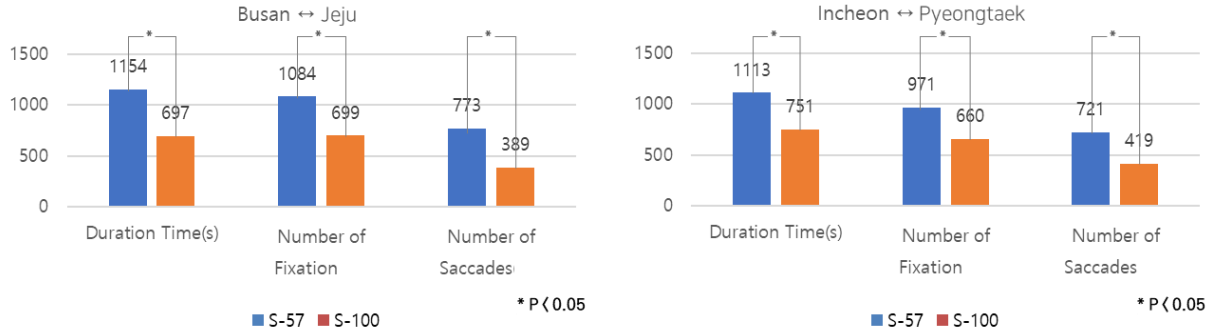


Fig. 3 Measuring results of quantitative evaluation using eye tracker equipment

- Measuring value using eye tracker: Duration time, Number of Fixation, Number of Saccades
- When comparing data by item according to equipment, a significant difference was confirmed at the significance level of 0.05
- Duration time: It measures taken to perform a task, and the smaller it is, the faster the task is performed (task execution time: S-57 > S-100)
- Number of Fixation: In AOI, the number of fixed gazes is smaller, meaning more efficient search/recognition (number of gaze fixations: S-57 > S-100)
- Number of Saccades: It indicates the number of instantaneous gaze movement, and the smaller it is, the less the gaze movement (number of gaze movement: S-57 > S-100)

C. Result summary

- The subjective discomfort level of S-100 based product service was smaller compared to the traditional products (S-57 ENC and nautical publications)
- The level of duration time, number of fixation and number of saccades for S-100 based product service is more efficient compared to the traditional products
- The usability of S-100 based product service is excellent, and in particular, compared to the traditional products, it has a higher usability in nautical products update, navigation warnings, checking surface current in the arrival port

Fig. 4. Usability test

7. According to the marine accident report by the Korean government, 86% of the accidents occurred in coastal areas (territorial sea) for the last five years. As for the cause of accidents, about 45% are collisions, shipwrecks, and capsizing which are considered to be human-affected. Therefore, we expect that digitalization and automation through the increase of machine-readability with S-100 based product services can reduce the probability of human errors, and this will allow us to navigate safer.

Economic efficiency of S-100 based product service (See Annex C for detailed report)

8. The efficiency test is a quantitative evaluation of the economic feasibility of using S-100 based product services in a ship operating environment. By applying dynamic and time-varying products, the optimal scenario to understand the economics of operation will be derived, and economic efficiency will be measured through a ship handling simulator or simulation operation program based on S-10X datasets.

(1) Possible factors to measure the ship navigation efficiency

From the perspective of the ship operator, the navigation plan focuses on the safety of the passage of the ship, and the indicators related to the operation efficiency can be organized into the navigation distance, the time required according to the speed, fuel consumption, and the operation time. The route planning targets how to reach to the destination safely and economically. Major considerations include provision and update of nautical products, no-go area zones, margins of safety distance, and marine navigation facilities such as Aton and entry/exit port information.

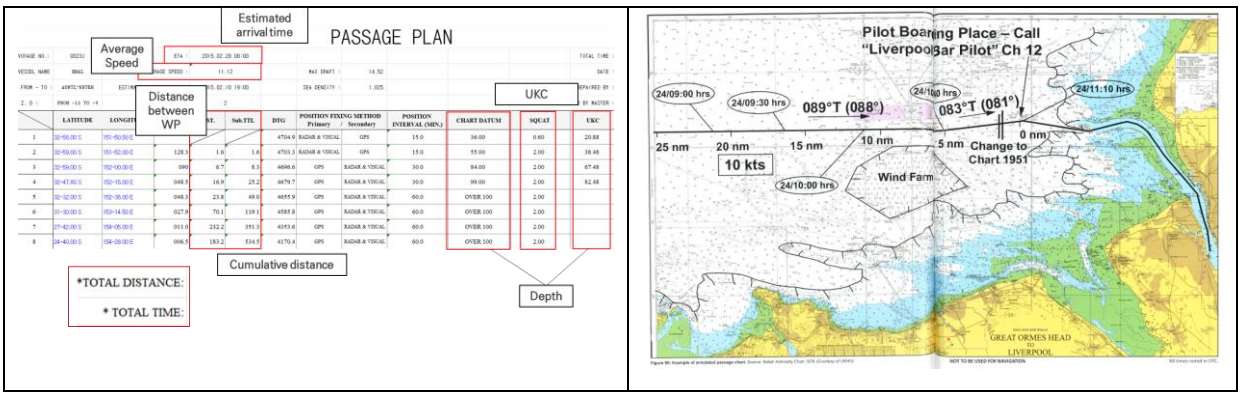
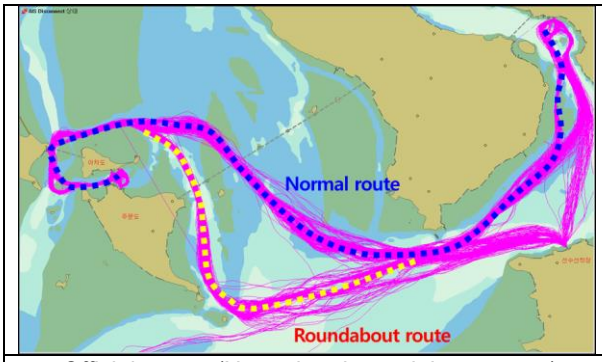


Fig. 5 Example of route planning

(2) Economics analysis of official routes for coastal passenger ships

The western coast of Korea (Incheon) is a region with strong tides, and two official routes are operated depending on high tide and low tide for passenger ship operations between islands. The figure below shows the normal and roundabout routes of a passenger ship called Sambo operating between Oepo ↔ Jumun Wharf in Incheon. The ferry operates 6 rounds a day and 2,190 rounds a year.



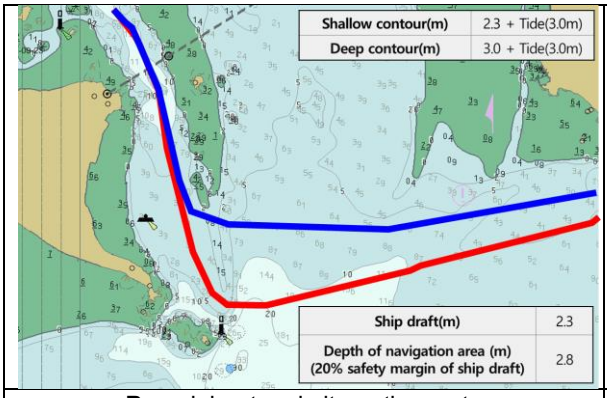
Official routes (Normal and roundabout routes)

Num	Jumun Departure	Oepo Departure
1	07:00	08:50
2	11:00	12:50
3	14:30	16:20

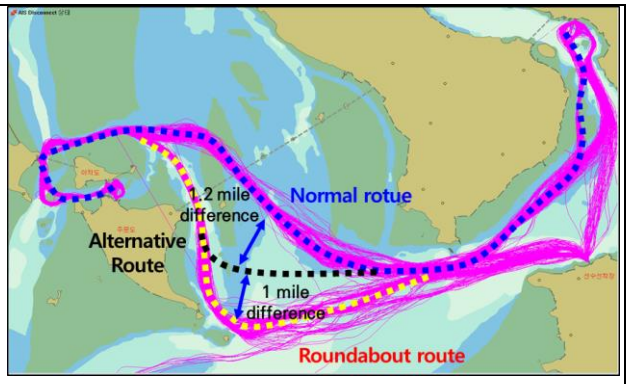
Passenger ship schedule

A normal route is a one used at high tide, and an official roundabout route is a one used at low tide. In case of using S-100 based product service (S-102 bathy + S-104 water level), it would be possible to identify an alternative route with a shorter distance while being safe for the roundabout route used at low tide.

With S-100 based product service, we could search alternative routes which is shorter and still safe than the official roundabout route operated at low tide. Travel time and distance were calculated.



Roundabout and alternative route



Distance difference between normal, roundabout and alternative route

The official roundabout was 4,157m while the alternative route using the S-100 based product service was calculated to be 2,306m. Since the passenger ship, Sambo uses the official roundabout average 1,196 times per year. We conclude that using S-100 based product can help to save cost about 124k USD (45.5% savings) per year.

Assuming that the fuel consumption per hour is 1,000 liters and the fuel cost per liter is calculated as $1.25, the formula for economic analysis of operation efficiency can be applied as follows

(Route distance) X (numbers of roundabout/alternative route navigation) / (vessel speed – 12kn) X (fuel consumption per hour) X (fuel cost per liter)

Passenger ship Route	Roundabout route	Alternative route explored using S-100 data service
Estimated distance (m)	4,157	2,306
Distance difference between normal and roundabout/ alternative(NM)	2.2	1.2
Total number of navigation	2,190 rounds	
Expected number of roundabout/alternative route	1,196 rounds	
Fuel consumption per hour	1,000 liters	
Fuel cost per liter	$1.25 per liter (include 0.01% MGO tax)	
Economics analysis of coastal passenger ships	(Route distance) X (Numbers of Roundabout/Alternative route navigation) / (Vessel speed – 12kn) X (Fuel consumption per hour) X (Fuel cost per liter)	
	(A) **$273,209**	(B) **$149,023**
	(A) - (B) = **$124,186 (45.5% savings)** Total annual cost savings of $124,186 (45.5% savings) would occur when the alternative route was used	

In addition, the official route change of coastal passenger ships was also used for economic analysis. In the 2022 S-100 test bed operation, for the quantitative evaluation of the economic feasibility of the S-100 based product service, alternative routes for coastal passenger ships were searched according to tidal water level, and operational efficiency economic feasibility analysis was conducted. It is assumed that there will be an effect on surface current such as tidal currents and ocean currents during long-distance voyages between international navigations, and it is necessary to analyse the economic feasibility of ship operation in terms of surface current.

Please refer to Annex A, Annex B and Annex C for detailed test reports of KHOA's 2022 S-100 testbed

Conclusions

KHOA improved the S-100 testbed system to check the technical aspects of the S-100 (S-98, DF concept, S-128 up-to-dateness). In addition, KHOA designed a quantitative analysis procedure for the usability and economic efficiency of S-100 based product service and summarized the research. According to the test result, we conclude using S-100 based product service can bring higher usability compared to the traditional products in terms of updating nautical products and integrating required information. Economic efficiency can be improved by exploring a safer and shorter route than the existing one by using dynamic products KHOA would like to invite interested Member States to participate in the technical test and the evaluation of the usability and efficiency of S-100 based product services and any kind of feedbacks to improve the test bed.

Action Required of [Council meeting]

The [Council meeting] is invited to:

a. note the results of the S-100 test bed project conducted by KHOA in 2022.

b. invite Member States to participate in the S-100 Testbed

Annex A. Report on technical issues of S-100

(1) S-98 Interoperability

The S-98 is a standard for interoperability of different products in the S-100 navigation system, and includes technical matters that should be referred to during the interoperability application stage and ECDIS development. KHOA newly developed the S-100 test bed system for the operation of the S-100 testbed in 2022, and in particular, prepared the interoperability catalogue application function according to S-98 Part A and Part B.

KHOA and NOAA carried out a joint project for cooperation in supporting the development of S-100 standards, and in particular, researched the S-100 interoperability catalogue in 2020 and 2021. In 2022, we analysis interoperability of S-10X products based on S-98 Level 1 and Level 2 application, and drafted draft interoperability catalogue, and conducted tests with the catalogue on the S-100 test system.

We have three application levels of the S-98 interoperability catalogue in the S-100 test system.

- Level 0: Switched off – no interoperability
- Level 1: Level 1 interleaving of features at a portrayal level
- Level 2: Substitution of feature classes for another based on available layers under Level 2.

The following are included as the types of S-10X products applied in the interoperability research.

- S-101 ENC data as the base layer, which may be replaced by S-57 ENC data where S-101 data is not available. Raster navigational chart (RNC) may be displayed if neither is available. In S-98, a clear priority is given to the S-101 data over the equivalent S-57 cells.
- Radar, ARPA and AIS target data overlays.
- Own ship information such as own ship symbol, heading and course information, safety contours, alerts and highlights caused by interaction or course with other data.
- Mariner-plotted information such as mariner-plotted hazards.
- S-102 Bathymetric Surface (Edition 2.0.0 and later).
- S-104 Water Level information for Surface Navigation.
- S-111 Surface Currents.
- S-124 Navigational Warnings.
- S-129 Underkeel Clearance.
- S-421 Route Plan.

The project considered the products that can be applied as additional data according to the user's selection also:

- S-122 Marine Protected Areas.
- S-123 Marine Radio Services.
- S-127 Marine Traffic Management.
- S-131 Marine Harbour Infrastructure.
- S-412 Weather and Wave Hazards

The project identified the products that would be useful to apply into the S-100 ECDIS system in the future :

- S-125 Marine Navigational Services.
- S-126 Marine Physical Environment.
- S-128 Nautical Product Catalogue.
- S-413 Weather and Wave Conditions
- S-414 Weather and Wave Observations

The interoperability between S-10X products and the display priority are summarized as below.

Data Groupings (*italics* - data other than S-101)	Drawing Priorities (0-9 scale)	Drawing Priorities (0-27 scale - GI Registry)	Drawing Priorities (proposed)
no S-101 data filled area pattern	0	0	0
Reserved	---	---	1-8
S-101 Skin of the earth filled areas *S-102 bathymetry coverages*	1	3	10-19
superimposed areas *S-123 radio service areas* *S-412 weather (non-hazardous)*	2, 3	6, 9	20-39
restricted area *S-122 protected areas*	5	15	50-59
traffic areas VTS areas *S-129 go/no-go areas* *S-127 traffic areas*	6	18	60-69
land features	4, 5	12, 15	40-59
water features *S-111 surface currents coverages* *S-104 water levels coverages* *S-411 sea ice*	3, 4, 5, 6	9, 12, 15, 18	30-69
coastline features	5, 6, 7	15, 18, 21	50-79
routeing lines *S-127 routeing lines*	5, 6, 7	15, 18, 21	50-79
symbols for lines and areas	4, 5, 6	12, 15, 18	40-69
hazards (bridge, safety contour) *S-124 navigational warnings* *S-102 safety contour* *S-412 hazards and storms*	8	24	80-89
Aids to navigation	8	24	80-89
Text *Operating times (schedules, etc.)*	8	24	80-89
Mariners VRM & EBL *S-421(?)*	9	27	90-98
own ship	9	27	99

In the detailed mapping table for each feature type, the feature code, interoperability application level, and viewing group, viewing group layer, display priority, additional comments and actions of the S-10 X product are described.

The Testbed applied interoperability catalogue from the ROK-USA joint project (from 2020 to 2021) and we checked S-101, S-102, S-111, S-124 and S-12X NPUB data overlays based on the Interoperability Catalogue.

Executive test summary and recommendation
- ROK-US joint project is improving the S-98 IC (Interoperability Catalogue) and it will be useful for OEMs and related stakeholders. - S-98 IC applied for harmonized display between S-10X data and scenario-based TDS for levels 1 and 2 are required. Current version of the draft IC needs to be refined. - We recommend taking S-98 IC as a part of S-164 TDS for type approval.

(2) DF-mode in the S-100 testbed system

S-98 Annex C – harmonised user experience for ECDIS and INS provides guidance on dual fuel systems. In order for the S-100 test bed system to support DF-mode, the guidelines related to S-98 were analysed and summarized as follows.

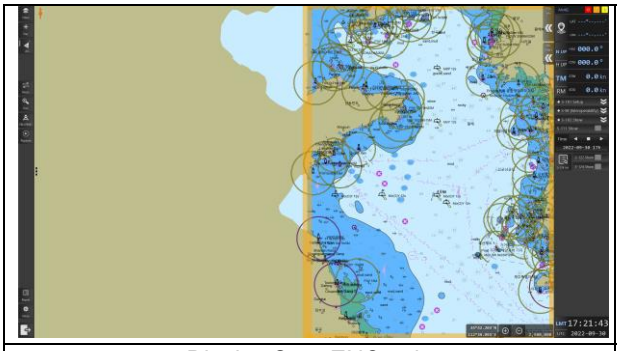
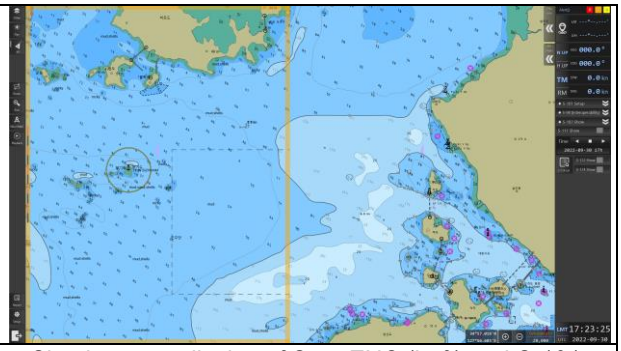
- Definition and considerations
  - Dual-fuel systems are systems that use both older (pre-S-100) and newer (S-100) data products that contain the same type of information (for example, S-57 and S-101 ENCs).
  - All stakeholders should anticipate a transition period during which new S-100 formats increasingly replace older formats.
  - An S-100 ECDIS must be able to handle both S-57 and S-101 ENCs during the transition period

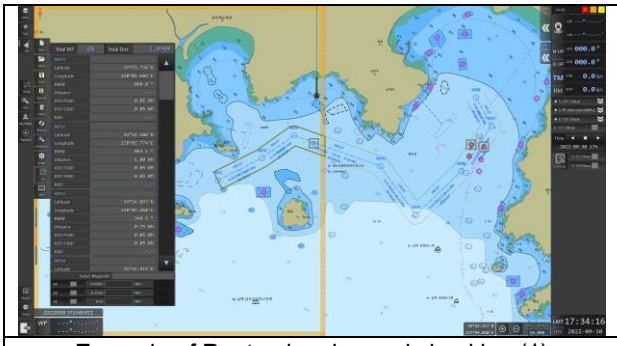
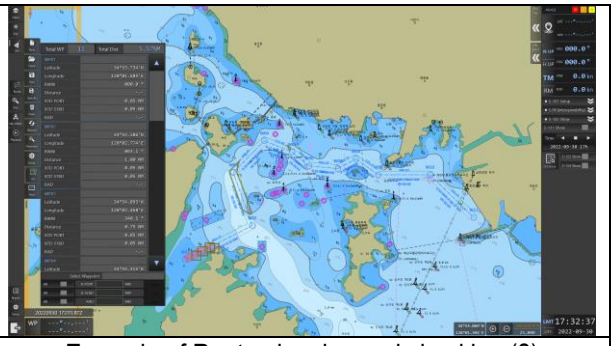
- Display of data available in both new and legacy formats
  - In general, systems should give newer formats priority over the older formats and utilise data from the older format only when there is no coverage of the new format data at an appropriate scale
  - S-101 ENC data should always be given priority over S-57 ENC data when both S-101 and S-57 ENCs provide data coverage at the Mariner's set display scale
  - Indicate when the screen is displaying older-format data and Indicate the boundary between new and old-format datasets if both new and old formats are being simultaneously displayed (one part of the screen is displaying new-format data and another old-format data)
  - Anticipate that the portrayal of newer formats aligns with the portrayal of the older formats during the transition period, so that dual-fuel capable systems will not show significant differences in portrayal of what is essentially the same data in different formats or between different regions where S-100 adoptions are occurring at different paces

- Additional information layers
  - The display of additional information layers is generally driven by mariner need
  - The Interoperability Catalogue concept for ECDIS (see S-100 Part 16 and S-98) is based on using S-101 ENCs as the base layer
  - In areas without S-101 ENC data, manufacturers and data producers should expect additional information layers to be displayed as overlays over S-57 ENC data
  - Data in legacy formats may be displayed as overlays over S-101 data
  - The applicable requirements in the IMO Performance Standards must still be met, especially requirements about not degrading the route monitoring display

- Concurrent applicability of S-52 and S-57
  - Dual-fuel capable systems should continue to use the principles defined in S-57 and S-52 for the presentation of chart data that conforms to S-57 instead of S-101
  - The principles in S-101 should be concurrently applied where S-101 data is displayed.
  - Overlays of S-100-based non-ENC data over S-57 chart data are left to manufacturer discretion, pending development of guidance by the IHO.
  - Where S-100-based non-ENC datasets are overlaid over S-57 data, they should be treated as "additional information" in the sense of IMO MSC.232(82), including the requirement to avoid degrading the display of ENC information
  - Activation of the new functionalities described in this Annex for screen regions where S-100 data is overlaid over S-57 ENCs is left to manufacturer discretion, pending the development of guidance by the IHO
  - The principles for chart furniture and miscellaneous display elements (scale boundaries, limits of data, safety contour, depth zones, update identification, legend, etc) are the same in S-52 and S-98 Annex C
  - Additional functionalities such as graphical indexes, data quality indication, etc, are independent of the legacy/modernised nature of the information. The names of colour tokens are the same

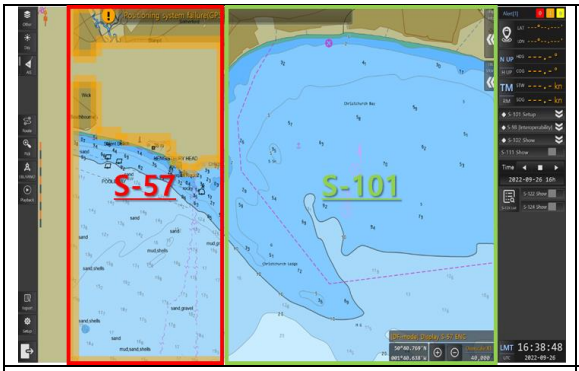
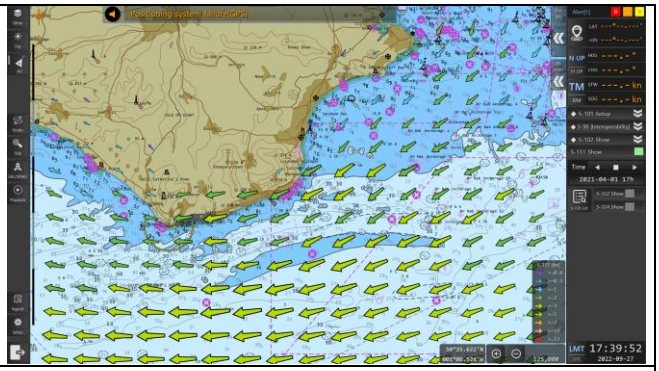
The figure below is a DF-mode test screen where both S-57 ENC and S-101 ENC are displayed. The figure on the left shows S-57 ENC according to S-52 PL 4.0 and S-101 ENC with S-101 PC latest. It is displayed differently due to different colours and chart loading. In accordance with the DF-mode guidelines, the colour table and chart loading were adjusted to display the same, and the boundary between the S-57 ENC and S-101 ENC was indicated.

	
Display S-57 ENC only	Simultaneous display of S-57 ENC (Left) and S-101 ENC (Right)

	
Example of Route planning and checking (1)	Example of Route planning and checking (2)

(4) DF-mode test of UKHO's S-100 data

UKHO provided a total of 6 types of nautical products including S-57, S-101, S-102, S-104, S-111 and S-122 to participate in the S-100 DF-mode test in progress at KHOA. UKHO's S-100 data loading and DF-mode function was checked.

	
Simultaneous display between S-57 ENC and S-101 ENC	Display of S-101 ENC and S-111 surface current using S-98 IC

Executive test summary and recommendation
- The S-98 Annex C – Dual Fuel (DF) concept needs to be clearer to ensure that the industry can develop the DF mode of the S-100 navigation system consistently. - S-98 should include defined rules to display seamless portray of two different types of ENCs such as symbol color, connection of shoreline, display of specific feature types in curve and polygon - It is important to match S-52 PL 4.0 and S-101 PC so that colors and symbols are displayed not differently in the S-100 navigation system - S-98 needs to provide the technical guideline for indicating the boundaries between S-57 ENC and S-101 ENC when they are simultaneously on the screen

(3) Up-to-dateness of S-100 data using the S-128 CNP (Catalogue of Nautical Product)

As the standard development extension was discussed to check the up-to-dateness of the S-100 data using S-128 standard CNP, tests were conducted on the production of S-128 TDS and checking the up-to-dateness in the S-100 navigation system. Through the chart manager function of the S-100 navigation system, the function of loading S-128 and checking whether it is up-to-date was confirmed.

The purpose of the S-128 test conducted by KHOA is as follows.

- Creation of S-128 TDS and review of the application schema of S-128 Ed. 1.0
- Development of ECDIS update status report by the S-128 TDS according to the S-98 Annex C
- Find considerable items from S-128 e 1.0 to improve its up-to-dateness by testing S-128 TDS in S-100 ECDIS

The S-128 test procedure can be summarized as follows. The test environment for checking the up-to-dateness of nautical products using S-128 data is as shown in the figure below.

- Prepare exchange set including S-10X TDS (S-101, S-102, S-104, S-111, S-122, S-123, S-127), S-57 datasets
- Creation of S-128 TDS with arbitrary change of update information (issue date, update number)
- Check the ECDIS update status reports by S-100 ECDIS considering the S-98 Annex C

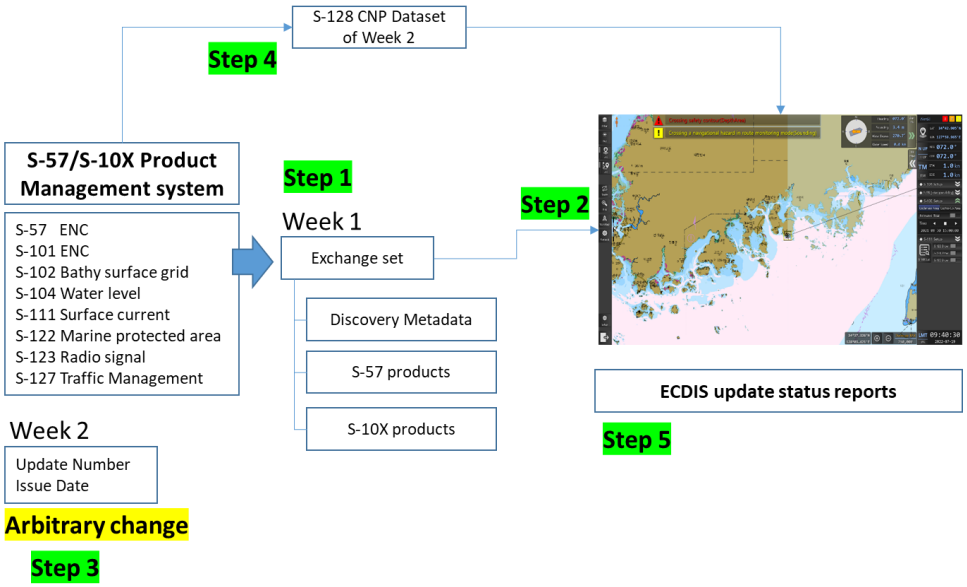


Fig. 1 Up-to-dateness checking process using S-128

S-128 dataset replaces the PRODUCTS.TXT of S-63 and aims to implement the ECDIS update status reports using S-128 dataset

The report on checking the up-to-dateness of navigation products in the S-100 test bed system is described in S-98 Annex C, Appendix C-3. S-128 dataset replaces the PRODUCTS.TXT of S-63 and aims to implement the ECDIS update status reports using S-128 dataset

[Revised Form]

Report Name: Electronic Navigational Charts (ENC) Update Status Report

Vessel Name:

Identifier:

Update Reference Date: (from S-128)

Date of Report:

Content: Filtered for Route Plan "Goteborg – Kiel"

Start WP:

End WP:

Chart Status:	Count
Total:	50
Up to Date	38/50
Not Up to Date	10/50
Withdrawn	2/50
Unknown	0/50

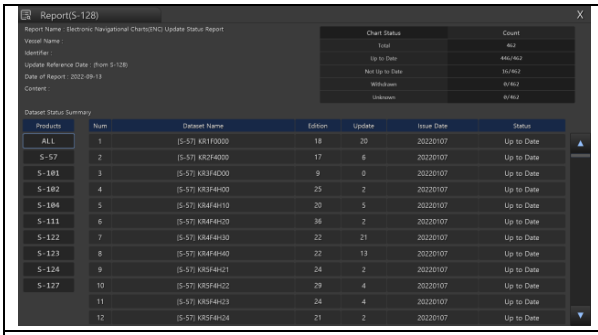
Dataset Status Summary

Data Server: XXXX

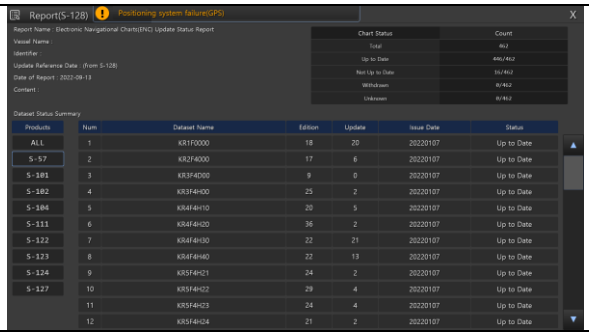
Product	Dataset Name	Edition	Update	Issue Date	Status
S-101	101US23495820	10	4	2020-01-02	Up to Date
S-102	102US29348021				

Fig. 2 S-100 Data Update Status Report in S-98

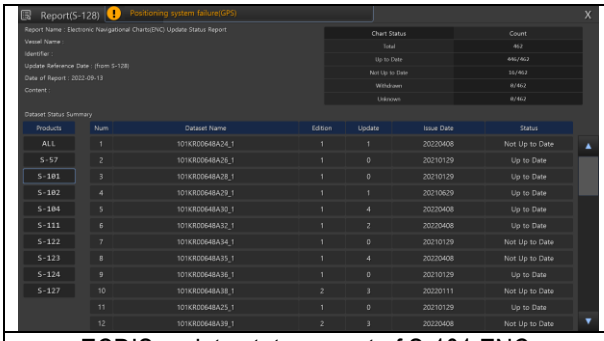
The figure below is the up-to-dateness checking procedure using S-128 dataset and the navigation product update status report screen in the S-100 navigation system. The update status report was developed according to the S-98 Annex C guidelines.



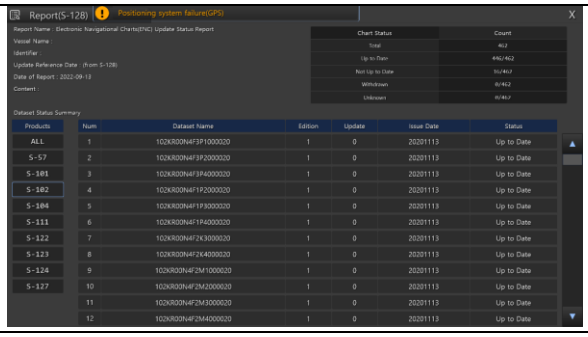
ECDIS update status report of all nautical data



ECDIS update status report of S-57 ENCs



ECDIS update status report of S-101 ENCs



ECDIS update status report of S-102 Bathy surfaces

The results of the S-128 test are summarized as follows.

- S-57/S-10X datasets - File directory of exchange set
- No seen for limitations and problems on the S-128 data model
- Need to specify the detailed scenario on quick update products like S-104 and S-111
- ECDIS update status reports of S-98 should be refined
- Need to define how S-128 dataset works in S-100 ECDIS
- Need to define how to provide the S-128 dataset to end-user

The KHOA research team reported the test results for checking the up-to-dateness of the S-100 test system using S-128 data to the NIPWG meeting, and suggested and discussed the following issues.

- Topic 1. Requirement of S-128 product
- Topic 2. Re-model of feature types for nautical products (Categorization)
- Topic 3. S-128 product service
- Topic 4. Validation rules of S-128
- Topic 5. Encryption of S-128 data
- Topic 6. Consideration for MASS

Executive test summary and recommendation
- There was no issue for the S-128 data model while verifying the up-to-dateness - Detailed scenarios for short interval products S-104 and S-111 should be defined - S-98 Annex C guideline of S-100 data update status report for S-100 navigation system needs to be improved for its details - The test bed proposes the way to produce S-128 TDS by considering different S-100 products and occasions (new, re-issue, update and cancel), and to apply it as the S-164 TDS.

Annex B. Report on usability test on S-100 service

The International Hydrographic Organization has established a roadmap for the S-100 implementation plan and is in the process of revising ECDIS-related regulations in cooperation with IMO and IEC. When introducing the S-100 based product service to the marine navigation environment, it is expected to be helpful in managing and utilizing marine information as nautical products such as nautical publications are digitized, but a quantitative analysis is needed on how useful it is from the end user (mariner) point of view. In 2022, S-100 test bed performed quantitative analysis on the usability of S-100 based product service from the end user's perspective. The analysis of the usability of S-100 based product service was applied only to the mariner's route planning task, which is normally second officer's duty.

Second officer's duty before departure:

- Route planning
  - Using ECDIS, calculate the approximate distance by taking a picture of the latitude/longitude coordinates on the screen using the mouse.
  - Calculation of detailed distance after inputting information such as odd number of main lines in ECDIS, setting safety depth, contour line, screen mode, and safety related alarms according to company guidelines
  - ETA calculation, ECDIS setting after predicting the expected speed considering the weather
- Update of chart and nautical publications
  - Check that the nautical charts and publications required for navigation are present and up-to-date
- Review of reporting document
  - If there is a mandatory report according to the sea area, it is indicated on the chart, etc., and the reporting method is reflected in detail in the voyage plan.

(1) Route planning task of Mariner
We filmed the process of establishing a route plan for a voyage on a training ship bridge at KMOU (Korea Maritime & Ocean University), and analysed the job of each process. Investigating the duties of mariners and analysing the work process of making the route plan was done. The mariners repeat the procedure to set the way point on ECDIS to establish the route plan, move to the chart table, and check the nautical publication such as sailing direction and tidal table.

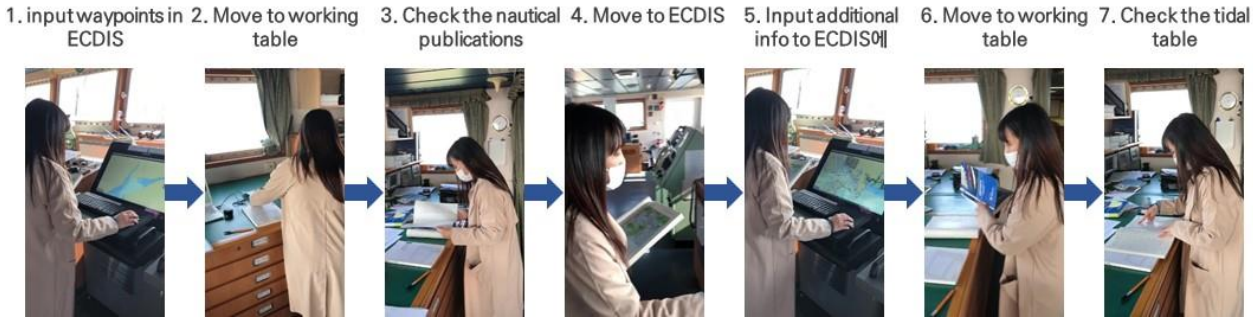


Fig. 3 Route planning

(2) Overview and procedure for quantitative analysis of S-100 based product service

Evaluate the usability of the newly introduced S-100 based product service compared to traditional hydrographic products

Testing procedure: Assignment of voyage planning missions with different levels of difficulty between "Busan↔Jeju" and "Incheon↔Pyeongtaek" routes. (4 courses in total)

Fig. 4 Usability testing procedure of S-100 based product service

(3) Participants and measuring equipment

- Conducted for 10 mariners with more than 3 years of navigation experience
- 8 out of 10 people are male and 2 are female (average of 30 years old)
- For testing and measuring equipment, S-57 ECDIS, S-100 testbed system and eye tracker

		
S-57 ECDIS	S-100 testbed system	Eye tracker (Ergoneers GmbH - DG3 Dikablis Glasses)

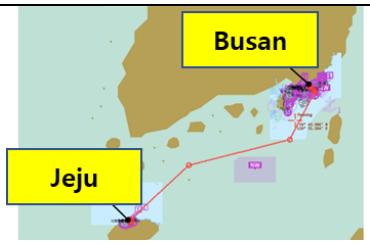
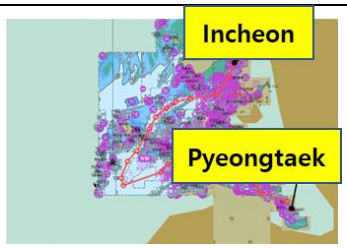
** Specification of eye tracker equipment

- Head set unit, consist of eBox
- Field camera speed is 30Hz, eye camera tracking speed is 60Hz for each eye
- Eye tracking accuracy of 0.05˚ for pupil tracking and 0.1~0.3˚ for eye tracking
- Video-based data analysis, AOI and heat map static and dynamic analysis possible
- Quantitative gaze data can be calculated through Heat Map, Gaze Path, and AOI

Condition of the experiments

- One monitor for the ECDIS which S-57 standard is applied
- In the case of using S-57 equipment, most nautical publications should be used to check information necessary for navigation preparation task
- ECDIS equipment to which S-100 standard is applied uses two monitors
- If the S-100 equipment is used, all information necessary for navigation work can be checked within the equipment.

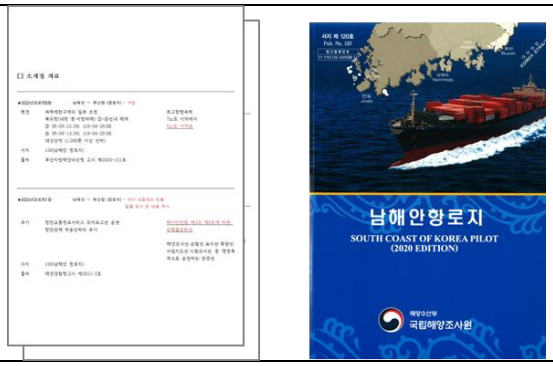
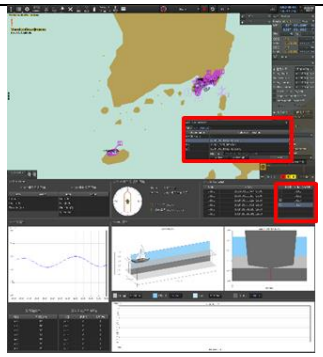
(3) Testing scenario

Detailed scenario	Busan↔Jeju	Incheon↔Pyeongtaek
- Task 1. Update of nautical products - Task 2. Navigational warning - Task 3. Route planning - Task 4. Check the surface current in the arrival port - Task 5. Confirmation of route and save		

A. Task 1. Update of nautical products

Updating the navigation information used in route planning to the latest information.

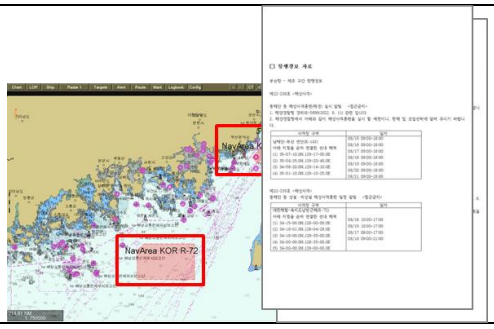
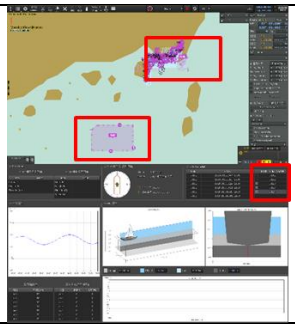
- Traditional products: Update the nautical publication manually using notice to mariners
- S-100 based product service: Update the S-123 and S-127 data in the S-100 testbed system

	
Traditional products	S-100 based product service

B. Task 2. Navigational warning

Check the navigation warnings generated near the departure and arrival points and reflect them in the navigation system so that they can be referred to in the navigation plan.

- Traditional products: Check provided navigational warnings and input those in ECDIS
- S-100 based product service: Inject the S-124 NW dataset to S-100 testbed system and check the NW symbol

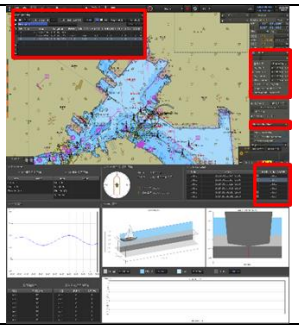
	
Traditional products	S-100 based product service

C. Task 3. Route planning

After setting the type of vessel and the safe water depth, check whether the planned route is appropriate

- Traditional products: After setting the safe depth and safety contours on ECDIS, mariner plans the route considering with the pilot boarding place and VHF channel. Then the mariner does inspection the route if it is appropriate.

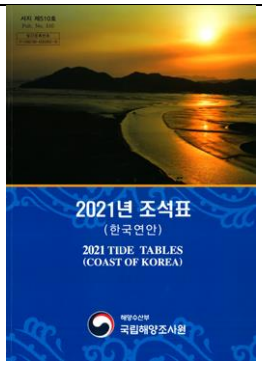
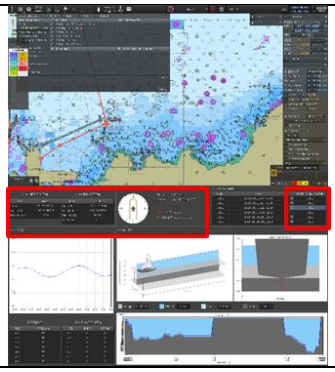
- S-100 based product service: After checking the navigable water area through the S-102 and S-104 layers, mariner plans the route considering with the pilot boarding place and the VHF channel. Then the mariner does inspection to see if it is appropriate.

	
Traditional products	S-100 based product service

D. Task 4. Check the surface current of arrival port

Check the surface current (current speed, current direction) of the destination port (Jeju, Pyeongtaek).

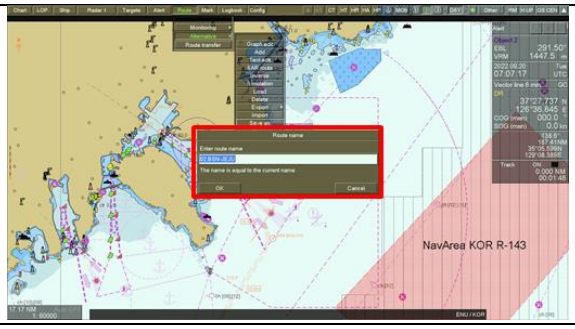
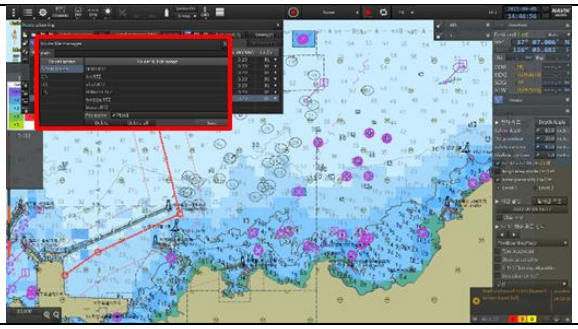
- Traditional products: Check the current information of the destination port using the tide table or the tidal chart for a given time
- S-100 based product service: Check the current information of the destination port using the S-111 surface current data for a given time

	
Traditional products	S-100 based product service

E. Task 5. Finalize route plan

Final check and save the designed route information

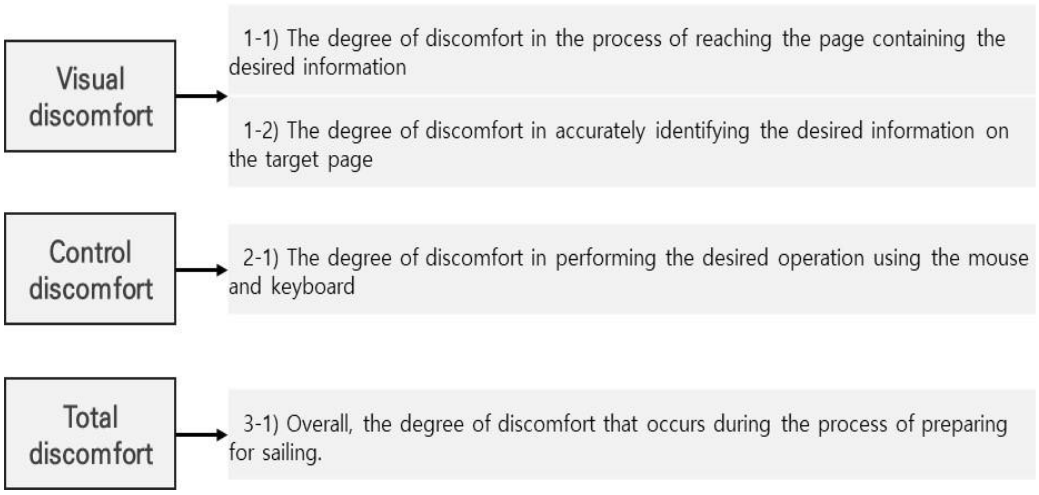
- The procedure is the same for both of the traditional products and S-100 based product service

	
Existing ECDIS	S-100 testbed system

(4) Qualitative and quantitative evaluation indicators

For qualitative evaluation indicators, Subjective visual discomfort, operational discomfort, and overall discomfort between the method of using the traditional products and the method of using S-100 based product service in the process of navigation provision. Questionnaire for subjective discomfort (Visual, Control, Total), 7 points scale for

visual and control discomfort (From 1 for very comfortable at all to 7 for very uncomfortable), 100 scores scale for total discomfort



In relation to quantitative evaluation indicators, eye tracking data that tracks eye movements between experiments was been utilized. Major gaze data such as Fixations, Saccade, and Cognitive Activity Index (ICA) were collected.

Data type	Contents
Fixation	• Occurs when the experimenter continues to stare at a specific location. • The place where Fixation appears is interpreted as the subject's interest and interest, and the concentration and gaze frequency are analyzed by grasping the continuous gaze.
Saccade	• Rapid eye movement refers to a sudden change in viewpoint. • It is a momentary movement of the gaze that occurs when the gaze moves from the gaze point to another gaze point after touching the stimulus.

(5) Total evaluation summary

A. Qualitative evaluation results
We compare the subjective discomfort of traditional products and S-100 based product service and conclude S-100 based product service is more comfortable. Based on paired T-test result
When comparing the discomfort scores according to the equipment, a significant difference was confirmed at the significance level of 0.05.

- Visual(Efficiency) discomfort: p-value = 0.001
- Visual(Intuition) discomfort: p-value = 0.008
- Control discomfort: p-value = 0.019
- Total discomfort: p-value = 0.002

The degree of discomfort for each item was measured as follows

- Visual(Efficiency) discomfort: 5.2 for traditional products and 2.3 for S-100 based product service, the S-100 based product service is more comfortable than S-57 ECDIS
- Visual(Intuition) discomfort: 4.4 for traditional products and 2.2 for S-100 based product service, the S-100 based product service is more comfortable than S-57 ECDIS
- Control discomfort: 3.9 for traditional products and 2.1 for S-100 based product service, the S-100 based product service is more comfortable than S-57 ECDIS
- Total discomfort: 66.8 for traditional products and 27.7 for S-100 based product service, the S-100 based product service is more comfortable than S-57 ECDIS

-

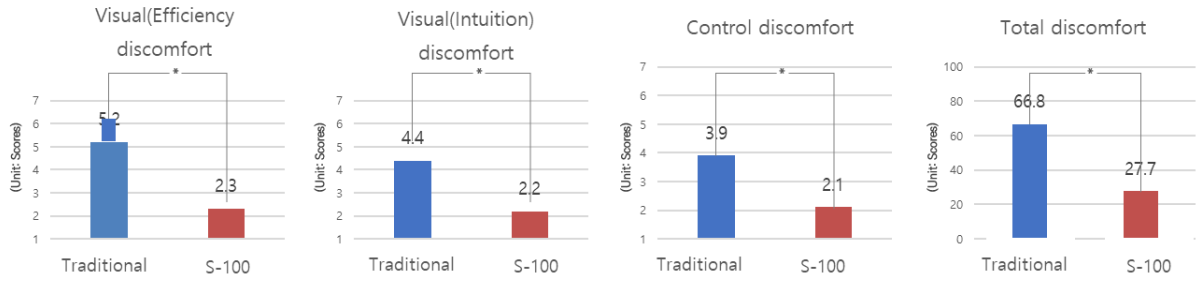


Fig. 5. Subjective comfort evaluation results

<Comments from the test participants>

Interview 1. How fast can you reach to the page that contains the information you want

- S-100 testbed system has a noticeable reduction in time in information search compared to traditional products
- The S-100 testbed system is very convenient as it allows you to display the necessary information for updated objects on the screen with a few clicks.
- For basic setting of S-100 testbed system, you have to memorize what S-XXX information means, but it is much more convenient than traditional products.

Interview 2. How easy can you get to the information you want on the target page?

- The S-100 testbed system is more intuitive to find the information on the screen.
- The S-100 testbed system is more convenient and faster to check surface current
- The S-100 testbed system was convenient for recognizing information because only the contents of the desired layer could be turned on and off easily.

Interview 3. How easy to operate with mouse and keyboard?

- The S-100 testbed system was convenient as it fundamentally reduced update task of nautical products.
- When using the S-100 testbed system, it was convenient to be able to move the screen with the keyboard during the planning process.
- The amount of information in the S-100 testbed system is huge, so it may require more operation when setting only the desired display.

B. Quantitative evaluation results

Measuring value using eye tracker: Duration Time, Number of Fixation, Number of Saccades

- When comparing data by item according to equipment, a significant difference was confirmed at the significance level of 0.05
- Duration time: It is the time taken to perform a task, and the smaller it is, the faster the task is performed (task execution time: S-57 > S-100)
- Number of Fixation: In AOI (Area Of Interest), the number of fixed gazes is smaller, meaning more efficient search/recognition (number of gaze fixations: S-57 > S-100)
- Number of Saccades: It is the number of instantaneous gaze movement, and the smaller it is, the less the gaze movement (number of gaze movement: S-57 > S-100)

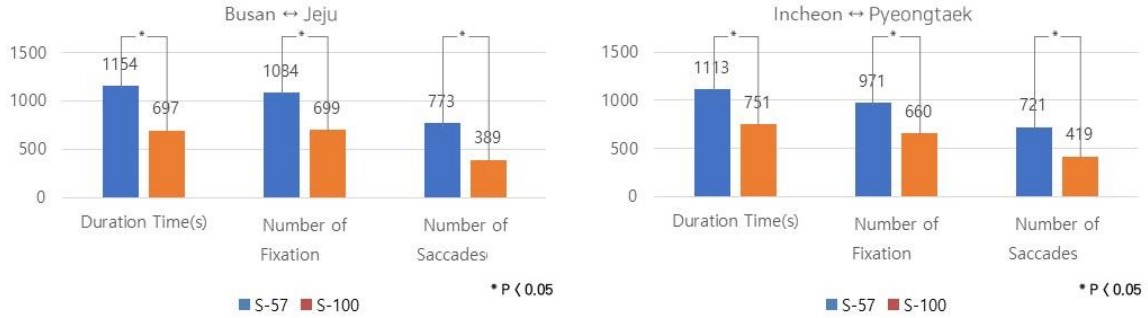


Fig. 6. Quantitative evaluation results

(Duration) There was no significant difference in Duration Time for each equipment in Task3 (route planning) and Task5 (final confirmation and saving of route). However, we found a significant difference in Task1 (updating nautical products), Task2 (navigational warning), and Task4 (check surface current of arrival port) and concluded that using S-100 testbed system saves a lot of time compared to using S-57 ENC and paper materials.

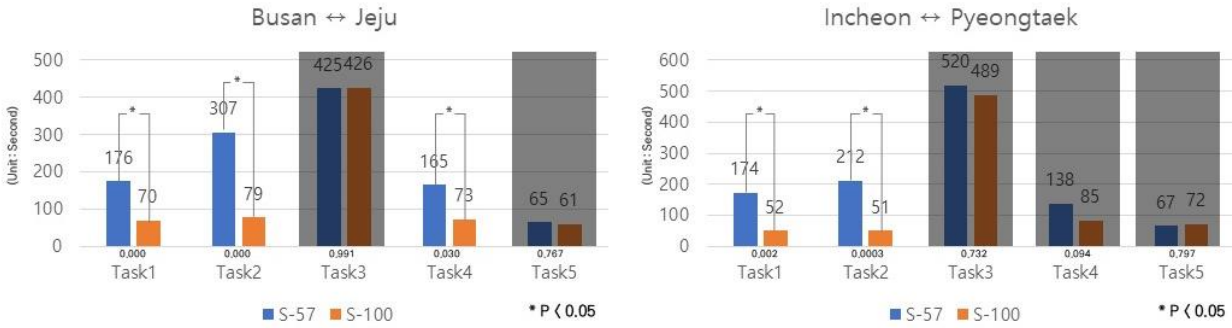


Fig. 7. Duration for each task

(Numbers of Fixation) We checked the significant difference in Task1 (updating nautical products), Task2 (navigational warning), and Task4 (check surface current of arrival port) and concluded that the S-100 testbed system provide efficient tool. Using S-100 based products can support exploring and recognition compared to the traditional products for Task 1,2 and 4.

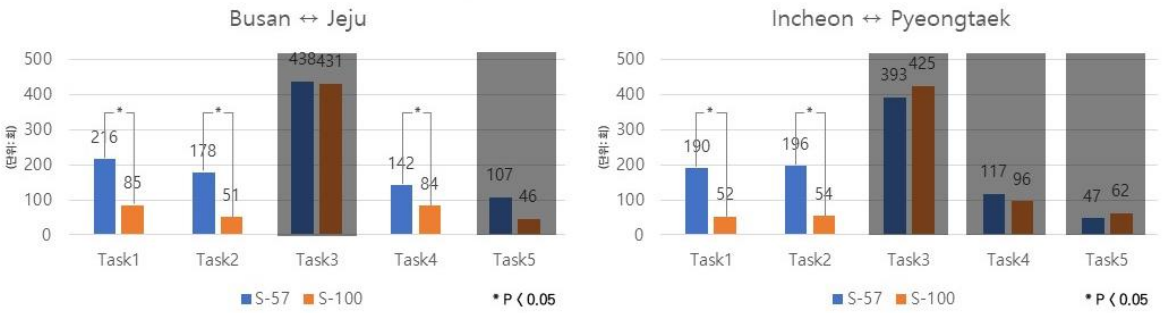


Fig. 8. Number of fixation for each task

(Number of Saccades) We checked the significant differences among Task 1 (updating nautical products), Task 2 (navigational warning), and Task 4 (checking surface currents of arrival port) and concluded that the S-100 testbed system allows the users with a smaller number of saccades which is expected to be less tiring.

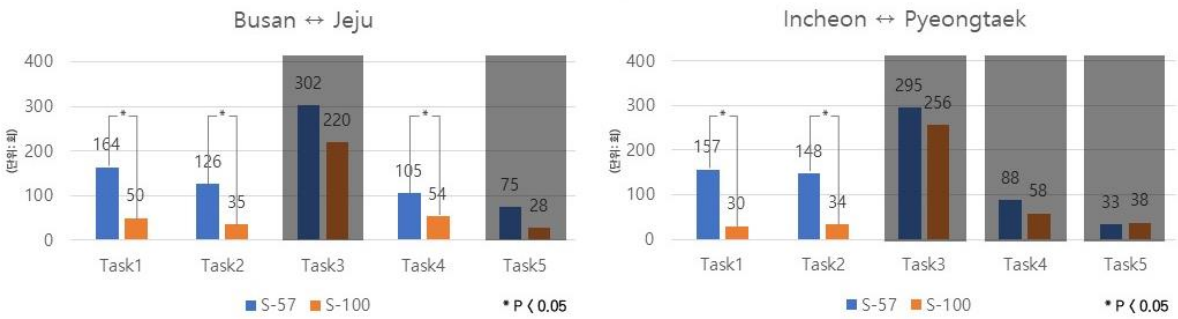


Fig. 8. Number of saccades for each task

(6) Result summary

Fig.9 S-100 data qualitative/quantitative measurement activity compared to the traditional products

It was confirmed that the subjective discomfort level of the S-100 test bed system was small compared to the use of the traditional products. The quantitative evaluation results (Duration Time, Number of Fixation, Number of Saccades) of the S-100 test bed system were excellent compared to the use of traditional products. The usability of the S-100 test bed system provides a higher usability compared to the traditional products in updating nautical products, navigational warning, and checking surface current in arrival port.

Fig. 10. Summary of evaluation result

Annex C. Report on economic efficiency of S-100 based product service

At the 5th IHO council meeting held in 2021, KHOA reported the usability analysis plan of S-100 based product service. The council meeting recommended not only the usability analysis of the S-100 based product service but also the economic analysis. KHOA conducted economic analysis according to the use of S-100 based product service in the operation of the S-100 test bed in 2022.

(1) Measuring factors of ship navigation economics
The navigation plan selects the route approaching the land so that the vessel can shorten the distance of the voyage safely and economically, in principle. The main considerations are:

- Provision of nautical chart and publications, up-to-dateness
- No-Go Areas
- Margins of safety
  - Ship size
  - Surface current and Tidal information
  - Ship handling performance
  - Draft of the vessel in relation to the water depth, UKC (Under Keel Clearance)
  - Weather status
  - Vessel traffic
- Aids to navigation (Lighted buoy, RACON, VTS, Pilot boarding place, etc)
- Port information (Location, Regulations, etc)

From the perspective of the ship operator, the navigation plan is a design that focuses on the safety of the vessel, and the indicators related to the operation efficiency can be organized into the navigation distance, time required according to speed, fuel consumption, and operation time.

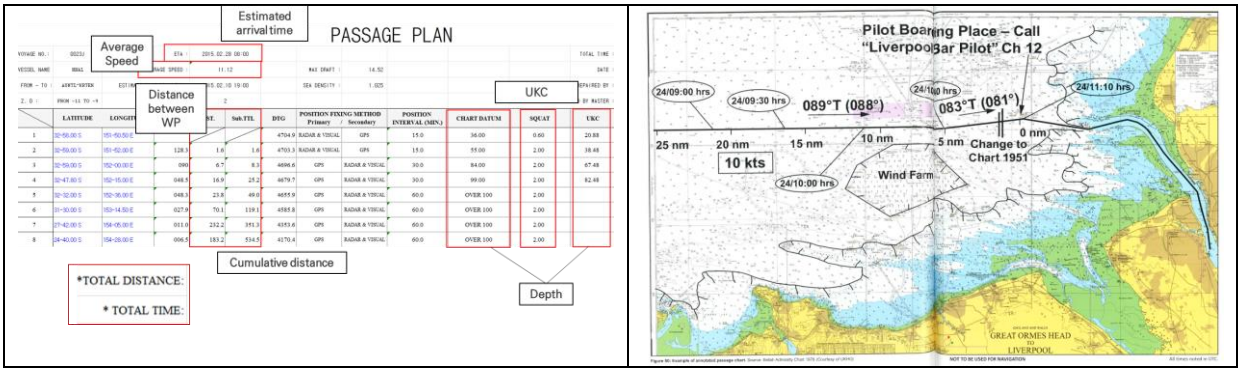


Fig. 11 Example of route planning

(2) Economics analysis of official routes for coastal passenger ships
In vessel navigation, hydrographic data can be used as main information to determine the course of a ship, and hydrographic data can be used in the following two aspects.

- Surface current: In the case of a region with a strong current or an area with a large influence of the current, the ship's route is decided in consideration of the surface current (coastal voyage + ocean voyage)
- Bathymetry and Tide: In the case of areas with large tides, the route of the vessel is determined to prevent grounding accidents according to the water level (coastal voyage)

We determined a ship route according to the tide level from S-102 bathymetry and 104 water level, and analysed if we can reduce the distance and duration of the voyage. The distance and time of the route are major indicators that affect economical efficiency. We consider that S-102 and S-104 are major variables to find the optimal route. We did a case study with using a passenger ship which takes detour when it is low tide.

(Case 1) Analysis of multiple (low tide/high tide) routes according to the water level
(Case 2) Alternative route analysis for official single route

(3) Case 1 - Analysis of multiple (low tide/high tide) routes according to the water level
The west coast of Korea (Incheon) is a region with a large range of the tide. There is a passenger ship, called Sambo 12, operates in Incheon has two official routes due to the low depth area. Depends on the tide, the passenger ship sometimes has to take the roundabout according the regulation.

〈Passenger ship operation management regulations〉

Ship specifications	
Gross tonnage	393
Hull length(m)	46.36
Hull width(m)	14.5
Depth(m)	2.5
Draft(m)	2.3
Speed(Knot)	13
Area Jumundo-Jumundo	

〈Passenger ship routes〉

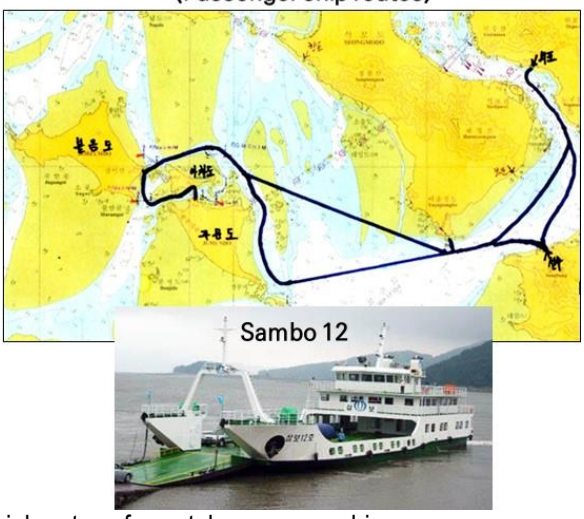
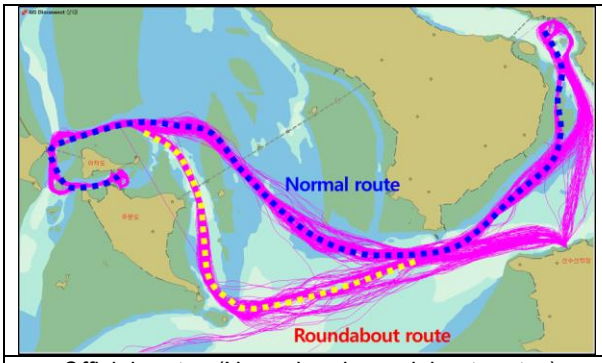


Fig. 12 Configuration and official routes of coastal passenger ship

The figure below shows the normal and roundabout routes of the Sambo 12 passenger. Because of the shallow depth area, 1,196 out of 2,190 times voyage should have been taken the roundabout route. It is about 54.6% of the total number of the voyage within a year took the roundabout instead of the normal route.

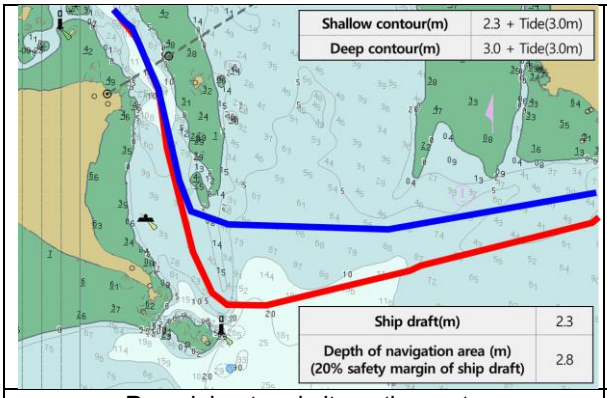


Official routes (Normal and roundabout routes)

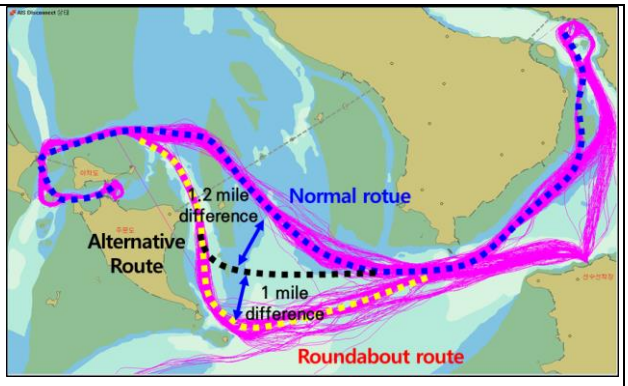
Num	Jumun Departure	Oepo Departure
1	07:00	08:50
2	11:00	12:50
3	14:30	16:20

Passenger ship schedule

In case of using S-100 based product service (S-102 bathy + S-104 water level), we assumed that using an alternative route calculated by S-100 based product would allow a route that is shorter while being safe at low tide. We identified shorter routes than the roundabout which are still safe at low tide. And we calculated how much cost and time we can save with the alternative one.



Roundabout and alternative route



Distance difference between normal, roundabout and alternative route

The roundabout route was 4,157m, the alternative route using the S-100 based product service was 2,306m. Within a year, 1,196 voyage should be using the roundabout to avoid dangerous situation. We set a hypothesis that the passenger ship takes S-100 alternative routes instead of the roundabout at low tide in an year, and calculate how much cost we can save based on fuel consumption. Assuming that the fuel consumption per hour is 1,000 liters and the fuel cost per liter is calculated as $1.25, the formula for economic analysis of operation efficiency can be applied as follows

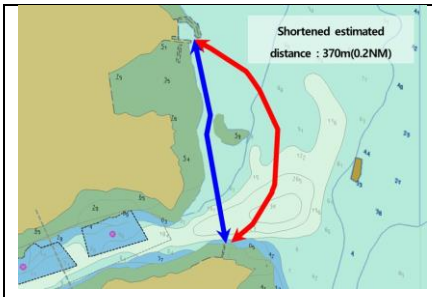
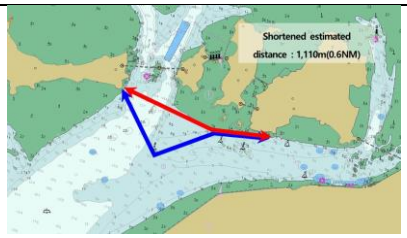
(Route distance) X (Numbers of Roundabout/Alternative route navigation) / (Vessel speed – 12kn) X (Fuel consumption per hour) X (Fuel cost per liter)

Accordingly, it was calculated that a total annual cost savings would be about 124K USD (45.5% savings).

Passenger ship Route	Roundabout route	Alternative route explored using S-100 data service
Estimated distance (m)	4,157	2,306
Distance difference between normal and roundabout/ alternative(NM)	2.2	1.2
Total number of navigation	2,190 rounds	
Expected number of roundabout/alternative route	1,196 rounds	
Fuel consumption per hour	1,000 liters	
Fuel cost per liter	$1.25 per liter (include 0.01% MGO tax)	
Economics analysis of coastal passenger ships	(Route distance) X (Numbers of Roundabout/Alternative route navigation) / (Vessel speed – 12kn) X (Fuel consumption per hour) X (Fuel cost per liter)	
	(A) **$273,209**	(B) **$149,023**
	(A) - (B) = **$124,186 (45.5% savings)** Total annual cost savings of $124,186 (45.5% savings) would occur when the alternative route was used	

(4) (Case 2) Alternative route for single official route

We searched several alternative routes using S-100 based product service for single official routes in Korea to see if there is any potential on the economic aspects. The figure below shows the official and alternative routes for (Passage 1) Boryeong Sea Area, (Passage 2) Incheon Sea Area A, and (Passage 3) Incheon Sea Area B.

		
(Passage 1) Boryeong Sea Area	(Passage 2) Incheon Sea Area A	(Passage 3) Incheon Sea Area B

The economic analysis was carried out in the same way as the method introduced in Case 1. We found three S-100 based alternative routes, and the estimated shortened distance for each route were 402m, 1,069m, and 872m, respectively. When the estimated shorten distance, number of possible alternative routes, sailing speed, fuel consumption per hour, and fuel cost per liter are applied, the results of the economic analysis of operation efficiency are shown in the table below.

Passenger ship route	(Route 1) Boryeong Sea Area	(Route 2) Incheon sea area A	(Route 3) Incheon sea area B
Estimated shorten distance(m)	402	1069	872
Estimated shorten distance(NM)	0.2	0.6	0.5
Total number of navigation	1,095	2,555	456
Expected number of alternative route	82	1,374	323
Fuel consumption per hour	1,000 liters		
Fuel cost per liter	$1.25 per liter (include 0.01% MGO tax)		
Economics analysis of coastal passenger ships	(Shorten route distance) X (Numbers of Roundabout/Alternative route navigation) / (Vessel speed – 12kn) X (Fuel consumption per hour) X (Fuel cost per liter)		
	$1,708	$85,875	$16,823

We would like to study further on economical efficiency of using S-100 based products. A study case on the long-distance voyages between international ports with S-100 based product, especially ocean current information, might be useful.