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Research on Quality-in-use Measurement for Marine Software

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Abstract

e-Navigation is used to collect, integrate, exchange, represent and analyze maritime information onboard and ashore by electronic means through the application of information and communication technology to the existing ship navigation technology. In 2014, a strategic implementation plan to realize e-navigation was released and it is expected to be implemented at some point after 2018. Software quality assurances and human-centred design guidelines are one of the key outcomes of the e-navigation SIP. To apply the goal-oriented guidelines, this paper compared the methods on how to measure usability in the standards related to each concept as a way of linkage between the SQA and HCD concepts with a specific focus on the usability. The comparison results showed that HCD-related standards provide measurement methods for particular criteria that are not provided in detail, and the usability of SQA and Quality in use-related standards provides appropriate methods. It was also found that it makes no difference whether the measurement methods of SQA standards for usability evaluation on the software of the equipment developed by applying HCD are used.

Keywords*: e-Navigation, Software Quality Assurance, Human-Centred Design, Usability, Quality-in-use*

1. Introduction

The International Maritime Organization (IMO) has introduced and promoted e-navigation strategies for the purpose of reducing marine accidents that occur due to human errors and protecting the marine environment. e-Navigation is the collection, integration, exchange, representation and analysis of maritime information onboard and ashore by electronic means through the application of information and communication technology to the existing ship navigation technology [1].

With the strategic introduction of e-Navigation, the usability and dependency of navigation systems and software has increased, and the quality of software has also emerged as an important issue. The rate of maritime accidents due to human errors has risen to about 60-80% [2], and therefore it is necessary to consider human factors in the system and software development. e-Navigation software quality assurance (SQA) and human-centred design (HCD) guidelines were developed with the expectation of improving user demand satisfaction and safety. It was officially approved as circulated documents of IMO in 2015[3]. This means that SQA/HCD is applied in practical business affairs for the development and management of the e-Navigation system. SQA and HCD parts can be applied either separately or jointly.

In this paper, a linkage method is investigated centering on usability as a focus with respect to cases of being jointly applied in SQA and HCD. According to the definition,

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the usability can be evaluated by 'Effectiveness', 'Efficiency', and 'Satisfaction′ in terms of HCD, and the relevant measurement methods are not provided in the international standards[4]. 'Effectiveness', 'Efficiency', and 'Satisfaction' are included in the five characteristics of software Quality-in-use (QIU) [5], and the measurement methods of the three characteristics are provided in ISO 25022[6]. The usability in terms of software product is one of the key features of the software product quality model and has six sub-characteristics [5]. The measurement functions are provided in ISO 25023[7].

For the study of the linkage method, items that measure effectiveness, efficiency and satisfaction provided by HCD-related standards were compared with the measuring items provided in ISO 25022. Then, items that measure effectiveness, efficiency and satisfaction of HCD standards were compared with items of software product usability provided in ISO 25023. Additionally, the items associated with e-Navigation software were sought out from those on the 'context coverage' and 'freedom from risk' other than effectiveness, efficiency and satisfaction among the QIU presented by e-Navigation SQA.

2. Related Researches

2.1. Usability Consideration in Marine Area

e-Navigation SQA and HCD guidelines were developed with the expectation of improving user demand satisfaction and safety. In this regard, this paper presents guidelines for applying SQA and HCD to effectively design and develop the marine system. The quality design attributes required for the development of the specific system are derived as requirements, and the process of testing whether these requirements are reflected in the implementation phase is included. In particular, the usability test can be dealt with from both SQA and HCD perspectives as shown in Figure 1[8].

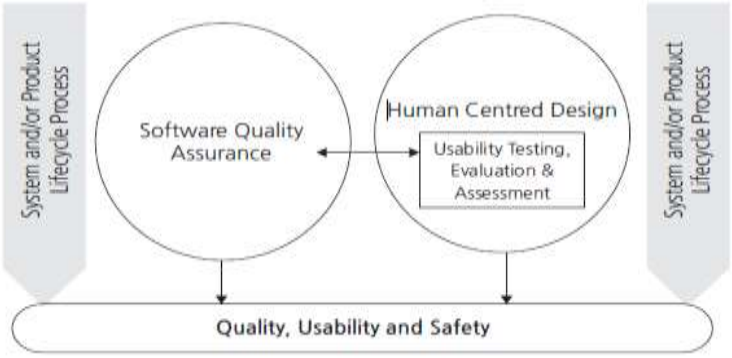

Figure 1. Relationship between the SQA and HCD

2.2. Usability

The characteristic that is commonly dealt with in SQA and HCD is that of usability. Usability is one of the eight main characteristics of the product quality model among software quality models. In addition, this usability is also the main objective of introducing the human-centered design methods in developing products.

Table 1. Usability Evaluation Items of SQA and HCD

	Usability in terms of Software Product Quality	Usability in terms of HCD	Quality-in-use
Evaluation Items	Appropriateness Recognisability Learnability Operability User error protection User interface aesthetics Accessibility	Effectiveness Efficiency Satisfaction	Effectiveness Efficiency Satisfaction Freedom from risk Context Coverage
Related International Standards	ISO/IEC 25010	ISO/IEC 9241-210	ISO/IEC 25010

Usability in terms of HCD provides the required items to be able to apply to evaluate effectiveness, efficiency and satisfaction respectively, rather than the methods and measurement functions on how to evaluate usability items.

On the other hand, usability standards designated to SQA provide functions to measure the items. For example, the effectiveness, efficiency and satisfaction are provided in ISO 25022. If focusing on software products, such items as appropriateness, recognisability, learnability, operability, user error protection, user interface aesthetics and accessibility are to be measured provided in ISO 25023.

3. Comparison of Usability Measurement Function of SQA/HCD – Perspectives on Quality in Use

3.1. Effectiveness Measures of SQA/HCD

Table 2. Effectiveness Measures of SQA/HCD

Usability Objective	Measures in terms of HCD (Based on the ISO 9241-11)	Measures in terms of SQA (Based on ISO/IEC 25022, 25023)
Rate of goal achievement	Percentage of goals achieved	Objectives achieved $\{X = 1-\sum Ai \mid X>0\}$ Ai= Proportional value of each missing or incorrect objective in the task output (maximum value = 1)
Rate of task completion	Percentage of users successfully completing task	Tasks completed X = A/B A = Number of unique tasks completed B = Total number of unique tasks attempted
Meet needs to walk up and use	Percentage of tasks completed successfully on first attempt	
Accuracy of task results	Average accuracy of completed tasks	Tasks with errors X = A/B A = Number of tasks with errors B = Total number of tasks
Error tolerance	Percentage of errors corrected or reported by the system	User entry error correction X = A / B A = Number of entry errors which provide a suggested correct value B = Number of entry errors detected
Meet needs of trained users	Number of power tasks performed	
Meet needs for infrequent or	Percentage of tasks completed successfully after a specified	This issue is not relevant because the software quality must be consistent even

intermittent use	period of non-use	though it is intermittently used.
Minimization of support requirements	Number of references to documentation	User guidance completeness X = A / B A= Number of described functions in user manual B= Number of required functions to be documented
	Number of calls to support	
Learnability	Number of functions learned	
UI Legibility	Percentage of words read correctly at normal viewing distance	User Interface customizability X = A / B A= Number of user interface elements that can be customized B= Number of user interface elements that could benefit from customization

Table2 is a table showing a comparison between measurement functions provided in the SQA-related standards– ISO 25022 and ISO 25023– and the measuring items provided in the HCD-related standard ISO 9241-11 with respect to the 'effectiveness' among the items for measuring usability.

In ISO 9241-11, the method for measuring the effectiveness of 'Minimization of support requirements' is to calculate the 'number of references to documentation and the 'number of calls to support'. ISO 25023 provides functions for measuring the 'User guidance completeness', which is calculated as the number of functions described in the manuals and tips/the number of total functions to be described in the documents. The method of calculating only the number of times, which is provided in ISO 9241-11, requires the establishment of a rating scale for each occurrence, whereas when functions provided in ISO 25023 are used, the effectiveness on the 'minimization of support requests' is estimated to be higher as the value is closer to 1.

In ISO 9241-11, the method for measuring the effectiveness of 'UI Legibility' is to calculate the ratio to be accurately read when words are seen from a normal distance, when the 'normal distance' is calculated differently depending on equipment and programs. ISO 25023 provides a function for measuring the ratio that enables users to customize UI through the 'UI customizability' item. Since this function also takes into consideration user properties without regard to the type of equipment or programs, performing measurements using the 'UI customizability' function provided in ISO 25023 is recommended, rather than using the items provided in ISO 9241-11.

3.2. Efficiency Measures of SQA/HCD

Table 3. Efficiency Measures of SQA/HCD

Usability Objective	Measures in terms of HCD (Based on the ISO 9241-11)	Measures in terms of SQA (Based on ISO/IEC 25022, 25023)
Time for task	Time to complete task	Task time
Meet needs to walk up and use	Time taken on first attempt	
Costs	Monetary costs of performing task	Cost-effectiveness X = A/B A = Objectives achieved B = Total cost of carrying out the task
Meet needs of trained users	Relative efficiency compared with an expert	Tasks with errors X = A/B

	user	A = Number of tasks with errors B = Total number of tasks
Minimization of support requirements	Productive time	X = Ta / Tb Ta = Productive time = time taken to complete the task - time spent getting help or assistance - time taken recovering from errors - time taken searching ineffectually Tb = Task time
Meet needs for infrequent or intermittent use	Time spent re-learning functions; Number of persistent errors	Usage efficiency X = A/T A = Objectives achieved T = Time
Error tolerance	Time spent on correcting errors	Usage efficiency X = A/T A = Objectives achieved T = Time
Learnability	Time to learn to criterion Time to re-learn to criterion	Usage efficiency X = A/T A = Objectives achieved T = Time
UI Legibility	Time to correctly read a specified number of characters	Usage efficiency X = A/T A = Objectives achieved T = Time

Table3 shows a comparison between functions provided in the SQA-related standards – ISO 25022 and ISO 25023 – and the measuring items provided in the HCD-related standard ISO 9241-11 with respect to the 'efficiency' among the items designed for measuring usability.

With regard to 'minimization of support requests', ISO 9241-11 presents only the items for measuring 'productive time', whereas ISO 25022 provides a function to calculate the function on the productive time. Since this value is closer to 1, the productive time spent on the work compared to the total working hours is greater, which indicates that the effectiveness is higher.

For the 'Meet needs for infrequent or intermittent use', 'learnability', 'error tolerance', and 'UI readability', ISO 9241-11 presents the time spent on the work as measuring items. ISO 25022 provides functions for calculating the goal attainment values compared to the time as functions for measuring the effectiveness.

3.3. Satisfaction Measures of SQA/HCD

Table 4. Satisfaction Measures of SQA/HCD

Usability Objective	Measures in terms of HCD (Based on the ISO 9241-11)	Measures in terms of SQA (Based on ISO/IEC 25022, 25023)
Frequency of complaints	Frequency of complaints	X = Σ(Ai) Ai = Response to a question related to a specific feature
Discretionary use	Frequency of discretionary use	X = A/B A= Number of users using a specific function, application or system is used B = Number of potential users

		who could have used the specific function, application, or system
Meet needs for infrequent of intermittent use	Frequency of use	
Meet needs to walk up and use	Rate of voluntary use	
Meet needs of trained users	Rating scale for satisfaction with power features	Satisfaction with features X = Σ(Ai) Ai = Response to a question related to a specific feature
Minimization of support requirements	Rating scale for satisfaction with support facilities	Satisfaction with features X = Σ(Ai) Ai = Response to a question related to a specific feature
Error tolerance	Rating scale for error handling	Satisfaction with features X = Σ(Ai) Ai = Response to a question related to a specific feature
Learnability	Rate scale for ease of learning	Satisfaction with features X = Σ(Ai) Ai = Response to a question related to a specific feature
UI Legibility	Satisfaction degree about the ease with which a reader can recognize individual characters in text within a proper distance	Satisfaction with features X = Σ(Ai) Ai = Response to a question related to a specific feature

Table 4 shows a comparison between satisfaction measurement functions provided in SQA-related standards – ISO 25022 and ISO 25023 – and the measuring items provided in the ISO 9241-11 with respect to the satisfaction among the items for measuring usability. For the method of measuring satisfaction, both ISO 9241-11 and ISO 25022 adopt questionnaires where users determine the rating scale on each questions asking their satisfaction as using the software. Users can respond to questions with satisfaction in a feature questionnaire by selecting a value on a scale that could have two points (*e.g.* agree, disagree) or several points on a scale (*e.g.* ranging from strongly agree to strongly disagree) [6]. Trust, pleasure and comfort will be measured using a Psychometric scales.

3.4. Freedom from Risk

Freedom from risk is the main characteristic of the software quality-in-use, and it refers to the degree of mitigation of risk factors affecting the economic status of the system, human life, health or environment. Freedom from risk is divided into economical risk mitigation, health and safety risk mitigation, and environmental risk mitigation.

The economic risk mitigation refers to the degree on which the risk to the finance of the system or commercial assets is mitigated. The measurement functions used to evaluate the economic risk mitigation include the return of investment and sales performance

assessment. Since these are parts that can be measured mainly through the business of the sales department by a developer, this paper does not deal with it.

The environmental risk mitigation focuses on the degree to which a user mitigates the risks of environments (noise and environmental pollution) while using the system. For measurement of the environmental risk mitigation, national regulations are established to evaluate how much influence the system has on the environment. Since this part is beyond the work scope of the developer or shipping company, it is not dealt with in this paper.

The health and safety risk mitigation refers to the degree to which the risk on the health and safety of a user using the system is mitigated. The measurement of the health and safety risk mitigation is also a professional part that cannot be handled by the developer or shipping company.

SQA and HCD are performance and risk-based processes [3]. Hazards are identified, associated risks assessed and, if necessary, risk reduction and control measures are implemented to ensure an acceptable level of quality, usability and safety. - MSC.1/Circ.1512. Therefore, although this paper does not deal with measurement functions for the three risk factors, it is necessary to measure whether e-Navigation software mitigates the three risk factors sufficiently through related international standards, laws and specialized evaluation companies, and to reflect the results in the quality assessment.

3.5 Context Coverage

Context Coverage is the main characteristic of the software quality-in-use, and demonstrates the degree that can be used, while meeting the effectiveness, efficiency, satisfaction and freedom from risk attributes not only in the context of use in which the system is specified, but also in the context of use in which it is not specified at an early stage. In regard to this, the context of use includes goals to be achieved using the system, interaction between stakeholders, work in the actual operating environment, user properties (physical factors and cognitive abilities), and social environment (corporate operating policies and procedures).

To apply SQA/HCD to the e-Navigation system and software development is to not ask users to adapt to the system, but to design the system according to the user's requirements: such as user properties, and objectives and tasks performed by the user. Accordingly, although it is not an item provided by the HCD-related standards for measurement, the measurement of context coverage is necessary in e-Navigation software.

Table 5 shows context coverage measurement functions provided in ISO 25022.

Table 5. Context Coverage Measures

Name	Description	Measurement Function
Context Completeness	The proportion of the intended contexts of use in which a product or system can be used with acceptable usability and risk	X = A / B A = Number of contexts with acceptable usability and risk B = Total number of required distinct contexts of use
Flexible context of use	Extent to which the product can be used in additional contexts of use.	X = A / B A = Number of additional contexts in which the product would have acceptable quality-in-use B = Total number of additional contexts in which the product might be used
Product flexibility	Extent to which a product can be adapted to meet different user needs.	X = A / B A = Number of new requirements

		from specified users for which can be met by adapting existing features B = Total number of new requirements from specified users
Proficiency independence	Extent to which the product can be used by people without specific knowledge, skills or experience	X = A / B A = Number of additional types of user without specific knowledge, skills or experience who can use the product B = Total number of potential types of user without specific knowledge, skills or experience

4. Usability Measurement Function – Perspectives on Product Quality

The measurement functions of the six sub-characteristics defined when the usability is viewed from the perspective of software product quality is summarized in ISO 25023. This can be used if necessary in addition to the characteristics and items mentioned in the previous chapter.

4.1. Appropriateness Recognisability

The quality measures for appropriateness recognisability are used to assess the degree to which users can recognize whether a product or system is appropriate for their needs [7].

Table 6 shows appropriateness recognisability measurement functions provided in ISO 25023.

Table 6. Appropriateness Recognisability Measures

Name	Description	Measurement Function
Description completeness	What proportion of usage scenarios is described in the product description or user documents?	X = A / B A= Number of usage scenarios described in the product description or user documents B= Number of usage scenarios of the product.
Demonstration capability	What proportion of functions has demonstration capability for users to recognize the appropriateness?	X = A / B A = Number of functions with demonstration capability B = Number of functions that could benefit from demonstration capability
Entry point Self-descriptiveness	What proportion of the commonly used landing pages on a website explains the purpose of the website?	X = A / B A = Number of landing pages that explain the purpose of website B = Number of landing pages in a website

4.2. Learnability

Learnability measures are used to assess the degree to which a product or system can be used by specified users to achieve specified goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use [7].

Table 7 shows learnability measurement functions provided in ISO 25023.

Table 7. Learnability Measures

Name	Description	Measurement Function
User guidance completeness	What proportion of functions is explained in sufficient detail to enable the user to apply the functions in user documentation and/or help facility?	X = A / B A= Number of functions described in user documentation and/or help facility as required B= Number of functions implemented that are required to be documented.
Entry fields defaults	What proportion of entry fields that could have default values are automatically filled with default values?	X = A / B A = Number of entry fields whose default values have been automatically filled in during operation B = Number of entry fields that could have default values
Error messages understandability	What proportion of the error messages state the reason why the error occurred and how to resolve it?	X = A / B A= Number of error messages which state the reason of occurrence and possibly the ways of resolution. B= Number of error messages implemented
Self-explanatory user interface	What proportion of information elements and steps presented to the user enable common tasks to be completed by a first time user without prior study or training or seeking external assistance?	X = A / B A = Actual number of information elements and steps that are presented in a way that the user could understand B = Number of essential information elements and steps needed to complete common tasks for a first time user

4.3 Operability

Operability measures are used to assess the degree to which a product or system has attributes that make it easy to operate and control [7].

Table 8 shows operability measurement functions provided in ISO 25023.

Table 8. Operability Measures

Name	Description	Measurement Function
Operational consistency	To what extent do interactive tasks have a behavior and appearance that is consistent both within the task and across similar tasks?	X = 1 – A / B A = Number of specific interactive tasks that are performed inconsistently B= Number of specific interactive tasks that need to be consistent
Message clarity	What proportion of messages from a system can be understood easily?	X = A / B A = Number of messages that convey the right outcome or instructions to the user B = Number of messages implemented
Functional customizability	What proportion of functions and operational procedures can a user customize for his convenience?	X = A / B A = Number of functions and operational procedures which can be customized for user's convenience B = Number of functions and operational
User Interface customizability	What proportion of user interface elements can be customized in appearance?	X = A / B A= Number of user interface elements that can be customized. B= Number of user interface elements that could benefit from customization
Monitoring capability	What proportion of function's state can be monitored during operation?	X = A / B A = Number of functions having state monitoring capability B = Number of functions that could benefit from monitoring capability
Undo Capability	What proportion of tasks that has a significant consequence provides an option for re-confirmation or undo capability?	X = A / B A = Number of tasks that provide undo capability or prompt for re-confirmation B = Number of tasks for which users could benefit from having re-confirmation or undo capability
Terminology understandability	What proportion of the terminology used in the user interfaces is familiar to the users?	X = A / B A = Number of terms that would be understood by the intended users B = Number of terms used in the user interface.
Appearance consistency	What proportion of user interfaces with similar items has the similar appearance?	X = 1 – A / B A = Number of user interfaces with similar items but with different appearances B= Number of user interfaces with similar items

4.4. User Error Protection

User error protection measures are used to assess the degree to which the system protects users against making errors [7].

Table 9 shows user error protection measurement functions provided in ISO 25023.

Table 9. User Error Protection Measures

Name	Description	Measurement Function
Avoidance of user operation error	What portion of user actions and inputs are protected against causing any system malfunction?	X = A / B A = Number of user actions and inputs implemented to be protected against causing any system malfunction B = Number of user actions and inputs that could be protected against causing any system malfunction
User entry error correction	To what extent do detected user entry errors with an identifiable cause provide a suggested correct value?	X = A / B A = Number of entry errors which provide a suggested correct value. B = Number of entry errors detected
User error recoverability	What proportion of user errors can be corrected or recovered by the system?	X = A / B A = Number of user errors that are designed and tested to be recovered by the system B = Number of user errors which can be occurred during operation

4.5. User Interface Aesthetics

User interface aesthetics measures are used to assess the degree to which the user interface enables pleasing and satisfying interaction for the user [7].

Table 10 shows user interface aesthetics measurement functions provided in ISO 25023.

Table 10. User Interface Aesthetics Measures

Name	Description	Measurement Function
Appearance aesthetics of user interfaces	To what extent are user interfaces and the overall design aesthetically pleasing in appearance?	X = A / B A= Number of display interfaces aesthetically pleasing in appearance B= Number of display interfaces

4.6 Accessibility

Accessibility measures are used to assess the degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use [7].

Table 11 shows accessibility measurement functions provided in ISO 25023.

Table 11. Accessibility Measures

Name	Description	Measurement Function
Accessibility for users with cognitive disability	To what extent can potential users with limited cognitive ability successfully use the system (with assistive technology if appropriate)?	X = A / B A = Number of functions successfully usable by the users with cognitive disability. B = Number of functions implemented
Accessibility for users with physical disability	To what extent can potential users with limited physical ability successfully use the system (with assistive technology if appropriate)?	X = A / B A = Number of functions successfully usable by the users with physical disability. B = Total number of functions implemented
Accessibility for users with hearing disability	To what extent can potential users with limited hearing ability successfully use the system (with assistive technology if appropriate)?	X = A / B A = Number of functions usable by the user with hearing disability. B = Number of functions implemented
Accessibility for users with visual disability	To what extent can potential users with limited visual ability successfully use the system (with assistive technology if appropriate)?	X = A / B A = Number of functions usable by the user with visual disability. B = Number of functions implemented
Supported languages	What proportion of needed languages is supported?	X = A / B A = Number of languages actually supported B = Number of languages needed to be supported

5. Conclusion

With the publication of the Guideline on Software Quality Assurance and Human-Centered Design for e-Navigation for implementing e-Navigation strategies, the demand to apply SQA and HCD to the design and implementation of the e-Navigation system is expected to occur in the maritime sector. In this paper, the measurement methods of QIU from the aspect of SQA were analyzed and compared with those from the aspect of HCD in order to derive the method for measuring the usability. As a result, it was found that it is allowed to use the QIU measurement methods of SQA standards (including effectiveness, efficiency and satisfaction) with respect to the software in measuring the usability of equipment developed by applying HCD.

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