Software Quality Assurance in e-Navigation

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Abstract. The International Maritime Organization (IMO) has decided that e-Navigation should be 'User Need' led and take into account the Human Element. In this paper the Author, which is a member of the IMO expert group on e-Navigation since 2006, will describe the IMO guideline on software quality assurance in e-Navigation. The guideline highlights that software in support of e-Navigation may be a standalone product or part of a larger more complex system incorporating data and information management. The guideline introduces quality models to assist in identifying the characteristics of system software which allows for the successful harmonization, integration, exchange, analyses and presentation of maritime data and information to meet user needs.

Keywords: e-Navigation · IMO · ITS · Marine navigation · MSI · Transport telematics · Safety of sea transportation · Software Quality Assurance (SQA)

1 Introduction

The International Maritime Organization IMO expert group led by Australia is preparing the draft Guidelines on Software Quality Assurance (SQA) [3], developing standards to harmonize ship and shore e-Navigation. However, everything indicates that it will be a part of a larger document containing three previously separately considered guidelines on Human Centred Design (HCD) for e-Navigation systems, on Usability Testing, Evaluation and Assessment (UTEA) for e-Navigation systems and on Software Quality Assurance (SQA) in e-Navigation.

SQA is a set of processes that ensures software meets and complies with required quality specifications. The IMO guideline on SQA highlights that software in support of e-Navigation may be a standalone product or part of a larger more complex system incorporating data and information management. The guideline introduces quality models to assist in identifying the characteristics of system software which allows for the successful harmonization, integration, exchange, analyses and presentation of maritime data and information to meet user needs.

e-Navigation is a current international initiative that is intended to facilitate the transition of maritime navigation into the digital era, is a vision for the integration of existing and new navigational tools, in a holistic and systematic manner that will enable the transmission, manipulation and display of navigational information in electronic format [1, 7].

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2 The IMO Guideline on Software Quality Assurance

Navigation systems increasingly provide a variety of information and services for enhancing navigation safety and efficiency. These systems require the connection and integration of onboard navigational systems as well as shore-side support systems and involve the collection, integration, exchange, presentation and analysis of marine data and information.

The merits of navigation systems can be found not only in their range of functions but also underpinned by their trustworthy software and overall usability. The IMO guideline is intended to complement and support the principle requirements as specified under SOLAS regulation V/15 [3].

Achieving trustworthy software and usability in the development of complex systems requires a disciplined and structured approach. The IMO guideline encourages such an approach in the development and management of e-Navigation systems, with a particular focus on Software Quality Assurance (SQA) and Human Centred Design (HCD) that includes Usability Testing (UT). Systems so designed, developed and managed throughout their life cycle deliver improved user performance, being stable and resilient, and most importantly support users in low and high workload environments; such as during challenging navigation and environmental conditions when users are most vulnerable to making mistakes and when error management and recovery is essential. Other important benefits include limiting the amount of operator familiarisation training that is needed and the time and resources required for system maintenance and support.

There are some significant challenges associated with digital data and software quality, including the use of both existing and new forms of digital data and the software required to operate the various types of e-Navigation-related systems and equipment. Most likely, software-related issues will become a significant challenge for achieving harmonized ship borne and shore-based e-Navigation. For this to occur, an established means/process for software quality assurance (SQA) is needed.

SQA focuses on defining and testing software quality and how that helps meet user requirements to ensure that high quality, robust, testable and stable software is used in e-Navigation systems. e-Navigation software quality needs to be evaluated to ensure relevant quality characteristics meet the requirements of the system.

The basic premise of HCD is that systems are designed to suit the characteristics of intended users and the tasks they perform, rather than requiring users to adapt to a system. UT is a key component of HCD and uses methods that rely on including users to test the ability of systems to support user needs. UT helps to identify potential problems and solutions during design and development stages by using an iterative approach to testing where the design evolves through rounds of prototyping, testing, analysing, refining and testing again.

The combination of SQA and HCD (including UT) provides opportunities to guide system design and development to improve data quality and information analysis, and to generally meet user needs and enhance safety.

The IMO developed guideline is not intended to be the sole source of guidance for SQA and HCD and associated activities. Rather, it is intended to provide a general understanding

of SQA and HCD for the effective design and development of e-Navigation systems. It draws extensively on existing relevant international standards.

3 Scope of the IMO Guideline on SQA

The scope of the IMO guideline on SQA is to provide an overarching document to ensure that e-Navigation quality design attributes are included in the development of e-Navigation systems. Figure 1 provides an overview of the quality design attributes that should be considered and includes "product and data quality", "meet user needs", "security" and "functional safety". This guideline mainly addresses software quality which incorporates "product and data quality" and "meet user needs". Consideration of all the design attributes will help ensure that software and human-based risks are addressed. Figure 1 also provides information on relevant standards that developers and designers of e-Navigation systems should consider in ensuring all quality attributes are addressed ensuring overall system quality.

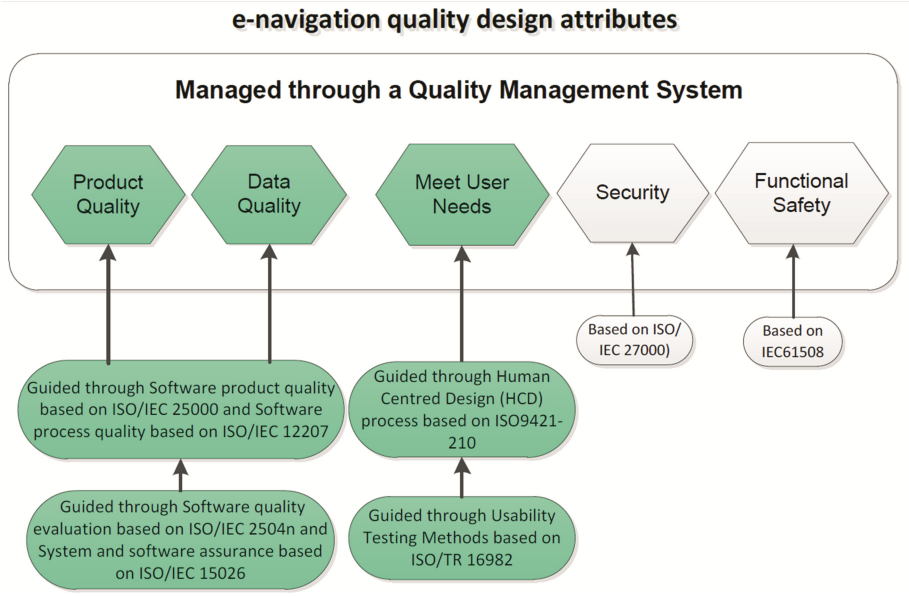

Fig. 1. Concepts and standards for e-Navigation quality design attributes [3]

This guideline is intended to be used by all stakeholders involved in the design and development of e-Navigation systems, with its primary users being those that develop and test e-Navigation systems. Stakeholders include equipment designers and manufacturers, system integrators, maritime authorities and regulators, ship-builders, ship owners, operators, Vessel Traffic Service authorities and Rescue Coordination Centres, and other relevant international organizations such as the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the International Hydrographic Organization (IHO).

Table 1 provides a summary of stakeholder involvement in the application of this guideline at each of the e-Navigation system life cycle stages.

Table 1. Stakeholder involvement [3]

Life cycle Stage	Stakeholder
Analysis Operational System Feedback	Manufacturers/system designers, users, ship owners/operators, regulatory authority
Stage 1: Concept development	Manufacturers/system designers, users
Stage 2: Planning and Analysis	Manufacturers/system designers, users
Stage 3: Design	Manufacturers/system designers, users
Stage 4: Integration and Testing	Manufacturers/system designers, users, approval authority (regulator), owners/operators
Stage 5: Operational	Users, owners/operators and manufacturers/system designers
Disposal	Owners/operators and manufacturers/system designers

The requirements in this guideline are goal based and are not intended to specify or discourage the use of any particular quality assurance, management process, or testing method. Hence, detailed and prescriptive design requirements, which specify design solutions, are not covered.

It is recommended that users of this guideline be generally familiar with contemporary quality management processes, software quality assurance and human factors.

This guideline does not address training requirements.

4 Definitions of Terms Related to SQA

There are the following definitions of essential terms related to SQA [3]:

e-Navigation: The harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth-to-berth navigation and related services for safety and security at sea and protection of the marine environment [1, 7–9].

Human Factors: The scientific discipline concerned with the application of validated scientific research about people, their abilities, characteristics and limitations to the design of systems they use, environments in which they function and interact, and jobs they perform to optimize human well-being and overall system performance [6].

Human Centred Design (HCD): An approach to system design and development that aims to make interactive systems more usable by focussing on the use of the system; applying human factors, ergonomics and usability knowledge and techniques.

The term "human-centred design" is used rather than "user-centred design" in order to emphasize that this process also addresses impacts on a number of stakeholders, not just those typically considered as users. However, in practice, these terms are often used synonymously.

Software Quality Assurance (SQA): A set of processes that ensures software meets and complies with required quality specifications. Designated SQA processes align with a system design life cycle.

Usability Testing (UT): Evaluation methods and techniques used to support Human Centred Design (HCD) and used for the purpose of increasing the usability of a system.

5 Quality Management System

It is recommended that SQA, HCD and associated activities are performed using a quality management system such as ISO/IEC 90003:2014 or relevant standards to ensure that quality requirements are embedded in the development life cycle process to achieve software quality, meet user needs and enhance safety of e-Navigation systems.

This guideline can be applied to the design of systems with varying levels of complexity, regardless of whether a new system is being developed or an existing system is being modified.

Figure 2 shows a typical generic life cycle [3] with the stages recommended as a minimum for the application of this guideline to the development of e-Navigation systems:

- Analysis of operational system feedback;
- Stage 1: Concept development;
- Stage 2: Planning and analysis;
- Stage 3: Design;
- Stage 4: Integration and testing;
- Stage 5: Operation; and
- Disposal.

The aim of SQA, HCD and associated UT activities is to ensure that for each stakeholder, user and task requirements are considered in the development process. This takes into account interactions between people, technology and the physical and organisational environments within which they work. Outcomes can be maximised if SQA, HCD and associated activities are applied by teams with relevant multi-disciplinary skills and experiences.

SQA and HCD are performance and risk based processes. 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. Because they are performance-based processes, validation is based on how the outcomes are achieved.

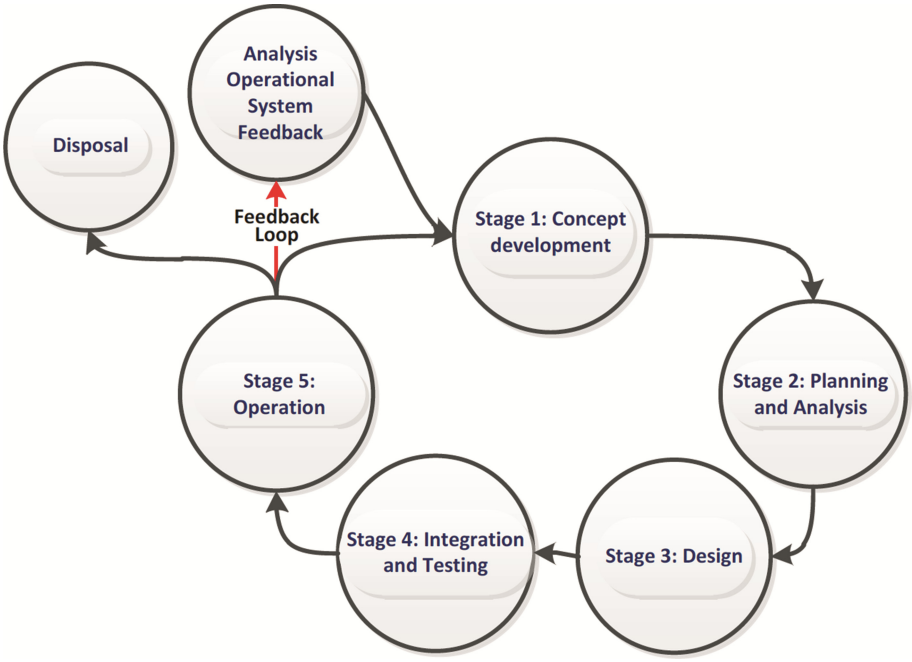

Fig. 2. Generic life cycle [3]

6 Software Quality Assurance

Key to ensuring software quality in e-Navigation is to address the quality attributes that need to be considered in the development and design of e-Navigation systems as highlighted in Fig. 1. Software in support of e-Navigation can be a product on its own, or part of a larger system and includes data and information. A key function of e-Navigation software is to harmonize, integrate, exchange, present and analyse maritime data and information to meet user needs.

Functional Safety: The performance of systems related to e-Navigation software should be assured in terms of required functions and level of integrity. The reliability and availability of safety related functions should be specified based on stakeholder requirements and traceable through documentation. Functional safety requirements should be defined, implemented and managed throughout the life cycle. The required level of functional safety can vary depending on the designed functionality and intended use, and should be determined by an appropriate risk based process. Guidance for ensuring functional safety is provided in IEC61508 [2] or relevant standards.

Security: It is important to consider and properly address security to prevent cyber-attacks, hacking or other illegal intrusions. Any e-Navigation implementation should provide a secure digital environment, in particular addressing avoidance, prevention and detection of any cyber security threats, locally, regionally and internationally. ISO/IEC 27000 [5] or relevant standards provides guidance on software and cyber security.

Software Quality Models for e-Navigation: This section introduces three types of quality models for e-Navigation software systems that are defined by the ISO/IEC 25000 series [4]: product quality, data quality and quality-in-use.

The product quality model categories are: functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability and portability. It should be noted that ISO 25010 [4] uses "usability" to describe the attributes that confer quality-in-use. The usage of usability in this guideline is different but very close to quality-in-use.

Software quality is also dependant on the quality of input data, which should conform to relevant international standards. As shown in Fig. 1, data quality is one of the key attributes of e-Navigation systems. Data quality requirements and data quality characteristics should be based on ISO/IEC 25012 [4] and related standards (i.e. International Hydrographic Organization (IHO) standards for nautical information including Electronic Navigation Charts (ENC)). These standards propose a general data quality model to support organizations to acquire, manipulate and use data with the necessary quality characteristics.

A systematic approach to ensure data quality is recommended, and can include:

- defining and evaluating data quality requirements in data production, acquisition and integration processes;
- identifying data quality criteria, also useful for re-engineering, assessment and improvement of data; and
- evaluating the compliance of data with legislation and other relevant requirements.

Producers of input data should have life cycle management practices in place to handle possible data format changes during the life cycle. These life cycle management practices should include timely announcements to software producers and end users about such changes. As part of the DQA producers of input data should test all data in service for conformance with relevant international standards.

The quality in use of a system characterizes the impact that the product (system or software product) has on stakeholders, measuring effectiveness, efficiency, freedom from risk and satisfaction in specific contexts of use. It is determined by the quality of the software, hardware and operating environment, and the characteristics of the users, tasks and social environment. All these factors contribute to the quality in use of the system. Examples of quality in use measures are given in ISO/IEC ISO/IEC 25024 [4].

Software quality evaluation: The required software quality depends on the intended use or objectives of the system of which the software is a part. Software products need to be evaluated during design, implementation and integration to determine whether the relevant quality characteristics are met.

Software quality evaluation processes are defined in relevant international standards, such as ISO/IEC 25040 which contains the following activities [3]:

- define the purpose and scope of the evaluation and identify software quality requirements;
- specify and develop the quality measures and establish decision criteria;
- develop the evaluation plan;

– carry out the evaluation applying quality measures and the decision criteria; and
– review the evaluation results and prepare an evaluation report and provide feedback.

For each activity identify applicable measurement tools, constraints, inputs and outputs. Outputs of previous activities can be used as inputs to subsequent stages. The first activity may include output from previous evaluations as an input.

When an evaluation is performed concurrently with software product development, associated activities can be performed as part of software life cycle processes (ISO/IEC 12207 or relevant standards) and/or system life cycle processes (ISO/IEC 15288 or relevant standards).

Figure 3 outlines the main activities that should be undertaken in the software life cycle, as below [3]:

– Pre-activity: Conduct preliminary hazard analysis;
– Activity 1: Stakeholder and system requirements definition;
– Activity 2: System requirement analysis;
– Activity 3: Software architecture design and implementation;
– Activity 4: Software testing, installation and acceptance;
– Activity 5: Software operation and maintenance; and
– Activity 6: System disposal.

Activity 1: Stakeholder and system requirements definition
This activity involves specifying the required characteristics and identifying the context of use of the system being developed. During this activity validation and conformance requirements of the system will also be identified.

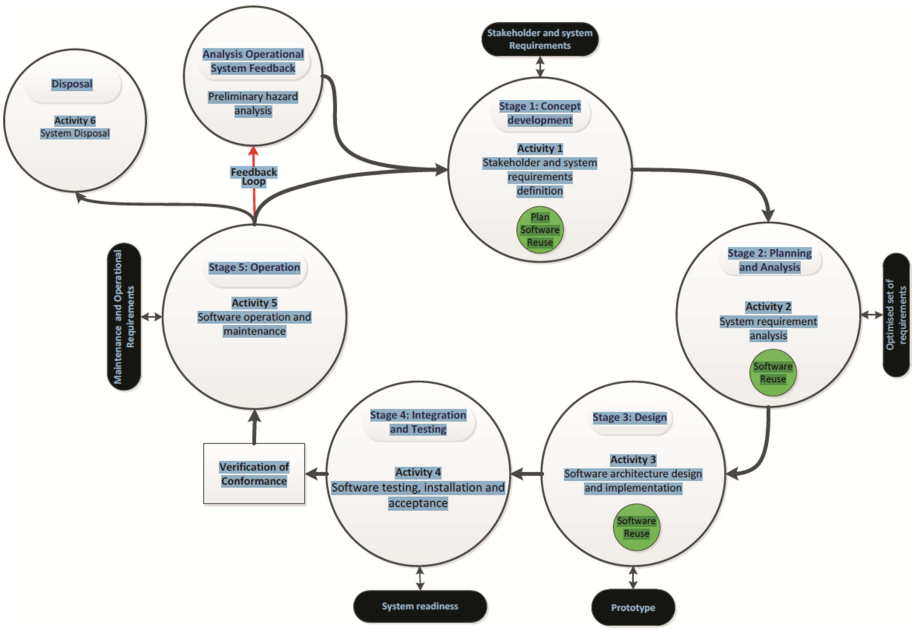

Fig. 3. Overview of Software Quality Assurance activities [3]

Activity 2: System requirements analysis
This activity involves defining a set of functional and non-functional system requirements with various configurations developed in order to ensure an optimized solution. This activity results in a prioritized, approved and updated set of system requirements including SQA requirements which are consistent and traceable.

Activity 3: Software architecture design implementation
This activity involves defining and structuring the elements of the system, ensuring it meets defined software quality requirements. The verification between the system requirements and the system architecture should also be carried out during this stage. A strategy for software integration based on the priorities of the system requirements needs to be developed with criteria to verify compliance.

An important aspect to be considered during the early stages of software design is software reuse. This needs to be considered during stages 1 to 3 of the software life cycle. Software reuse is the use of existing software assets in some form within a software development process. Software assets include products from prior developments such as components, test suites, designs and documentation. Software assets may be modified as needed to meet new system requirements.

Activity 4: Software testing, installation and acceptance
This activity ensures that the integrated software is compliant with the system requirements. Appropriate methods and standards for testing software should be developed to ensure the reliability and validity of the software qualification test and as much as possible conformance to expected results. Software qualification testing should take place in its intended operational environment. As previously mentioned, appropriate test data sets provided by relevant international organizations such as IALA, IHO, etc. should be used to ensure conformance with shore based data. An important pre-condition is to ensure that the use of shore and ship based data has been subject to a DQA process. This activity also involves evaluating and testing the integrated system using pre-defined criteria with evidence produced demonstrating quality assurance.

Verification of conformance: It is recommended that certificates of conformance with existing software and data quality should meet relevant standards to ensure the verification of software systems.

It is recommended that the verification process for e-Navigation SQA be carried out by reviewing the related documents on e-Navigation software system or data, by inspecting the implementation of the e-Navigation software system and testing the software functions. It is recommended that the testing environment covers berth-to-berth operation, ship-to-ship communication, ship-to-shore communication as well as shore-to-shore communication.

Activity 5: Software operation and maintenance
This activity involves the identification and evaluation of conditions for correct operation of the software in its intended environment. An operation and maintenance strategy needs to be developed in consultation between the software developers and users. This will ensure that any software and system modifications, upgrades, changes to the existing system interface and updating of system and software documentation are appropriately managed and do not compromise product requirements or safety.

Activity 6: System disposal
A system disposal strategy should be developed to facilitate knowledge retention and analysis of long-term impacts. A hardware disposal strategy should also be developed to promote the use of non-hazardous materials during manufacturing.

7 Conclusion

The combination of the five e-Navigation solutions, and the three guidelines, Guidelines on Human Centred Design (HCD) for e-Navigation, Guidelines on Usability Testing, Evaluation and Assessment (U-TEA) for e-Navigation systems and Guidelines for Software Quality Assurance (SQA) in e-Navigation, proposes an e-Navigation implementation that facilitates a holistic approach to the interaction between shipboard and shore-based users.

To provide the benefits for all stakeholders, regarding on software/system/software service and data used in software through the life cycle Customers can be served qualified software/data. Providers can verify their qualified software/data. e-Navigation SQA will support the two types of viewpoints by how to dealing with.

SQA process will be designed in detail. Key activities will be developed for the SQA process. Practices will be developed for support the SQA process.

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