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HUMAN FACTORS AND ERGONOMICS IN VTS

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1. INTRODUCTION

VTS is recognized as a complex socio-technical system where operators, organization and technology and the interactions between them play a crucial role in the quality, safety and efficiency of VTS services. Human factors and ergonomics support workplace activities in terms of:

- collecting information about work activities and setting in which they are performed;
- what to do to make it better; and
- how to explain and measure the possible benefits of the change.

1.1. AIMS AND OBJECTIVES

This Guideline provides awareness regarding the role of the human factor in the performance of a VTS. It is intended to present a source of information to assist the VTS provider in the preparation and implementation of systems to support operational performance. It is not intended to provide specific information on the safety culture or portrayal of data.

Furthermore, this Guideline provides guidance in implementing human factors during the training cycle (e.g., initial On-the-Job, recurrent, updating and adaptation training).

This Guideline is associated with Recommendation *R0119 Establishment of a VTS*, which is a normative provision of IALA Standard *1040 Vessel Traffic Services (*VTS). This Guideline specifies best practices and may be observed as necessary.

2. VTS AS SOCIO-TECHNICAL SYSTEM

2.1. OVERVIEW

Traditionally, technological advancements have been a driver for research and development activities in the VTS domain. Thus, many activities have primarily focused on the development of technical equipment and information sources within the domain. However, in the past 15 years, an increasing body of work has taken a human factors approach rooted in a socio-technical systems perspective to increase the understanding for interactions across operators, technology, and organization). In recent years, an increased focus on future VTS operations and the potential of human-autonomy interactions within shore operation centres has developed [1].

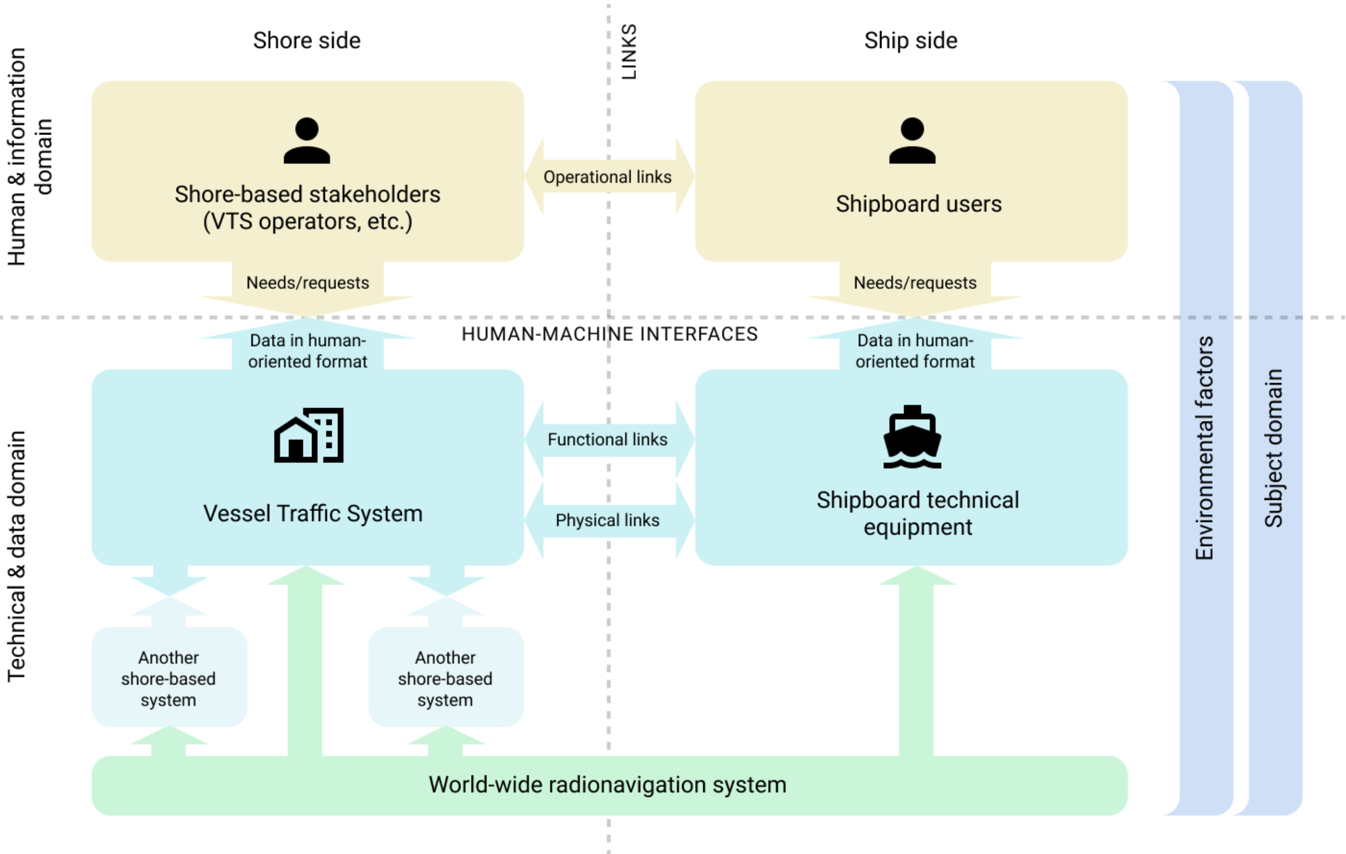

Figure 1 VTS as socio-technical system

VTS can be considered as a socio-technical system (see Figure 1) where operators provide services to a larger variety of customers. While staffing and local organization might differ, VTS is very often, but not always, part of a port system, including VTS, pilot services, tugs, ship/s and crew/s. Studies have shown that all the actors in this system need the same information but perhaps at different levels of granularity [2][3]. Thus, coordination and cooperation among the different actors within the port system become a key for the service's quality, and the overall safety and efficiency of traffic movements within the area.

Figure 2 highlights the complexity of the work environment for VTS operators. The operator provides information services in an area that is located on the port entrance of one of northern Europe's largest ports. Within the centre, the operator is collocated with operators for the pilotage ordering service and the port. Thus, information for service provision can be gained both through the decision support system, VHF radio and from other services.

Figure 2 VTS Operator in Gothenburg VTS centre

When addressing the purpose of VTS, information from the different sources available (Figure 3) are used by the operator, thus drawing attention to both physical (e.g., proximity to other services or workstation layout), and cognitive aspects (e.g., decision making, interpretation of current traffic picture in the VTS area and reactions with multiple communication means). This forms the daily routine of VTS.

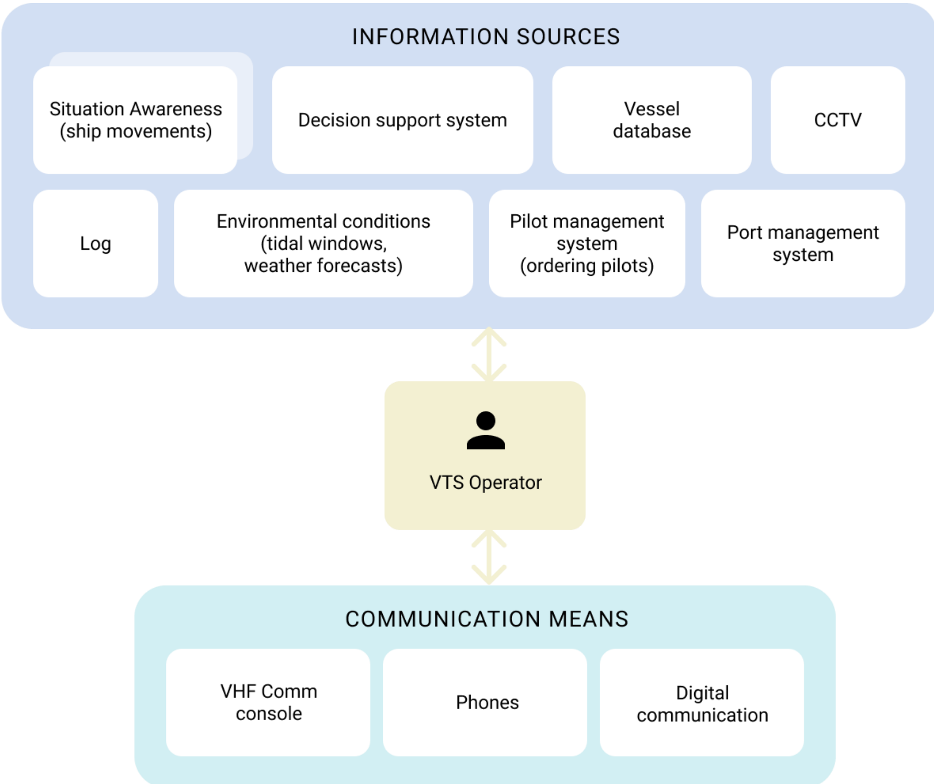

Figure 3 Information sources and communication used by a VTS Operator

Therefore, the operator's expertise and experience based on both technical and non-technical skills become crucial for the service provision [4][5]. In addition to the physical and cognitive aspects of the work, the organizational framework of the VTS, including training, service and staffing levels, operational procedures and integration with other services, also shape the precondition of work [6].

2.2. CHARACTERISTICS

Table 1 (adopted from [7]) presents an overview of the characteristics of VTS as a socio-technical system. As there are many different organizational, human, and technical aspects to the VTS operations, human factors and ergonomics become important facilitators to design a system that can balance quality, safety, efficiency, and economic aspects of operations.

Table 1 Characteristics of socio-technical system applied to VTS

Characteristic	VTS
Interactions of various layers	• External interactions with vessels, allied services, general public • Interactions with multiple equipment, including operational procedures and maintenance/service
Large problem domain	Complexity of everyday work based on: • subject domain knowledge (regulations, best practices, etc.) • uncountable number of variables (ship-related, environmental, geographical, technical etc.).
Dependence on communication and coordination	Multiple means of communication: • VHF as main means of coordination through communication between vessels and shore • Phone, email, information systems of allied services
Distributed	• VTS personnel operating in co-located/different centres, communicating to each other • Dependency on remote sources of information
Dynamic	Multiple dynamic elements in VTS affecting: • Ships moving independently • Changing shifts of VTS personnel • Dynamic environment (weather, hydrographic situation, navigational constraints — for instance, military exercises) • Technical constraints (evolving and changing systems, equipment failures and maintenance, etc.)
Couplings	Complex net of technical, human, and organizational functions
Automation	• Decision support system • Technical innovation • New developments affecting VTS (i.e., MASS)

3. HUMAN FACTORS AND ERGONOMICS

Human factors and ergonomics describe the scientific discipline and domain of practice concerned with the understanding of interactions among humans and other elements of a system [8]. Human factors and ergonomics as terms that are used interchangeably along with user experience (known as UX). Human factors are often referred to in American settings, while the ergonomics is more commonly used within Europe. In this document, the term human factors is used.

Human factors apply theory, principles, data, and methods to design to optimize human well-being and overall system performance.

Human factors is a systems approach to understand human work in complex environments. As an approach, human factors is holistic. It includes the design and evaluation of tasks, jobs, products, environments, and systems considering physical, cognitive, and organizational factors. Work and work settings are analysed taking human operators, systems, and work environment into concern.

Based on the approach of the International Ergonomics Association (IEA), the three main areas of human factors are:

- *Cognitive factors*: related to perception, memory, reasoning and motor responses, human-computer interaction, communication, and teamwork.
- *Physical factors*: related to human anatomy, physiology, anthropometrics, and biomechanics.
- *Organizational factors*: related to operating procedures, shift schedules, administration, regulations.

Each of these factors have overlapping areas which need to be considered in interactions within the operational environment.

3.1. HUMAN – TECHNOLOGY – ORGANIZATION

The human-technology-organization (HTO) is an analytical framework within the human factors domain. The approach is rooted within the nuclear power industry. It was in the late 1990s as a response to the increasing need to create a deeper understanding for the complex interplay between human operators, technology, and organization in safety-critical operations [9]. The HTO perspective emphasizes the importance of understanding the interactions and interdependencies between a socio-technical system's human, technical and organizational parts (Pot). Since the late 1990s, this perspective has gained an increased acknowledgement and is now applied across many different industries.

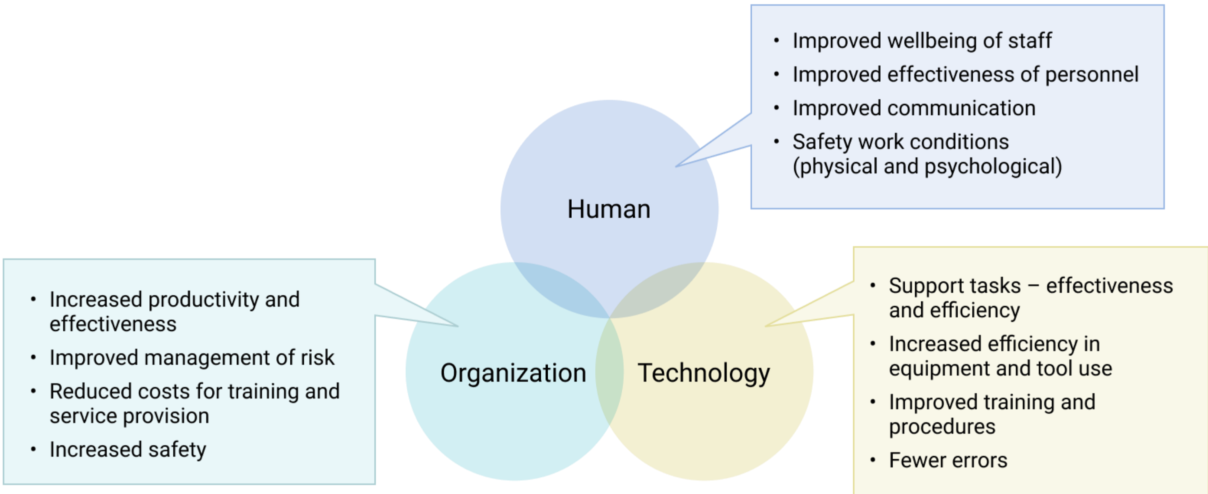

Figure 4 Potential benefits of HTO-approach

Within this document, it is suggested that an HTO perspective be adopted, with specific focus on system performance can be understood and support operator well-being. The benefits of applying an HTO-perspective to system design and analysis are exemplified in Pot (adopted from [10]). The figure shows potential improvements in three categories: Human, Technology and Organization.

Adopting an HTO to VTS may help to structure discussions on how the work environment - technology, operator, and organization - are coupled to each other. It can also emphasize the need to acknowledge the interactions and interdependencies among these to shape the precondition for safe and efficient service provision in the VTS domain.

3.2. SITUATION AWARENESS

In the context of VTS systems, situational awareness is a major systematic characteristic requires particular attention. It is the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status [11].

Supporting a proper level of situation awareness across all stakeholders (including VTS staff, vessels crews, allied services personnel, etc.) is crucial for safety and to support the purpose of VTS. The role of human factors to support this situational awareness is extremely important because it relies on cognitive and physical particularities, working environment, practical implementation of information delivery, etc.

4. HUMAN FACTORS AND ERGONOMICS IN VTS OPERATIONS

VTS can be considered as a complex socio-technical system. There are multiple aspects, which may affect operator work, system performance and operator well-being. Table 2 presents key areas to address within the design, evaluation and assessment of VTS systems based on the HTO framework; these are covered in more detail later in this section.

To acknowledge the difference between VTS systems world-wide, a fourth category, environment, has been added, noting service provision, service level, and demands may vary. These factors are taken into consideration for the VTS Operational area, including specific aspects of the fairway, traffic, meteorological and hydrographic elements.

Table 2 Human factors in VTS

Category	Key Areas to Address
Human	• Performance and shaping factors (workload, stress, fatigue) • Attitudes and commitment • Technical skills (expertise/operational experience, e.g., conflict detection and management, service provision) • Non-technical skills (communication, decision-making, situation awareness/sensemaking, leadership, teamwork, task management, problem solving, creativity)
Technology	• Human-centric design • User needs • Information presentation/representation • Level of automation and human-automation interaction • Information structure and integration of sensors within the VTS system • Workplace design

Category	Key Areas to Address
	• Workstation design • Physical workstation arrangements/spatial design
Organization	• Preconditions for work (work schedule, staffing, selection criteria) • Resilience/High reliability • Procedures – Standard Operating Procedures (SOPs) etc. • Training provision • Training needs analysis • Assessment and evaluation techniques • On the job training • Safety and quality management • Appraisal procedures • Reporting system (e.g., incidents/accidents) and follow-up procedures including organizational learning • Working conditions (light, noise, temperature)
Environment	• Operational environment/service integration within port system • Particularities of geographic error • Weather and other environmental factors

4.1. HUMAN ASPECTS

Humans and machines differ by nature. They have their own particularities that affect the overall organization, and it would be limiting to take a purely technical approach. To improve efficiency of the socio-technical VTS system, understanding of particularities of both humans and machines is needed.

4.1.1. SENSORY INPUTS

Humans get the information from the external world by sensory inputs. The most critical inputs are vision and hearing because most of the information is received by them. Other senses, such as touch and smell, are also important, but are used less consciously. For instance, touch response helps to quickly identify hardware controls without direct observation, while smell allows to identify hardware failures because of short circuits or before to respond to fire before it is too late. Every sensory input has its own particularities, possibilities, and limitations.

It is important to consider the relative bandwidth. This is the limitation of the information that can be perceived in time. Compared to the machines, the bandwidth for humans differs depending on the circumstances and human state (e.g., fatigue). If there is more information provided than current bandwidth allows, the human gets overloaded, and critical signals may be ignored.

4.1.2. MUSCLE RESPONSE

Humans interact with the external world using their muscles, and their voice. For VTS this is mostly through manipulation of hardware (dedicated buttons, keyboards, mouse and touchscreens) and changing position to get better access to specific input and output devices.

Muscle motions are separated into two major types: gross motor skilled actions, that require less efforts, and more precise fine motor actions, that require more attention. For example, swipe gesture on touch screens is gross motor actions, while pointing to specific area on display with a mouse is fine action. Properly designed workflows and layouts considering these types of actions allow to increase the speed of interaction and avoid fast fatigue.

4.1.3. MEMORY

Human memory is one of the factors that are used for decision making. Three types of memory are identified:

- *Short term* — this memory is very fast compared to other types but has low volume and duration which affects the amount of perceived information we can process at any given time. The information in short term memory is easily replaced with new inputs and we typically don't recognize that something is lost
- *Mid term* — this memory has more volume, but it is harder to access. It can be subject of multiple distortions and biases, however, it helps to keep the overall context of the situation
- *Long term* — this can be termed the knowledge that we have. It can be fast but requires regular updates to be used effectively. Also, it Is easier to put information with strong emotional connection into the long-term memory, which can be critical for training — it is naïve to expect that a single formal training will be enough for further effective work process.

4.1.4. COGNITION FACTORS

Table 3 briefly highlights basic cognition shaping factors which critically affect human performance. Disregarding these factors typically results in a drop in efficiency of performance.

Table 3 Cognition factors

Factor	Description
Single focus of attention	Humans are not able to perform several tasks simultaneously, it is possible only to switch with relatively slow speed between tasks, depending on their complexity. Also, under stress, the focus on specific (recognized as critical) task can lead to "tunnel perception" — any other inputs can be ignored, even if they are distinct, strong and lead to dangerous situations.
Learning curve and automated actions by reflexes	Some time is needed to start using the system in the most effective way — conscious actions are transformed into subconscious, automatic actions, that are based on the mechanics of conditional reflexes. It can significantly increase the speed, but reflexes can lead to their own issues, because they result in loss of conscious awareness.
Fatigue	Long activities, especially monotonous ones, decrease the efficiency of the humans because of fatigue, that affect all human capabilities: perception, cognition and decision making, response etc. Multiple incidents across all industries are caused by fatigue and improper fatigue management at organizational level.
Stress	Stress is a situation of internal resources mobilization under the threat of dangerous consequences. In short term, it can significantly raise the efficiency of operator, but right after it the efficiency decreases significantly because of fast fatigue. As it was mentioned, stress can also cause tunnel perception.
Errors	Humans are prone to errors. The following types of errors are differentiated [12]: • Slips of actions ("not doing what is expected") • Lapses of memory ("forgetting to do something midway through the task") • Rule-based and knowledge-based mistakes ("decision making failures") • Biases Biases relate to the "mistakes" type of the error, and they are based on multiple perception and cognition particularities, that are result of evolution. Basically, biases are based on "survival best-practices", but they tend to affect the performance in the irrelevant situations, that are not recognized as such.

Factor	Description
	Informing during training about cognitive biases as well as other types of errors is a critical step for their prevention, but their minimization requires systems approach, including proper organization and design of the system etc.

4.2. TECHNOLOGICAL ASPECTS

Some of the technological aspects are covered in Table 4:

Table 4 Technological aspects

Aspect	Description
Automated systems	Automated systems are used to decrease workload on humans, but they are also source of subsequent side effects, which require higher technical level of expertise, dependency on the uncontrolled (hidden) technical factors, etc. More sophisticated systems require more maintenance, training, and if they are designed in non-human-centric way, it creates potential of human errors and major incidents by their own reasons.
Ergonomics and safety of workplace	Ergonomics is the study of people's efficiency in the working environments — it covers the factors, related to organization of workspaces, including working room conditions and arrangement, workplaces layout, safety and comfort to provide the environment for optimum performance.

4.3. ORGANIZATIONAL ASPECTS

Some of the organizational aspects are covered in Table 5:

Table 5 Organizational aspects

Aspect	Description
Subject domain	Subject domain defines top-level formal aspects of VTS activities: • Formal VTS objectives and role • Regulations and procedures defined by top-level authorities • Language that is used (including standard terms, phrases, professional slang, multiple languages usage and probable language barriers etc.)
Organization	• Standard operating procedures (SOPs) • Resource management procedures — similar in some extent to Cockpit Resource Management (CRM) in aviation and Bridge Resource Management (BRM) in shipping companies that support effective usage of technical and human resources during 24/7 routine and emergency activities • Approach to initial and regular training procedures, how formal or goal-oriented they are
Culture	Traditions, that exist in every organization and affect formal and informal relations between VTS staff, especially between operators and their supervisors, less experienced and more experienced colleagues. One particular aspect is openness to discussions — culture of best practices exchange and error tolerance in organization. In some organizational cultures less experienced colleagues that

Aspect	Description
	recognise human errors made by more experienced tend to consider that this is their false misinterpretation and don't raise their concerns, taking passive role in evolving situations.
Financial	Even with non-commercial nature of VTS systems, availability and limitations of financial resources affect the overall effectiveness and safety of VTS organization in following ways: • Amount of available personnel and, as consequence, their workload, expertise and motivation • Availability and coverage by technical equipment, including regular upgrades • Availability of comfortable working conditions

4.4. ENVIRONMENTAL ASPECTS

Environmental aspects cover a wide range of contexts related to a specific VTS, such as:

- Geographic extent and particularities of area
- Weather and other environmental conditions, including forecasts
- Military and Coast Guard divisions, Maritime Rescue Coordination Centres (MRCCs), port infrastructure and other organizations operating in the same area that require interaction between operators

5. RECOMMENDATIONS TO ORGANIZE HUMAN FACTORS ACTIVITIES IN VTS

This section of the document contains practical recommendations to support human factors and corresponding activities in VTS centres.

5.1. MAKING HUMAN FACTORS PART OF VTS ACTIVITIES

This section provides recommendations how to embed human factors in VTS organization and activities.

5.1.1. HUMAN-CENTRIC DESIGN PROCESS

A VTS should consider human factors when making decisions about the human-centric design and implementation process, that is basically irrelevant to application — whether these are the user interfaces of VTS information systems, working area spatial design or development of standard operational procedures.

Figure 5 illustrates human-centric design (HCD) process (adopted from IMO MSC *Circ. 1512*):

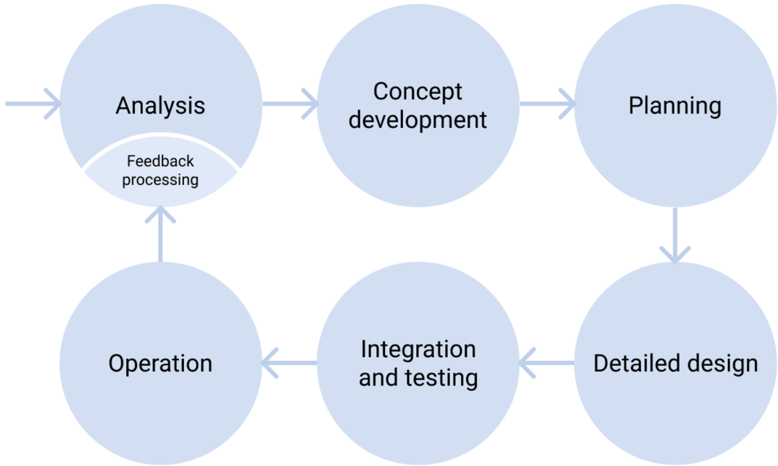

Figure 5 Steps of human-centric design process

The process is iterative, and is divided into the following steps:

- *Analysis*
  During this step all the requirements to the product (as final outcome of process) are gathered from stakeholders and other sources, analysed and defined, including high-level goals, business and functional requirements, user roles and needs.
- *Concept development*
  The conceptual decisions are made how to organize the product design, what are its principles, primary workflows and scenarios, already considering human particularities, limitations and needs. Detailed aspects are not covered, to get the bird's-eye view of the final product and check the vision with stakeholders.
- *Planning*
  Based on conceptual design, the real development activities are organized and planned, including dedication of human and financial resources, risks assessment, definition of the schedule.
- *Detailed design*
  At this phase all necessary details are defined and developed.
- *Integration and testing*
  All the decisions made during the previous phases are to be verified internally for human factors and validated with real users and operators. This guarantees that they are not isolated or irrelevant to particular aspects of human factors and ergonomics, and that sufficient feedback is gathered and considered.
- *Operation*
  Only after previous steps starts the real operation/usage of the resulting product. The feedback is gathered regularly, and based on it, next iteration of product development/improvement can be started.

This process illustrates that human factors activities are not just a single "did-it-and-forgot-it" sequence. It is recommended to perform the process consistently during the whole lifecycle of the system, especially when there are major changes in design, regulations, or after incidents occur.

5.1.2. TRAINING HUMAN FACTORS

Training plays a significant role to emphasize human factors and their role. With proper training activities, all the VTS personnel become aware of the role of human factors in safe and efficient daily routines and the prevention of accidents.

It is recommended to consider the following training activities:

- Initial training for new VTS operators - cover human factors in general, their role in accidents, best practices to prevent them, review of critical elements and risky situations based on the historical incidents and accidents.
- Regular training - keep the awareness of human factors at the appropriate level, that briefly cover topics from initial training.
- Ad hoc training – focus on the topics that are identified as necessary to be improved based on previously held analysis of recent VTS activities and/or new incidents occurred both in the particular VTS and outside it. It requires to have information channels organized to get fresh and important reviews about human factors related topics, including incidents — for instance, review of official investigation reports.

The training may include the following recommended topics:

- General explanation of human factors role in VTS
- Components of human factors (those identified in this Guideline)
- Typical human errors to be aware of:
  - Errors in perception
  - Errors in cognition
- Typical risky situations where human factors play significant role and affect the safety and performance (see ANNEX B).

The training materials and procedures should not be limited to a formal training approach, but should also provide practical guidance, examples (such as reviews of past situations and accidents occurred) and best practices.

5.1.3. QUALITY ASSURANCE

Human factors should be included in quality assurance procedures of a VTS centre. To facilitate this, a VTS Provider may consider having access to a human factors specialist who can supervise the state of human factors and consider all aspects mentioned in this guideline, including operational workplace conditions, training, communication with manufacturers related to equipment ergonomics and usability, etc.

To track the state of human factors in the VTS centre, the human factors specialist can use quality and performance metrics, such as those provided in ANNEX C.

Special procedures and the authority to address human factors by the VTS Provider could be defined and included in a role within the VTS.

5.2. VTS SETUP RECOMMENDATIONS

In this section some practical recommendations about VTS setup are provided. ANNEX A contains general checklist of workplace ergonomics with additional details.

5.2.1. WORKING ENVIRONMENT

An important part of human factors is related to the organization of comfortable environmental conditions, considering light, noise, temperature and air quality:

- Avoid direct sunlight, and glare from artificial light on shared wall-mounted and workstation displays.
- Minimize ambient and equipment sound noise, use sound absorption materials, panels and carpets to minimize reverberations.

- Organize workplaces and partitions to avoid audio distraction (noise) from other operators.
- Minimize visual noise with calm interior colours that have low contrast, minimalist furniture, movement corridors organized to avoid peripheral vision distractions by someone walking from one place to another, etc.).
- Provide optimal temperature range, proper ventilation and air conditioning.
- Track noise level, light and temperature, air quality (including CO_2 levels).

5.2.2. WORKSPACES, INCLUDING ANTHROPOMETRIC ASPECTS

The layout and spatial design of the workplace is another element in human factors. This focuses on providing a comfortable working area and includes:

- A method to organize the workstation layouts depending on the priorities of the tools and information provided.
- Set up of static chart displays for situational awareness, dynamic screens for contextual tasks.
- Selection of hardware (displays, input devices) to fit workstation ergonomic criteria.
- Features to support work when the operator is in front of the workstation for both sit / stand positions, noting this helps to decrease the fatigue and keep the concentration.
- Selection of VTS systems with intuitive user interfaces and hardware controls that support operations, changes in day/night light conditions, etc. Note - the identification of primary controls should be available without direct observation (sense of touch). Groups of controls to differ by form and material texture to avoid confusion.

5.2.2.1. Support of situation awareness

- Shared access displays (video walls) are used to support situation and operational context sharing among operators and supervisors.
- Critical alerts are to be duplicated by sound signals to minimize chance of being ignored when the operator is focused in another area and is not observing the displays. The signals should be clear and definitive, not too loud (avoid irritation), but differ from ambient noise.
- The practice of duplication of alerts by using dedicated wall mounted signal panels can be considered, to cross-check that the situation is not ignored by multiple operators or head of the watch.

6. DEFINITIONS

The definitions of terms used in this Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

7. ABBREVIATIONS

The following abbreviations are used within this document:

CCTV	Close Circuit Television
GOMS	Goals, Operators, Methods, Selection rules (specialized human information processor model for human-computer interaction)
HCD	Human Centred Design
HTO	Human-Technology-Organization (analytical framework)
IEA	International Ergonomics Association
MASS	Maritime Autonomous Surface Ships
MRCC	Marine Rescue Coordination Centre
SOP	Standard Operating Procedure
UX	User Experience
VTS	Vessel traffic services or vessel traffic services (dependent on context)

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ANNEX A SAMPLE CHECKLIST OF WORKSPACE ERGONOMICS FACTORS

This appendix provides the checklist to be used for organization of personal workplaces for VTS operators (adopted from [13],[14]):

A.1. WORKSPACE POSITION

- Workspace position is located in such way that no direct sun light or bright light form artificial sources interferes observation of displays and working surfaces by operator.
- The workstation is accessed easily by the operator.
- It is possible to have another assisting person or trainee to stand or sit close together and observe the displays of the workstation (during shift, critical/emergency situations, training)
- The workstations of operators allow simultaneous voice communication without interference.
- Shared working area (including videowalls) is observable from different workspaces.
- Local air quality and temperature conditions (including heating, air conditioning, ventilation equipment selection and location) are considered to provide balanced working environment that will maximize comfort and avoid probability of “battles for conditioning/thermostat”.

A.2. WORKSTATIONS & DISPLAYS

- Workstations are located that they don’t disturb the operator (for instance, their location don’t result in less space for legs under table desk).
- Noise pollution from workstations is minimized.
- Workstations are regularly upgraded.
- All the displays are observed from the seated / standing positions without distortions.
- The displays are ordered by priority/importance — most critical in central vision field, less important in peripheral area.
- The size of the displays corresponds to the information presented and information is readable by operators.
- The brightness of all the displays is the same.
- It is possible to adjust the brightness of all the displays by single control

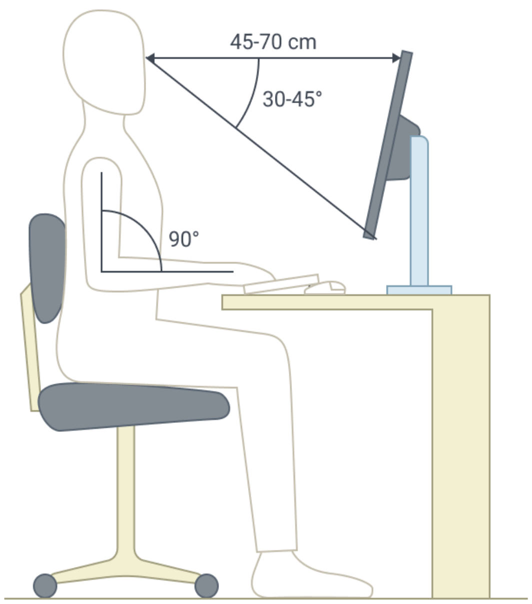

Figure 6 Example of viewing distance and angle

A.3. OFFICE CHAIR

- It is possible to easily move the chair in necessary position or to move it away
- The chair height, seat and back can be adjusted
- Feet are fully supported by the floor or stand
- The chair supports lower back
- No pressure is felt by back of the knees

* Armrests allow to sit close the workstation surface
* Shoulders are relaxed

A.4. WORK SURFACE (DESK)

* When working, the upper arms are relaxed
* The angle between forearms and upper arms is 90° or greater
* The keyboard, pointing and other control devices are accessed from the seat without its movement and are positioned at approximately the elbow level
* During typing, the wrists are in line with forearms and not bent
* There is a space to keep arms relaxed on the work surface
* These aspects relate to both sit and sit-stand desks

A.4.1. SIT-STAND DESKS

* When standing, stand up straight with shoulders back, do not hunch over or lean on the desk.
* Lift or lower the standing desk to meet your elbow height
* When standing, wear comfortable shoes
* Alternate between sitting and standing.

ANNEX B RISKY SITUATIONS RELATED TO HUMAN FACTORS

This annex is intended to highlight the role of human factors in VTS in potentially risky situations and examples of incidents occurred during them with references to official investigation reports. Some examples are not related to VTS, but still added, because although the situations are irrelevant to subject domain, they are related to human factors and are important for illustration — it is better not to wait for incidents to occur but be well prepared. *It is important to emphasize, that accidents never happen because of single cause, and the provided examples can be easily interrelated in a single situation. Human factors require holistic, systems approach.*

B.1. FALSE ASSUMPTIONS

Proper situational awareness means adequate understanding of current situation status and synchronization between all the stakeholders participating in it. Multiple accident reports mention insufficient communication between VTS and vessel personnel, that result in loss of situation awareness (like being aware of ongoing traffic, anchored ship drifting, etc.)

In many cases the reason is in fault assumptions, that another side of activity is aware of current and upcoming events and reacts accordingly — for instance VTS operator assumes, that crews of the vessels are making procedures correctly and are aware of each other. It results in passive observation of evolving dangerous situation and when it is clear, that previous assumptions are wrong, it is too late to respond.

Recommendation:

- During training, pay specific attention to the need that all assumptions must be cross-checked with available means and by other personnel.

VTS-related accidents:

- Helga Ingstad collision with the Sola TS (November 8, 2018)
- Collision of Donald Redford with the pier (November 1, 2003) — fault assumption that slurred speech of junior captain answers via VHF is not related to alcohol intoxication.

B.2. VAGUE COMMUNICATION STYLE

Using informal, spoken-language communication between VTS and vessels may result in distortion of transferred messages and misunderstanding between stakeholders, ignoring direct orders, or shadowing the reasons/intentions behind the perceived messages.

Recommendation:

- Clear, unambiguous phrases that do not allow more than a single interpretation, using, especially for communication with foreign crews, Standard marine communication phrases.
- During training emphasize the role of repeating orders and “closing communication loops” methods, voice actively expectations, concerns and assumptions.

VTS-related accidents:

- MV Full City grounding at Sastein, Norway (July 31, 2009) — miscommunication resulted in different expectations of VTS operator and vessel crew and subsequent loss of situation awareness.
- Maersk Kendal grounding (September 16, 2009). One of the reasons was misinterpretation by Maersk Kendal master and chief officer of information about the vessels that were referenced by VTS operator.

Other accidents:

- Costa Concordia grounding (January 13, 2012), particularly the situation of communication between the ship's master and helmsman on the bridge, when the order to turn starboard was perceived as to turn port by the helmsman, and it was not identified.
- Collision of two Boeing 747 airplanes on the runway of Los Rodeos Airport, Tenerife Island (March 27, 1977). One of the reasons was mutual misunderstanding between crew of one of the airplanes and ATC operator.

B.3. OVERLOAD AND FATIGUE OF VTS OPERATOR

If there is an insufficient number of operators handling the dynamic traffic situation, or an inadequate organization of working schedule, the operators can or get quickly tired or overloaded, resulting in loss of awareness and communication effectiveness, ignoring otherwise obvious signs of evolving dangerous situation.

Recommendation:

- Procedures assigned to proactively change the working schedule if the number of operators available is affected by sickness, personal problems, etc., or switch operators on the watch if there are signs of fatigue, loss of concentration, etc.

VTS related accidents:

- Collision of Donald Redford with the pier (November 1, 2003) — personal problems and fatigue of VTS operator resulted in ignorance of behavior of the ship and slurred speech of its master over VHF.

Other accidents:

- Collision of DHL and Bashkirian Airlines airplanes, (July 1, 2002) — ATC operator was put alone for night shift in dense air traffic environment, also with reduced technical equipment support, resulting in fatigue and loss of situation awareness because of insufficient cognitive resources.

B.4. WORKFLOW INTERRUPTIONS AND WATCH HANDOVER

Watch handover is a critical procedure, because the situation that is clear and obvious to the VTS operator leaving the watch can be not so obvious to the upcoming operator. Especially it is critical if the dangerous situation occurs exactly during watch change.

Recommendation:

- The watch change procedure should be organized including active communication of current situation from one operator to another, but not causing the loss of awareness/responsibility during it.
- Technical VTS systems should be designed and set up to support single actions to return to previous states and/or activities that had been interrupted.

B.5. INTERPERSONAL RELATIONSHIPS AND RESPONSIBILITY

Sometimes an operator will notice a dangerous situation that is outside of their direct area of responsibility but is not noticed by the operator who is responsible. The operator who noticed the danger may feel uncomfortable addressing their concerns to the other operator, relying too much on formalities and fearing the intervention may affect the interpersonal relationship with other members of the VTS centre.

Recommendations

- Organizational culture should support active assistance and open-mindedness. If another operator observes that the operator (even with higher rank) ignores some "obvious" information, they proactively announces their concerns without risks of being ashamed.

VTS related accidents

- MV Full City grounding at Sastein, Norway (July 31, 2009) — among other reasons, the ship was anchored in the area, that was behind of VTS area, so the operator didn't consider its duty to provide instructions about anchorage, while the crew expected to receive them.
- Helga Ingstad Frigate collision and grounding (November 8, 2018) — VTS operators considered that the situation is under control of vessels' crews.

B.6. TUNNEL PERCEPTION UNDER STRESS CONDITIONS

When some complex task or dangerous situation makes an operator concentrated on it, it is easy under stress to ignore simple activities to resolve it or ignore another evolving dangerous activity.

Recommendations:

- During operator training, attention to limitations and consequences of stress conditions must be paid.
- Resource management activities need to be organized, similar to BRM (Bridge resource management) on vessel's bridges or CRM (Cockpit resource management) in aircraft's cockpits, especially considering that no single operator should participate in problem resolving without supervisor's assistance. For example, if one operator is concentrated on the evolving problem, another operator keeps situation awareness for all remaining activities in area of responsibility of first operator.

Other accidents

- Eastern Air Lines Flight 401 (December 29, 1972) — the problem of burned-out landing gear bulb was being solved by the whole aircraft crew, resulting in loss of situation awareness and crash.
- Air France Flight 447 (June 1, 2009) — stress conditions because of insufficient training resulted that no standard actions to put the airplane from stall were performed.

B.7. DEGRADATION OF TECHNICAL EQUIPMENT

During lifecycle of VTS there is always a probability of losing functional capabilities of VTS technical systems — by incident or intentionally (e.g., during maintenance and upgrade procedures), and the overall support of situation awareness may be degraded significantly.

While cases of degradation that happened by incidents are typically covered by alert management systems, in some cases it can be better tracked by VTS staff, compared to planned degradation, which can be poorly organized and lead to issues in awareness about existing degradation.

Even if there are no issues in with notification, limited functionality increases workload of operators, leading to stress and fatigue.

Recommendations:

- Define specific procedures to inform VTS personnel and other stakeholders about planned and current maintenance procedures and resulting degradation of system's function.
- In case of degradation, it is recommended to pay specific attention to fatigue management, because degradation typically causes excessive workload of operators.
- VTS systems should support explicit notification about new functional limitations, including those that were actively triggered by service and technical staff.

Accidents:

- Crash of V-22 Osprey (October 1, 2014) — the aircraft was left in maintenance mode with limited engines power, and the pilots didn't notice it before the take-off, because of missing indications and flight manual SOPs covering this aspect.

ANNEX C QUALITY AND PERFORMANCE METRICS

For quantitative measurement of the quality of VTS organization and work process with respect to human factors, several quality and performance related metrics can be used.

While it is hard or even impossible to measure quality in absolute values, the comparison of numeric results provides the opportunity to evaluate relative changes in human factors in time, trigger proactive research of reasons of changes, affect them and measure their effectiveness.

This section provides some examples of these metrics.

C.1. ERRORS

These metrics assist to estimate the error rate during routine and critical operations of VTS:

1) Errors made by operators per period in general
2) Errors for specific types of operational scenarios
3) Errors by severity
4) Errors by cause (unproper training, stress and fatigue, poor usability, etc.)

The metrics are used to identify the crucial parts of the system and factors to be reviewed. Also, they can help to estimate the general progress of human factors approach.

C.2. COGNITIVE LOAD

Cognitive load metrics help to identify the issues with excessive load of the operator during daily procedures, that can cause stress, fatigue with ongoing efficiency decrease and increase the chance of human error.

C.3. INTERPRETATIONS

This aspect is used to determine the amount of cognitive (internal) efforts to understand the information provided by VTS technical sources. For example, if timestamps of alerts are presented to the operator, they have to interpret how old are they compared to current time. Or if targets speeds and courses are provided, how high the risk of collision is.

By measuring the amount of data occurrences and their probable interpretations, what time it takes to interpret, and which additional information sources (like current time in example above) are needed to close the “perception -> interpretation -> decision making -> action” loop, we can estimate the overall cognitive efforts and identify areas for optimization of interaction between stakeholders, including VTS operators, vessel personnel, and VTS systems.

There is always a risk of too narrow predefined interpretations.

C.4. CLUTTER (SIGNAL/NOISE RATIO)

There is a need to find the proper balance between the amount of information provided and its relevance to current situational context and tasks. Excessive and useless information can distract operator from more critical data, and lead to the ignorance of relevant messages and loss of situation awareness (known as “Boy who cried the wolf” problem). But too filtered information can also lead to the same result.

Example: “Loss of target” alert, that triggers every time the radar loses the acquired target because of waves. But we can result with cases when the loss of the vessel was not identified.

During test sessions, the events of information updates (both visual and audible, including VHF contacts, visual indications, sound alerts, VTS notifications, etc.) and responses to them can be measured, grouped by type, source, severity, modality (visual, audio) etc., and the relevance and usefulness can be estimated., allowing to count the signal/noise ratio.

C.5. USAGE SPEED

One of the simplest and most important metrics, that helps to measure how many actions and for how long it takes to perform certain operational scenarios, from the beginning to the end, including time for perception, actions to reach necessary information at the workstation, interpretation and decision making.

In general, the less is the best, but It is also important to estimate the risks of awareness loss and incorrect interpretations during every step.

The most basic methods to measure usage speed are Critical path analysis and GOMS [15].

Based on the results, technical methods to minimize, for instance, time to access information or trigger commands can be considered, like the usage of multiple displays, designing dedicated hardware controls for frequent actions.

C.6. LEARNING CURVE

The learning curve metrics are used to estimate effectiveness of continuous usage of general and advanced procedures of VTS in connection with training, and identify areas of expertise to improve:

- *Affordance rate:* How many procedures are completed before training, after training and after some period of system usage (or extra training)
- *Experience rate:* The ratio between time required to complete the specified task at the first time right after the training, and the time for the same task after some period of system usage — helps how the system supports experienced users and forming of strong habits
- *Decay rate:* How many tasks from the training operators are able to complete without errors after some time period.

C.7. EMOTIONAL RESPONSE

Emotional response highlights the general satisfaction with work environment and tools provided. This is identified by general anonymous questionnaires provided to VTS operators, with closed and open questions like:

- How are you satisfied with the workroom conditions (workstations, design of the interior, etc.)?
- How often you feel negative emotions (including rage) to the system you are working with?
- If you had negative emotions on your workplace recently, please describe them and their cause.

The higher (or less negative) response is observed, the better is, because emotional factors easily lead to errors, issues in communication and effectiveness of operations, accumulation of stress and consequent burn-out.

Additional attention can be added to the aesthetical factor, because there is evidence [16], that the systems, perceived by operators as “ugly” or “fancy” can lead to the drop of usage efficiency.