International Journal of Occupational Safety and Ergonomics

ISSN: 1080-3548 (Print) 2376-9130 (Online) Journal homepage: www.tandfonline.com/journals/tose20

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To cite this article: Mikko Lehtimäki & Anna-Maria Teperi (2026) Developing behavioural markers of high-speed workboat crews' competencies, International Journal of Occupational Safety and Ergonomics, 32:1, 44-57, DOI: 10.1080/10803548.2025.2499338

To link to this article: https://doi.org/10.1080/10803548.2025.2499338

Published online: 22 May 2025.

INTERNATIONAL JOURNAL OF OCCUPATIONAL SAFETY AND ERGONOMICS (JOSE)
2026, VOL. 32, NO. 1, 44–57
https://doi.org/10.1080/10803548.2025.2499338

Developing behavioural markers of high-speed workboat crews' competencies

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ABSTRACT
This study defines the competencies, structured as behavioural markers, that lead to an excellent performance by high-speed workboat crews in cockpit work and can promote maritime safety and operational efficiency. A need to better understand crew performance in cockpit work has been identified in this maritime specialty. The behavioural marker taxonomy is based on aviation standards, further reasoned by human factor models and maritime knowledge. It was formed utilizing content analysis and validated at the prototype level using observation data from actual cockpit work. The tested behavioural markers modelled crew behaviours in eight competency areas. This study contributes to improving crew and operative performances and safety, and to developing socio-technical systems in the field. The study also reveals further research topics for supporting cockpit and bridge crews in safety-critical high-speed maritime environments.

KEYWORDS
behavioural markers; cockpit work; high-speed workboats; human factors; maritime safety

1. Introduction

As the operational environment of high-speed workboat (HSW) cockpit work is challenging and fast paced [1,2], safety [3–5] is a crucial issue in the crews' performance. HSWs (defined in Appendix 1) are used in rescue, defence and police operations, as well as in other maritime environments, such as those critical for the security of supply and the energy sector.

The impact of human factors (HFs) [6] on operations in the maritime industry [7] is insufficiently known, although it is constantly evolving [8]. Despite the information obtained from safety research [9–12], shortcomings have been highlighted in HSWs, especially in the group work and resource management of cockpit work [13]. The crew competencies essential for effective resource management have not been specified. The non-technical skills [9] required for performing operations [10] such as those in safety-critical sectors are particularly poorly understood and insufficiently supported [11].

This study defines the behavioural markers (BMs) of HSW crew competencies as vital to crew performance and achieving cockpit work objectives. BMs refer to a taxonomy of the key skills associated with effective, safe job performance in a given operational environment and illustrate them using example behaviours [12]. BMs help develop sharp-end work and positively influence background processes such as regulations, working methods [14,15], training and performance requirements [16–18] and human–machine interface optimization [19].

1.1. *Cockpit work – objectives and working as a team*

HSW cockpit work objectives have been defined [13, p.1] as:

> the safe management of a boat in ever-changing conditions [20], which is in line with the definition in aviation – 'aviating, navigating and communicating' [21] to follow a predetermined route plan [22] – and reacting to factors encountered during the voyage, such as other waterborne traffic [23].

The aim of cockpit work is operative performance [24] and the safety of the parties involved [5,16], which requires detecting and reacting to threats [25]. The efficiency of operations considers the limited time for executing tasks [3,25,26]. The results are affected by resources [27], the demands of the situation and the task and ability of crews to return to normal operations after adverse situations [28].

On HSWs, cockpit work requires a high level of resource management and teamwork to advance common goals [29], utilize determinants and carry out cognitive, verbal and behavioural tasks and processes [30]. Crews form an effective team when they dynamically and interdependently combine their roles to promote interaction and to achieve goals [18,31].

Group work has been described as, e.g., input–process–output–process [32], work phases or interpersonal activity [30]. The results of work are visible or related to human reactions [29], efficiency and the achievement of goals [33]. They are incorporated into background activity, and modifying frontline teamwork's input factors and features [10,32,34]. In reality, crews are complex, adaptive and dynamic entities that interact with the operating environment [35,36]. This process perspective has also been criticized for ignoring emergence [30] and the non-linearity of teamwork [37], whereas others have noted that grouping human activities gives structure to the interrelationships and feedback mechanisms involved in processes [38].

To promote teamwork and resource management in cockpit work, the demands placed on crews must be detailed [39]. In this study, these requirements were structured according to competence areas as BMs, the formation of which is discussed in the following.

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/10803548.2025.2499338.

Table 1. Examples of behavioural marker taxonomies.

Model	Author(s)	Industry	Description
NOTECHS NTS	Van Avermaete [45]	Aviation	NTS of multi-pilot aircrew, considering interconnectedness with technical skills
Evidence-based training	EASA [14], based on IATA [25]; ICAO [46]	Aviation	Skills, attitudes and knowledge needed by crew to master situations and prepare for changing, unpredictable situations
Prototype taxonomy	Kontogiannis and Malakis [47]	Air traffic services	Strategies that controllers use to cope with complexity
ANTS Anaesthetists' NTS	Fletcher et al. [41]	Health care	NTS important for good anaesthetic practice
The nuclear team skills taxonomy	O'Connor et al. [48]	Nuclear industry	Team skills required by nuclear power plant operation team members
NTS (in BMs)	O'Connor and Max Long[49]; da Conceiçlo et al. [50]; Saeed et al. [51]	Maritime industry	NTS of bridge teams and deck officers
	Fjeld et al. [44]	Maritime industry	Literature review 'NTS used by ships' bridge officers in connection with navigation'

Note: ANTS = anaesthetists; BM = behavioural marker; EASA = European Union Aviation Safety Agency; IATA = International Air Transport Association; ICAO = International Civil Aviation Organization; NTS = non-technical skills.

1.2. Defining behavioural markers

Crews' requirements can be structured into competencies and measurable BMs [27] that are needed in technical or non-technical work phases and can be linked to work performance [12,40]. BMs should be simple, comprehensible, usable, valid, sensitive and reliable [12]. They are combined with assessment scales used by trained and calibrated assessors. However, calibration is not always consistently implemented in all assessments [41], as in this study.

BMs have been defined in several safety-critical fields (Table 1). The historical BM ground-breaker was the University of Texas' Behavioral Markers taxonomy [42], which was used to construct the Line Operations Safety Audit (LOSA) [43]. BM models have clarified how non-technical skills are managed in the maritime industry, but detailed descriptions of BMs, particularly with regard to human interaction within crews, are still scarce [44].

Competency-based learning pedagogy related to the use of BMs promotes competencies and continuous development [52] and has been utilized in the maritime sector [53], yielding mixed results [54]. Training and assessment tools still need to be adapted for the maritime industry [44,55,56], due to different operationalization in different fields [9]. This requires applicable methods [12], understanding of HFs [9,49,57] and sector-specific information [58]. This study took these requirements into consideration when implementing the aviation BMs in the HSW maritime industry.

2. Aims

This study examined the BMs of critical HSW crews' cockpit work competencies by modelling crew performance. The taxonomy was tested using observation data from actual operations.

The research questions were as follows:

RQ1. What are the critical crew competencies and BMs in HSW cockpit work?

RQ2. How does the BM taxonomy prototype structure the activities of the crew?

3. Materials and methods

This study utilized content analysis to form a taxonomy prototype of the BMs of critical HSW crews' competencies. The BMs were tested utilizing recordings of observations during actual operations. The study process consisted of four phases (Table 2).

Table 2. Study process.

Phase	Description
Forming the taxonomy prototype	Document analysis
Forming the assessment principle	Synthesis of STCW, NOTECHS NTS and EBT principles
Observations	Development of data recorder for observations in actual cockpit work. Also used in Lehtimäki and Teperi ([85]). Observations of actual sea voyages
Testing the taxonomy	The crews' observed and technically recorded behaviours were analysed, compared to BMs and classified as 'acceptable' or 'unacceptable' based on the assessment principle (see Section 3.2.2 and Table 6) The testing revealed missing and non-functional BMs and the need to improve their content, grammar and mutual order The functionality and fluency of the assessment principle were tested The taxonomy prototype was developed and finalized based on test results

Note: BM = behavioural marker; EBT = evidence-based training; NTS = non-technical skills; STCW = International Convention on Standards of Training, Certification and Watchkeeping for Seafarers Code.

3.1. Materials

3.1.1. Data for taxonomy prototype

The BMs were formed on the basis of the materials and perspectives presented in Table 3. Other data were also employed, as presented in Table 4.

3.1.2. Observation data

Technically recorded observation data from actual cockpit work were gathered to test and develop the BMs. The first author of this article (later 'researcher') conducted the observations in sea areas and inland waters in five Finnish HSW maritime organizations in the autumn of 2022. Data were also used from a voyage during which the recording technology was tested.

The observation cases ($N = 6$) were selected to comprehensively represent the HSW field. The crews used different cabin boat classes, technical designs and working methods,

Table 3. Materials for the BMs.

Material	Source	Description
BM taxonomies		
EASA taxonomy	EASA [14]	Characteristics and behaviours of human activity leading to good performance, essential for executing a task [38]. Nine competency categories: (KNO) application of knowledge; (PRO) application of procedures and compliance with regulations; (COM) communication; (FPA) aeroplane flight path management – automation; (FPM) aeroplane flight path management – manual control; (LTW) leadership and teamwork; (PSD) problem-solving – decision-making; (SAW) situation awareness and management of information; (WLM) workload management; including 73 BMs
NOTECHS non-technical skills	Van Avermaete [45]	Describing original non-technical skills for aviation: attitudes and behaviours not directly related to management of aircraft or systems and use of standard operating procedures [14,45]. Four categories: cooperation; leadership and managerial skills; situation awareness; and decision-making; including 15 elements and 39 BMs
HF models		
CRM	EASA [59]	Concept to ensure optimal utilization of technical, information and human resources in safety-critical fields [34]; improving leadership, communication, human performance and safety in a systemic and resilient way [14]; including 21 themes handling EASA competencies and other HFs
BRM	STCW Tables A-II/1 and 2 (IMO) [53]	CRM for maritime industry [60]. Knowledge, skills and attitudes, three categories: maintaining a safe navigational watch; applying leadership and teamwork skills; and using leadership and managerial skills (last of which is assigned to masters or mates of ships with 500 gross tonnage or over). Categories structured into levels that describe competence, understanding and professionalism in slightly different ways. Levels divided into competence assessment criteria (14 pcs)
HF Tool	Teperi [61]	Systemic concept, based on description of HFs on four levels of socio-technical system: individual factors and actions; work characteristics; group/team factors; and organizational factors; levels include 37 details
Maritime sources		
Documents	HSW organizations ($N = 5$)	Procedures, formal requirements and guidelines ($n = 28$), including cockpit work-related mentions ($n = 118$). Data request made in May 2022 on basis of research permits granted by organizations between December 2021 and April 2022
Incident analysis	Lehtimäki and Teperi [13]	Factors ($n = 112$) that have positively or negatively affected HSW incidents in Finland ($n = 76$)
Regulation in Finland	Agreements, laws, decrees and official regulations	Workshop to select dataset held by Finnish Transport and Communications Agency Traficom and Regional State Administrative Agency for Western and Inland Finland in December 2022. Researcher finally selected eight regulations aimed specifically at cockpit work from entire dataset (28 pcs)
Cockpit work-related technical skills	STCW Table A-II/3 (IMO) [53]	Three competency categories: plan and conduct a coastal passage and determine position; maintain a safe navigational watch; and manoeuvre ship and operate small ship power plants. Categories include seven levels and 23 BMs

Note: BM = behavioural marker; BRM = bridge resource management; CRM = crew resource management; EASA = European Union Aviation Safety Agency; HF = human factor; HSW = high-speed workboat; IMO = International Maritime Organization; STCW = International Convention on Standards of Training, Certification and Watchkeeping for Seafarers Code.

which the researcher studied before commencing observations [58]. The observed sea voyages were carried out for research purposes only. The organizations that granted the research permit selected the crews to be observed. Observations are described in more detail in Section 3.2.

3.2. Methods

3.2.1. Forming the taxonomy prototype

The BMs were formed on the basis of document analysis (Table 3), which evaluated the cockpit work contents of the datasets (BM taxonomies, HF models, maritime sources) and their relationships. The data were first broken down into parts and simplified during the open coding process. They were then grouped using axis coding on the basis of the European Union Aviation Safety Agency (EASA) taxonomy [14], using the basic structure of BMs. The EASA competencies of 'Flight path management automation' and 'Flight path management – manual control' were combined and modified as one competency category, called 'Route plan management', which was then further divided into 'Route planning' and 'Route plan control' subcategories.

The data were continuously compared to the EASA taxonomy (Table 5), other datasets were derived in the selective coding phase and the final BMs were developed and verified. Existing BMs were cited or modified, data synthesized or new BMs were formed. The data were processed in Microsoft Excel version 16.90.

Figure 1 shows the relationships between the datasets and the finalized BMs in competency categories. The figure includes the cumulatively coded parts of the datasets (total 592 pieces) that rationalized the BMs (17 pcs), were modified or combined (231 pcs), or were used as complementary justification (344 pcs).

Figure 2 illustrates the relationship between the coded parts (277 pcs) of the datasets, employed as a concept-level justification for the BMs.

The BMs were operationalized into HSW by ensuring that they were suitable for preventing common HSW cockpit work incidents [13], they considered critical technical skills in cockpit work (facilitated by International Convention on Standards of Training, Certification and Watchkeeping for Seafarers Code [STCW] Code Table A-II/3 [53]) and they complied with regulations in Finland.

The taxonomy was structured as two levels: primary BMs and complementary BMs, the latter of which consisted of 26 primary BMs. Both levels could be utilized to assess the user's choice. The BMs were numbered at three levels (e.g.,

Table 4. Other sources used to form the behavioural markers.

Behavioural marker(s)	Source	Reference
1.7.5 Avoiding 'heads-down' situations by communicating if necessary3.4 Involving crew in sea voyage planning and feedback7.3 Ensuring sufficient time to carry out assigned task without unnecessary sense of urgency	Active Pilot Monitoring Working Group, 2014	[62]
2.2.2 Communicating actively and adequately	Helmreich and Foushee, 34	[34]
2.2.3 Avoiding extra communication	Broom et al., 2011	[63]
2.3 Effectively using description of work phases	Active Pilot Monitoring Working Group, 2014; Gillespie, 2013	[62,64]
2.5 Confirming that recipient demonstrates understanding of message2.5.2 Addressing monosyllabic responses2.5.3 Making sure the message is understood correctly2.6.2 Not answering monosyllabically	Federal Aviation Administration (FAA), 2005	[65]
3.8 Monitoring compliance with a route plan in a timely manner, taking necessary measures	Klampfer et al., 2001; da Conceiçlo et al., 2017; Active Pilot Monitoring Working Group, 2014	[12,50,62]
4.2 Proposing solutions and expressing opinions without questioning authority	Klampfer et al., 2001; Saeed, 2017	[12,51]
4.4.1 Leading the crew and not shirking responsibilities	Ginnet, 66	[66]
5.1 Identifying problems and contributing factors together with crew	Orasanu, 67	[67]
6.3 Maintaining situation awareness of crew and their capacity to carry out the mission6.4 Being aware of one's own functional capacity and communicating its impact on work	Teperi, 61; Flin et al., 2003	[61,68]
7.11 Reacting to indications of a harmfully high or low workload for the crew	International Labour Organization (ILO), 2021; Hollnagel, 16; Siegel and Schraagen, 69	[6,16,69]

1.1.1: competency, primary BMs, complementary BMs). Footnotes for practitioners were also justified and attached to the BMs to refine the content, but they are not reported in the article.

3.2.2. Forming the assessment method

The intention was not to evaluate all of the competencies or BMs simultaneously. The behaviour assessment principle was synthesized (Table 6) to recognize safe and sufficiently effective crew performance [14,53]. The Venn model in the evidence-based training concept [24] was used to specify when the criteria had been exceeded, and the threat and error management level was measured by how often the targeted necessary behaviour was repeated in the competence area and how well it was implemented when necessary. Competence was rated on two tiers [45].

3.2.3. Observations

The observation data were technically recorded and analysed retrospectively. A data recorder was developed for the study (Zilar Security Systems, Finland) (Figure 3), which recorded the following on a timeline (Figure 4): several video cameras; HSW movement factors on a map application; cockpit communication; and subjective mental workload data measures (Lehtimäki and Teperi [85]).

The crews were entrusted with implementing the route plan created by the researcher, except for one case in which the crew carried out operational tasks. The crews were instructed to use at least 90% of their boat's top speed or > 40 knots, but to maintain a safe situational speed. The crews were observed, as in Lehtimäki and Teperi [85], for almost 10 h, from before departure to arrival at the port, over a distance of 269 nautical miles (376 waypoints) and at an average speed of 28 knots (mean speed range 17–34 kn). The external conditions were mild (mean wind 5 m/s, visibility 49 km, dry weather, dark or light). The researcher carried out the observations but did not participate in working in the cockpit.

3.2.4. Testing and developing of taxonomy

The BMs (draft 1.15, completed in June 2023) were tested using the observational data. In testing, the researcher analysed the crews' technically recorded activity 'second by second', also utilizing the repetitions of the recording. All of the crews' observable behaviours were compared to BMs. The assessment method introduced earlier (Table 6) was used, and the behaviours were analysed by 'how often the targeted necessary behaviour was repeated in the competence area and/or how well it was implemented when necessary'. When the crew acted according to a particular BM on 'at least minimum

Table 5. Datasets related to EASA taxonomy.

	Dataset							
EASA competency (BM)	CRM	BRM	NOTECHS NTS	HF Tool	DOC	FAC	STCW	REG
Application of knowledge (7)	0/7	0/7	1/7	+	5/7	2/7	4/7	4/7
Application of procedures and compliance with regulations (7)	1/7	3/7	1/7	+	5/7	4/7	4/7	4/7
Communication (10)	+	+	0/10	+	5/10	3/10	0/10	1/10
Flight path management automation/manual control (8)	1/8	1/8	0/8	+	6/8	5/8	5/8	6/8
Leadership and teamwork (11)	+	+	8/11	+	6/11	3/11	0/11	2/11
Problem-solving – decision-making (9)	+	+	5/9	+	2/9	5/9	0/9	0/9
Situation awareness and management of information (7)	+	+	3/7	+	3/7	5/7	1/7	4/7
Workload management[a] (10)	+	3/10	5/10	+	5/10	4/10	1/10	2/10

[a]EASA BM 3.5 incorporated into workload management (originally nine BMs).
Note: '+' indicates content applicable to EASA BMs at a concept level. BM = behavioural marker; BRM = bridge resource management; CRM = crew resource management; DOC = maritime documents; EASA = European Union Aviation Safety Agency; FAC = factors behind high-speed workboat incidents; NTS = non-technical skills; REG = high-speed workboat cockpit work regulations in Finland; STCW = International Convention on Standards of Training Certification and Watchkeeping for Seafarers Code.

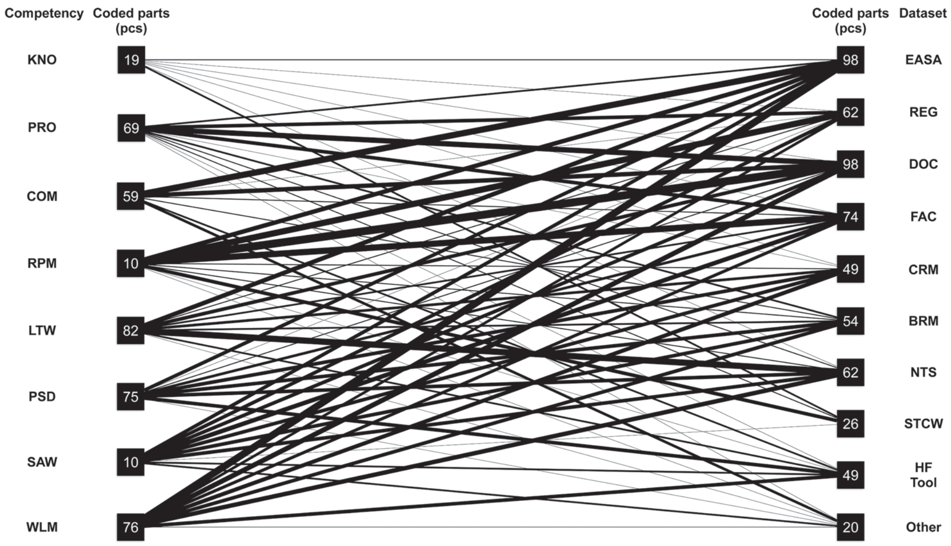

Figure 1. Primary rationale behind behavioural markers. Note: BRM = bridge resource management; COM = communication; CRM = crew resource management; DOC = maritime documents; EASA = European Union Aviation Safety Agency; FAC = factors behind high-speed workboat incidents; KNO = application of knowledge; LTW = leadership and teamwork; NTS = NOTECHS non-technical skills; Other = references presented in Table 4; PRO = application of procedures; PSD = problem-solving and decision-making; REG = high-speed workboat cockpit work regulations in Finland; RPM = route plan management; SAW = situation awareness and management of information; STCW = International Convention on Standards of Training Certification and Watchkeeping for Seafarers Code; WLM = workload management.

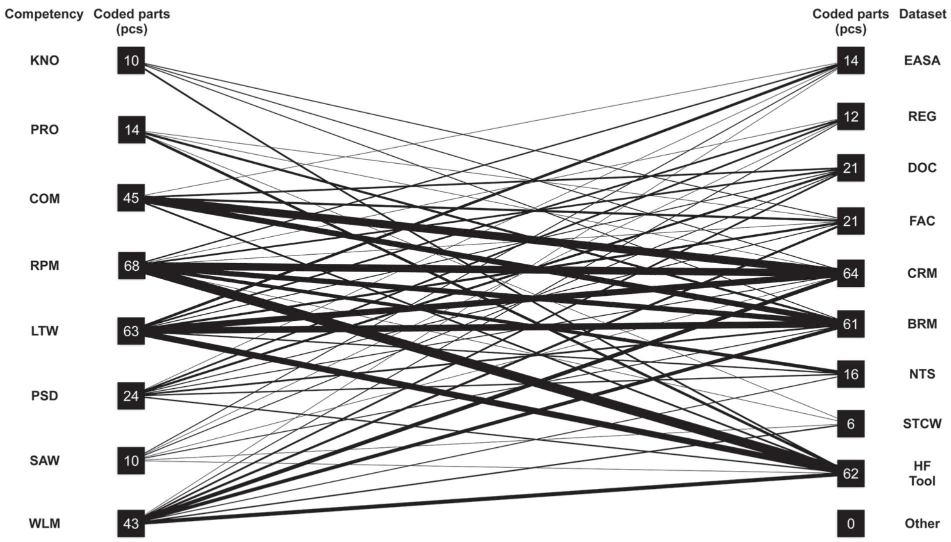

Figure 2. Concept-level rationale behind behavioural markers. Note: BRM = bridge resource management; COM = communication; CRM = crew resource management; DOC = maritime documents; EASA = European Union Aviation Safety Agency; FAC = factors behind high-speed workboat incidents; KNO = application of knowledge; LTW = leadership and teamwork; NTS = NOTECHS non-technical skills; Other = references presented in Table 4; PRO = application of procedures; PSD = problem-solving and decision-making; REG = high-speed workboat cockpit work regulations in Finland; RPM = route plan management; SAW = situation awareness and management of information; STCW = International Convention on Standards of Training Certification and Watchkeeping for Seafarers Code; WLM = workload management.

Table 6. Assessment principle.

Parameter	How often does the target behaviour recur if necessary?		How well is the target behaviour implemented when necessary?	Result of assessment	Assessment of competence
Negative mark	Target behaviour is rarely or hardly ever repeated	and/or	Inefficiently	Crew showed little or none of the necessary behaviour. The action led or could have led to an unacceptable deterioration in safety	Unacceptable
Positive mark	Target behaviour is repeated at least intermittently	and/or	Minimum acceptance	Crew demonstrated required behaviour to at least a minimum acceptable level and the action did not lead to any deterioration in safety	Acceptable
Usage	Score kept by marks		Marked positive or negative		
Source	Paraphrasing Venn model (EASA) [14]		Paraphrasing Venn model (EASA) [14]	Paraphrasing IATA [24]; EASA [14]	Van Avermaete [45]
General principle	Safe, sufficiently effective performance considered sufficient (STCW, Part A, Chapter I) [53]				

Note: EASA = European Union Aviation Safety Agency; IATA = International Air Transport Association; STCW = International Convention on Standards of Training Certification and Watchkeeping for Seafarers Code.

Figure 3. Data recorder.

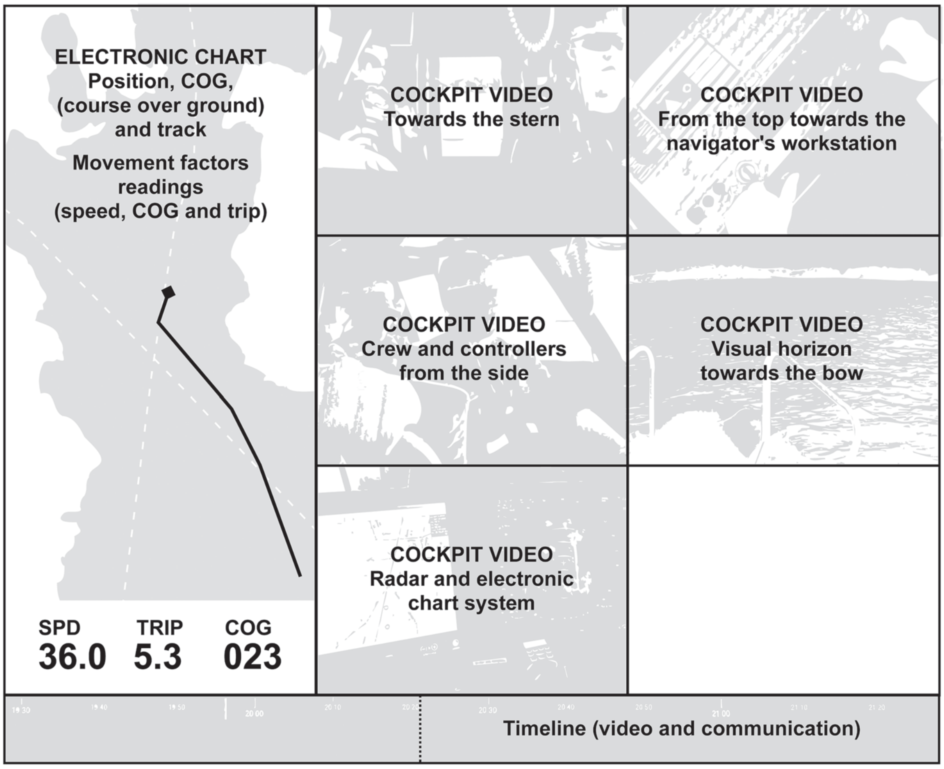

Figure 4. Data recorder timeline. Note: COG = course over ground; SPD = speed; TRIP = distance travelled.

acceptable level and the action did not lead to any deterioration in safety', it was assessed as 'acceptable' and recorded with a positive mark on a paper form, based on the BMs. When the behaviour was repeated 'inefficiently' and 'led or could have led to an unacceptable deterioration in safety', it was considered 'unacceptable' and a negative mark was recorded. In the BMs testing, only observable behaviour was classified as 'acceptable' or 'unacceptable'. Missing behaviours were not recorded.

Testing ensured that the crews' recorded activity modelled actual behaviour rather than the norms that guided it [14,70]. During the testing, the researcher developed the taxonomy by reacting to missing and non-functional BMs and improving the content, grammar and mutual order of the BMs. The functionality of the assessment principle was also tested assessing the fluency of its use. This process enabled us to finalize the taxonomy prototype (version 1.18). In this version, one overlap and one contradiction of BMs were observed during the peer

Table 7. Taxonomy prototype behavioural markers in eight competency areas (version 1.18).

Primary behaviour	Complementary behaviour
Application of knowledge (KNO)	
0.1 Demonstrating practical knowledge of boat systems and their interaction	
0.2 Demonstrating knowledge of applicable operational guidelines	
0.3 Demonstrating knowledge of physical operating environment	
0.4 Demonstrating knowledge of information on key applicable regulations	
0.5 Demonstrating knowledge of key themes of CRM	
Application of procedures and compliance with regulations (PRO)	
1.1 Applying appropriate operating instructions and working methods	
1.2 Following SOP for cockpit work in work phases	
1.3 Deviating from SOP or operating instructions to ensure safety or for some other justified reason	1.3.1 Identifying and justifying the need for deviations together
	1.3.2 Deviating and returning to SOP by communicating together
1.4 Supervising in the use of standard procedures and addressing deviations	
1.5 Using boat's systems and equipment correctly and monitoring their status and functionality	1.5.1 Using the organization's standardized data display settings
1.6 Acting in accordance with regulations	
1.7 Effectively observing sea terrain	1.7.1 Arranging and ensuring continuous lookout
	1.7.2 Taking ships and other objects into consideration
	1.7.3 Anticipating objects behind the obstruction of vision
	1.7.4 Communicating lookout observations between the crew
	1.7.5 Avoiding 'heads-down' situations by communicating if necessary
1.8 Giving way and preventing collisions	1.8.1 Determining the movement factors of other vessels
	1.8.2 Acting with clearly visible intentions and avoiding harmful traffic behaviour
	1.8.3 Giving way before near misses arise
	1.8.4 Giving way as a group effort
	1.8.5 Ensuring the impact of giving way measures
1.9 Manoeuvring the boat to the starboard edge or within one third of fairway area whenever possible	
Communication (COM)	
2.1 Identifying recipient's readiness and ability to receive information	
2.2 Appropriately choosing what, when and to whom to communicate	2.2.1 Identifying the information that is necessary to communicate at any given time
	2.2.2 Communicating actively and adequately
	2.2.3 Avoiding extra communication
2.3 Effectively using description of work phases	
2.4 Communicating clearly, accurately and concisely	2.4.1 Ensuring sufficient volume is used
	2.4.2 Sharing messages as needed (rhythms)
	2.4.3 Making effective use of non-verbal communication
2.5 Confirming that recipient demonstrates understanding of message	2.5.1 Requiring closed communication loop (notification if message not replied to)
	2.5.2 Addressing monosyllabic responses
	2.5.3 Making sure the message is understood correctly
	2.5.4 If necessary, expanding communication to ensure understanding
2.6 Actively listening and demonstrating understanding of message	2.6.1 Replying to messages using closed communication loop
	2.6.2 Not answering monosyllabically
	2.6.3 Indicating when message is not perfectly heard or understood
	2.6.4 Expanding communication until message is understood correctly
2.7 Asking relevant and effective questions	
2.8 Using organization's standard communication approach	2.8.1 Using standard terms and phrases
	2.8.2 Using common working language correctly enough to ensure safety and that instructions are followed
Route plan management (RPM)	
Route planning (RPL)	
3.1 Planning route before starting sea voyage or new mission	
3.2 Making high-quality route plan that contains necessary information	
3.3 Efficiently using permanent route plans or route library	
3.4 Involving crew in sea voyage planning and feedback	3.4.1 Involving crew in route planning and planning of sea voyage
	3.4.2 Providing a high-quality, effective briefing before departure
	3.4.3 Providing a high-quality, efficient debriefing after sea voyage

(*continued*).

Table 7. Continued.

Primary behaviour & Complementary behaviour	
Route plan control (RPC)	
3.5 Monitoring compliance with route plan in a timely manner, taking necessary measures	3.5.1 Detecting deviations to route plan whilst managing other tasks and distractions
	3.5.2 Ensuring implementation of correct steering line in future work phases
	3.5.3 Communicating result of monitoring and ensuring common understanding of situation
	3.5.4 Efficiently correcting steering line as a team effort
	3.5.5 If necessary, reducing speed or stopping boat to ensure compliance with route plan
3.6 Deviating deliberately from route plan, if necessary to ensure maritime safety and/or critical task performance	3.6.1 Identifying and justifying the need to deviate from route plan
	3.6.2 Implementing a temporary deviation from the route plan by communicating together
	3.6.3 If necessary, making a new route plan and briefing the crew
3.7 Effectively using information sources to follow route plan	3.7.1 Emphasizing most useful source of information at any given time
	3.7.2 Interpreting information correctly
	3.7.3 Validating movement factors by cross-checking at least two sources of information
	3.7.4 Using visual views and manoeuvring signs as sources of information
	3.7.5 Using technical systems and equipment as sources of information
	3.7.6 Ensuring that display settings are optimized efficiently and dynamically
3.8 Steering boat accurately, smoothly and safely in accordance with situation	
3.9 Using automation in the right work phases	3.9.1 Using autopilot in suitable work phases and conditions
	3.9.2 Closely monitoring the operation of automation
	3.9.3 Detecting deviations in operation of automation and effectively addressing them
Leadership and teamwork (LTW)	
4.1 Encouraging participation and promoting an open atmosphere	4.1.1 Asking for suggestions for solutions
	4.1.2 Asking more than telling
	4.1.3 Avoiding competition and emphasizing the crew rather than the individual
	4.1.4 Focusing on what is right instead of who is right
4.2 Proposing solutions and expressing opinions without questioning authority	
4.3 Considering the initiatives and suggestions of others	4.3.1 Reacting to initiatives and proposals
	4.3.2 Giving reasons if initiative or proposal cannot be implemented
	4.3.3 Objectively considering initiatives despite differences of opinion
4.4 Showing initiative and determination in leadership and indicating the direction of action	4.4.1 Leading the crew and not shirking responsibilities
	4.4.2 Clearly indicating the task, direction of action and objective to the crew
	4.4.3 Contributing to the success of the task
4.5 Taking responsibility for decisions and actions	4.5.1 Showing initiative and ensuring that the task is successful
	4.5.2 Communicating uncertainties, deviations and safety
	4.5.3 Refusing to complete a task if lacking the required skills and experience
	4.5.4 Obeying instructions and commands
4.6 Giving and receiving constructive feedback	
4.7 Dealing with and resolving conflicts constructively	4.7.1 Behaving calmly in cases of conflict
	4.7.2 Proposing solutions to conflicts
Problem-solving and decision-making (PSD)	
5.1 Identifying problems and contributing factors together with crew	
5.2 Obtaining accurate, reliable information for decision-making	5.2.1 Showing a positive drive to acquire knowledge and encouraging others to do the same
	5.2.2 Reserving sufficient time for acquiring information
	5.2.3 Obtaining information from the crew
	5.2.4 Obtaining information from the cockpit's information sources
	5.2.5 Acquiring information from outside the boat

(*continued*).

Table 7. Continued.

Primary behaviour & Complementary behaviour	
5.3 Identifying and considering suitable alternatives together	
5.4 Identifying, assessing and managing threats and errors in timely manner together with crew	
5.5 Continuing to work tirelessly to solve problem and ensure safety	
5.6 Comprehensibly informing crew of content of decisions and expectations regarding tasks and standards	
5.7 Jointly monitoring consequences of decision and, if necessary, changing the policy	
5.8 Adapting to situations that have no instructions or procedures	
5.9 Demonstrating resilience and ability to act in unforeseen situations	
Situation awareness and management of information (SAW)	
6.1 Monitoring boat movements and systems	6.1.1 Reacting without delay to problems, deviations and changes
	6.1.2 Ensuring shared situation awareness about boat movements and systems through communication
6.2 Collecting information on operating environment	6.2.1 Taking information into account and reacting to it without delay
	6.2.2 Ensuring shared situation awareness about operating environment through communication
6.3 Maintaining situation awareness of crew and their capacity to carry out the mission	6.3.1 Considering the human needs of the crew and communicating them when necessary
	6.3.2 Asking the crew about their operational capability and monitoring any noticeable changes
	6.3.3 Dimension expectations in relation to crew capacity and its changes
6.4 Being aware of one's own functional capacity and communicating its impact on work	
6.5 Ensuring the reliability of information and related errors and reacting to deviations by communicating	
6.6 Using an alternative information source when original is unavailable or unreliable	
6.7 Reacting to indications of impaired situational awareness	
6.8 Creating contingency and emergency plans for different situations on basis of risk assessment	
Workload management (WLM)	
7.1 Concentrating on task and on matters important for work phase	
7.2 Planning, prioritizing and scheduling tasks efficiently	
7.3 Ensuring sufficient time to carry out assigned task without unnecessary sense of urgency	
7.4 Managing situational speed safely and efficiently	7.4.1 Using situation speed that is in proportion with the anticipated strain of the situation
	7.4.2 Defining situational speed as a group decision based on performance
	7.4.3 Implementing speed changes as a separate work phase, and allocating sufficient time
	7.4.4 Ensuring that speed changes great enough to have a real impact on workload (speed reduction) or operational efficiency (speed increase)
7.5 Monitoring and identifying crew's need for help, offering and providing assistance	
7.6 Requesting assistance if necessary and accepting it when offered	
7.7 Delegating tasks efficiently when needed	7.7.1 Ensuring sufficient division of labour
	7.7.2 Ensuring that delegated tasks are carried out in accordance with objectives
	7.7.3 If necessary, giving the crew additional guidance to perform a task
7.8 Completing the assigned tasks according to the objectives	
7.9 Ensuring efficient recovery from interruptions, disturbances, deviations and faults	
7.10 Using automation in the right work phases in terms of workload management	7.10.1 Avoiding the use of autopilot during monotonous operations
	7.10.2 Changing control system only in low-workload work phases
7.11 Reacting to indications of a harmfully high or low workload for the crew	

Note: CRM = crew resource management; SOP = standard operating procedure

Table 8. Primary behavioural markers not identified in testing.

BM no.	Behavioural marker
1.3	Deviating from SOP or operating instructions to ensure safety or for some other justified reason
2.1	Identifying when the recipient is ready and able to receive information
3.6	Deviating from route plan if necessary
3.10	Using automation in suitable work phases
4.4	Showing initiative and determination in leadership and indicating direction of action
4.7	Dealing with and resolving conflicts constructively
5.8	Adapting to situations that have no instructions or procedures
5.9	Demonstrating resilience and ability to act in unforeseen situations
6.8	Creating contingency and emergency plans for different situations on basis of risk assessment
7.6	Requesting assistance if necessary and accepting it when offered
7.8	Completing assigned tasks in accordance with objectives

Note: BM = behavioural marker; SOP = standard operating procedure.

Table 9. Crew behaviours by competency, observed in taxonomy testing.

Competency area	Positive[a] (*n*)	Negative[b] (*n*)	Combined[c] (*n*)
Application of knowledge (BMs in this competency area were not specifically tested)	6	2	8
Application of procedures and compliance with regulations	100	89	189
Communication	127	127	254
Route plan management	109	131	240
Leadership and teamwork	73	4	77
Problem-solving and decision-making	8	30	38
Situation awareness and management of information	38	36	74
Workload management	29	55	84
Total	490	474	964

[a]Crew demonstrated required behaviour to at least a minimum acceptable level and the action did not lead to any deterioration in safety (assessment of competence: acceptable).
[b]Crew demonstrated target behaviour inefficiently, the action led or could have led to an unacceptable deterioration in safety (assessment of competence: unacceptable).
[c]Positive and negative marks combined.
Note: BM = behavioural marker

review phase of the study, which were corrected before the publication. The change did not affect the expressed justifications of BMs or the validity of the BM testing.

4. Results

This section presents the taxonomy prototype and its test results.

4.1. RQ1. What are the critical crew competencies and BMs in HSW cockpit work?

The BMs were finalized in April 2025. The taxonomy consisted of eight competency categories, structured as 66 primary BMs and 86 complementary BMs (Table 7).

4.2. RQ2. How does the BM taxonomy prototype structure the activities of the crew?

Using the BMs enabled efficient classification of the observed crew activity. Although all of the targeted behaviours could be classified as BMs, not all BM behaviours were observed. As the research strategy did not contain testing of the competency area of 'Application of knowledge', it remained mostly unproven.

Testing showed that 51 of the 62 primary BMs (and/or complementary BMs in the area) of the taxonomy covered all of the observed crew behaviour necessary for effective crew performance. However, other BMs not subject to the observations were also relevant to crew performance and were added to the taxonomy (Table 8).

Detailed complementary BMs were typically used when available. In summary, 32.5% of the markings ($n = 313$) were aimed at primary BMs, compared to the 67.5% of markings ($n = 651$) aimed at complementary BMs, of which 66% were labelled.

4.2.1. Using the taxonomy prototype

A prerequisite for an accurate analysis was technical recordings, which would enable one to repeatedly watch a specific part of the observation data timeline. Recording observations on paper forms was efficient in office conditions, but familiarization with the structure required effort.

4.2.2. Competency-specific observations

The BMs modelled the activities that promoted or hindered crew performance. Testing showed that BMs that promoted crew performance were often repeated (51%) (Table 9). However, almost half of the observed crew behaviours (49%) hindered crew performance.

There were few crew behaviours in the category 'Application of knowledge', as they were recorded, as in other competencies, only by observable actions. In this category, critical to practical crew performance, the assessments would also require questionnaires or specified tasks to gather data about the realization of the competency. BMs related to 'Communication' and 'Route plan management' were recorded the most frequently, followed by competency in 'Application of procedures and compliance with regulations'. In several categories, the distribution of positive and negative entries was even, with some exceptions as follows: in 'Leadership and teamwork', behaviour was positive; observations of competency in 'Problem-solving and decision-making' were more often negative than positive, but the number of observations was low; and the BMs connected to 'Workload management' were often negative (65%).

5. Discussion

This study defined the BMs of crew competencies in a taxonomy prototype for modelling crew performance in HSW cockpit work. The taxonomy was based on aviation knowledge, reasoned with HF concepts and operationalized using maritime-specific information. The BMs were tested using observation data and validated at a prototype level.

The study complemented previous research on maritime BM taxonomies and contributed to assessing and supporting crew performance, developing the socio-technical system of HSWs and improving maritime safety.

5.1. RQ1 critical crew competencies and behavioural markers in HSW cockpit work

Firstly, the study revealed a need to better understand crew performance in maritime HSWs. Despite contradictions, the aviation standards [14,45] provided a foundation for evolution, supported by reasoning using HF models [14,53,61]. Operationalizing BMs in a maritime context [56] prevented the needless use of practices from other industries [60].

In their review article, which partly inspired this study, Fjeld et al. [44] argued that the descriptions of bridge crew skills needed improvement and that new models should ensure sufficient coverage, detail and relevance when describing human activity, and pay particular attention to non-technical skills such as crew interaction. We propose that this study's detailed BMs confirmed this, but also complemented the previous research, even though the target was the specialized area of HSWs. Previous studies have focused on non-technical skills [49–51,71], but we did not separate them from technical skills in this study, as they were both prerequisites for safety and efficiency [25,44,46] and were difficult to divide [45].

We claim that the taxonomy BMs formed an entity promoting crew performance, considering the diversity of human activity [72] and despite the lack of analysis of BM interactions [44]. The basic idea of the taxonomy was facilitating effective resource management and crew cooperation, and to create the right attitude for this [14,25,46] that was lacking in individual-centred and technical-oriented maritime situations [7,73]. Knowledge of the mastery of HF was improved by integrating 'Crew resource management knowledge' as a compulsory component to crew training, as in merchant shipping [53]. Standard operating procedures were considered a fundamental prerequisite for efficient crew performance, considering the transitions with non-linear methods [74]. Unlike the primaries of non-technical skills [45], a separate communication competency was justified by the threats and development needs in the field [13]. Ensuring the effective use of route plans and controlling the outcome was carefully planned to facilitate the use of resources. Interpersonal activities, including leadership in teams [34,48,56,68], were highlighted and complemented previous maritime BMs [44]. Encouraging analytical, process-based [75] group decision-making [67,76] promoted intuitive perspectives, which are essential in rapidly changing situations [77]. Shared situation awareness [78] was highlighted over individual perspectives. Workload management – crucial for unified, proactive actions – was included as a competency area and suggested as a development target in the maritime industry [44].

Because teamwork is non-linear [37], the competencies, which all promoted crew cooperation and proactive resource management, were not organized as a process, although helpful illustrations were available [38].

5.2. RQ2 behavioural marker taxonomy structuring the activities of the crew

Secondly, the BMs modelled all of the observed behaviours essential for competent cockpit work crew performance. The researcher did not observe all of the BMs, but eliminating any of them was unjustified. Behaviours in certain competence areas were generally less noticeable, which was predictable [9].

The BMs described actual work according to the principles pursued [12] and testing revealed differences between crews. Using BMs enabled us to identify explicit behaviours that promoted or hindered crew performance. We also observed a possible dependence in the taxonomy behaviours, and deviations in the visible outcomes that could facilitate supporting the crews [45]. However, the study's results were reported on the group level, and individual crews were not compared.

Despite the simple and detailed expressions of the prototype BMs, operators need to understand the underlying phenomena [41] and their evaluation principles so as to ensure fairness and accuracy. Using the BMs enabled effective behaviour analysis of the cockpit recordings. In actual operations or real-time simulations, the researcher or practitioner should examine only a range of BMs.

5.3. Practical contribution

To conclude, the trainers in high-speed maritime organizations may use the taxonomy BMs to assess and develop crew competencies, the crews may enhance their self-reflection and the organizations may improve training systems [9,14,41,46]. The taxonomy could be used to enhance safety management, synchronize organizational levels [12], optimize the interaction between socio-technical components [79], and improve incident investigations [41] and standard operating procedures. The study's strategic benefit was related to future research and development [44] of the maritime industry.

5.4. Limitations and future research

When forming and testing the BMs, we sought content validity using all possible means [80], but further validation and proof of inter-rater reliability remains a topic for further research [12]. The number of cases for observation was reasonably low, which affects generalization. The crews may have overemphasized normative behaviour during the observations [12]. The qualitative data required interpretation by the researcher when developing the BMs, because some contents lacked precise boundaries. We suggest that future research should use international data, and that the researchers cooperate with each other.

5.5. Ethics

All of the materials were processed confidentially in accordance with the requirements of the target organizations and the agreements made with the parties involved. The participants were informed of the study's objectives on 20 May 2022 (request for data for organizations) and 30 August 2022 (study information sheet for observational participants). A privacy notice was created in connection with the evaluation. The University of Vaasa Human Science Ethics Committee confirmed, by its decision submitted on 30 August 2022, that no ethical review was needed for the research.

6. Conclusion

To summarize, the taxonomy prototype and BMs created a comprehensive framework for crew competencies in HSW cockpit work. The taxonomy was based on the systemic aviation standard [14], and was further justified by HF models [53,59,61] and maritime materials. Several areas requiring improvement were identified in the HSW maritime area. The competencies formed an entity that can be used to mitigate these by developing crew cooperation and resource management. We believe that our extensive synthesis of the datasets and testing of the BMs validated the model at the prototype level.

The scientific contribution of this study complements the chain of previous maritime BM taxonomies. The taxonomy prototype facilitated the analysis of the interaction between sociotechnical system components in order to improve operative performance [24] and safety [5,16]. Practitioners can use the taxonomy prototype to develop several levels of HSW cockpit work operations.

Acknowledgements

The authors wish to thank the following for their invaluable support: the Finnish Cultural Foundation of South Ostrobothnia, the Otto A. Malm Foundation, the Ella and Georg Ehrnrooth Foundation, the Coastal and Freshwater Traffic Foundation, the Gustav B. Thorden Foundation, the Foundation for the Promotion of Fisheries and Maritime, the Finnish Maritime Foundation, and the Funder of work research and development. They are also grateful to the participating maritime organizations, the Traficom and Regional State Administrative Agency for Western and Inland Finland, the Safety Investigation Authority of Finland and the aviation community for all the information they have provided.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Finnish Cultural Foundation of South Ostrobothnia; Otto A. Malm Foundation; Ella and Georg Ehrnrooth Foundation; Coastal and Freshwater Traffic Foundation; Gustav B. Thorden Foundation; Foundation for the Promotion of Fisheries and Maritime; Finnish Maritime Foundation [no grant numbers].

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Appendix 1. Definition of an HSW

A high-speed workboat (HSW) refers to a professional boat [81] 5.5–24 m in length that moves at a speed of more than 20 knots without using the ground effect or exiting the water [84], has a sliding or semi-sliding hull and is employed for professional or trade purposes; or a vessel intended for non-recreational purposes. An HSW can also be used in an oil spill response team, by a fire brigade or as a police boat [82]. The International Maritime Organization (IMO) uses the term 'high-speed craft' (HSC) to describe the operational profile of HSWs [84]. Warships and troop carriers were included in the scope of this study, although they are not included in the IMO's definition of HSC [84], as these often operate faster than other traffic, and their speed is occasionally used as a tool to avoid collisions. Active measures that violate water transport regulations are sometimes also required to avoid a collision [83].