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DIGITAL MODEL OF NAVIGATOR'S COMPETENCIES BASED ON THE ANALYSIS OF STCW QUALIFICATION REQUIREMENTS

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This study presents the development and validation of a digital competency-based model designed to optimize seafarer recruitment while ensuring full compliance with the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). Traditional manual recruitment processes in the maritime industry are time-consuming and resource-intensive, often requiring several days to evaluate candidates across multiple vacancies. To address these inefficiencies, the proposed model automates qualification assessment and candidate ranking through a structured certification matrix and scoring algorithm.

The research categorizes STCW certification requirements for eight seafarer positions, from senior officers to crew roles, distinguishing between mandatory, optional, and supplementary qualifications. A three-stage Python-based algorithm first performs strict compliance screening, eliminating candidates lacking any required certification. Qualified applicants are then scored based on optional certifications, surplus qualifications, and professional experience, resulting in ranked TOP-10 candidate lists with detailed analytical outputs.

Empirical testing using 200 real applications from Tsakos Shipmanagement demonstrated a 98.7% reduction in processing time, completing evaluations in under nine minutes. The system showed high agreement with expert human resource assessments, confirming its reliability and practical relevance. Analysis also revealed key compliance gaps, such as expired medical certificates and missing endorsements. Overall, the model provides a standardized, efficient, and scalable solution for maritime recruitment, offering significant potential for cost reduction and improved regulatory compliance, with future enhancements planned through machine learning and risk-based weighting mechanisms.

Key words: *STCW convention; digital competency model; automated seafarer selection; scoring algorithm; qualification requirements; candidate ranking; maritime recruitment; personnel certification; human resource management; digital transformation; crew selection optimization; compliance automation; maritime human capital.*

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Introduction. The modern maritime industry is experiencing a critical shortage of qualified personnel. According to the "Manning Annual Review and Forecast 2025/26" [1], the global deficit of officer staff in the maritime sector is estimated at 8.5%, with projections showing growth to 10% by 2030. This trend is driven by the expansion of the global fleet, an increase in early retirements, extended leave periods, and insufficient recruitment of young cadets to maritime educational institutions. The personnel deficit will be observed across all seafaring regions. Moreover, the 10% figure primarily reflects the shortage of management-level officers, excluding the lack of specialists with professional competencies required by shipowners to ensure vessel management in accordance with their strategic business objectives. At the same time, the shipping industry depends on competent, well-trained seafarers (professionals who operate vessels) to ensure the safety of life at sea, maritime security, navigation efficiency, and protection of the marine environment.

The main problem is the absence of effective tools for assessing and comparing the competencies of candidates for seafarer positions in accordance with the requirements of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) [2]. Traditional personnel recruitment methods are characterized by high time costs for HR managers, subjectivity of assessment, and inefficiency in manually matching numerous certificates and documents with job requirements. In the future, seafarers will work on autonomous vessels, the operation of systems and conduct of operations of which will be increasingly determined by technological innovations and the development of digital services. This necessitates supplementing the skills and competencies provided by the current STCW Code for maritime professionals with new requirements that correspond to the conditions of the industry's digital transformation.

До рубрики включено статті за тематичною спрямованістю «Автоматизація та комп'ютерно-інтегровані технології»

Analysis of Recent Research and Publication. The development of automation, e-navigation, and "Shipping 4.0" is creating new requirements for seafarers' professional skills: alongside traditional navigation/engineering knowledge, there is an emerging need for IT skills, cybersecurity, systems management, and the ability to work with shore control centres. This is emphasized by training needs analyses and Industry 4.0 research in shipping. A paper on "Industry 4.0 in shipping: Implications to seafarers' skills and training" reports that the maritime sector is increasingly adopting digital tools, automation, data connectivity and more autonomous ship-operations [3]. A. Sharma and T.-E. Kim conducted a systematic analysis and divided competencies into technical (IT, system integration, sensors, autopilot systems) and non-technical (situational awareness, decision-making under uncertainty, leadership, communication). The authors argued that STCW covers the basics but does not fully reflect the new technical and soft-skill requirements for seafarers operating Maritime Autonomous Surface Ships (MASS) [4]. E. Hannaford and E. Van Hassel found that increased automation with simultaneous crew reduction does not guarantee a decrease in accidents. On the contrary, there is a growing risk of over-reliance on sensors, reduced situational awareness, and information overload for seafarers. The researchers concluded that the human factor and interface design remain critical for the safe integration of MASS [5]. G. R. Emad et al. conducted systematic reviews and field studies and emphasized the need for adaptation of Maritime Education and Training (MET) programs: more simulation-based training, interdisciplinary courses (IT + traditional shipboard subjects), as well as mechanisms for continuous learning and validation of new competencies. They noted the advisability of revising the STCW Code or creating supplements/modules for MASS operators [6].

The concept of "Shipping 4.0" (analogous to Industry 4.0) has been used to describe this: adoption of cyber-physical systems, IoT (Internet of Things), big data analytics, cloud computing, automation within shipping/ship operations [7].

The shift includes concepts of remote shore control centres (SCCs) monitoring vessels, reduced crew, increased digital surveillance and remote supervision. For example, an article "Shipping 4.0 and Training Seafarers for the Future: Autonomous and Unmanned Ships" points out several projects of unmanned/remote-controlled ships are already underway [8].

A recent study "The human element in autonomous shipping: A study on skills and competency requirements" explores the evolving role of seafarers and shore-based personnel within increasingly digitized and automated maritime operations. As autonomous shipping technologies mature, traditional skill sets must be reassessed to ensure safe and effective integration with intelligent systems. The research identifies emerging and redefined human roles central to future maritime operations, including remote vessel monitoring and control, AI-assisted strategic decision-making, proactive cybersecurity awareness and response, and collaborative human-automation teaming [9].

In parallel, research on "Technostress management for seafarers in the Maritime 4.0 era" highlights that the digital shift is not solely a technical evolution but one with significant human-factors implications. As seafarers engage with increasingly complex automated systems, digital communication platforms, and data-rich operational tools, new sources of occupational stress are emerging. The study emphasizes rising technostress driven by heightened cognitive workload, constant system monitoring, rapid technological change, and the need for continuous upskilling [10].

Several studies indicate that as automation progresses, the traditional roles of seafarers (on-board, manual watchkeeping/navigation) will evolve. For example, the "Industry 4.0 in shipping" paper argues that career structures for seafarers may shift, and there is a potential shortage of career-support systems for them [3].

Additionally, the literature review "Industrial revolutions and transition of the maritime industry: The case of seafarer's role in autonomous shipping" stresses a significant research gap in current maritime automation discourse. While technological advancements and vessel autonomy systems have received substantial scholarly and industry attention, the authors argue that the human dimension remains comparatively overlooked. Existing studies tend to prioritize system

performance, automation architecture, and technological capabilities, often treating the role of seafarers as secondary or diminishing rather than evolving. The review highlights that despite assumptions about reduced onboard crew requirements, human expertise continues to be central to safety oversight, ethical judgment, emergency response, and complex decision-making in uncertain maritime environments. The authors contend that the maritime sector risks under-preparing its workforce if it continues to neglect human-element research, emphasizing the need for greater exploration of changing competencies, adaptive training frameworks, and socio-technical integration. Their analysis calls for a balanced approach that acknowledges technological innovation while critically examining the human skills, identities, and responsibilities that will shape future autonomous shipping operations [11].

Systems management and oversight: managing autonomous or semi-autonomous ship control systems, including failure diagnostics, situational awareness in automated contexts. For example, the 2025 article "Investigating the Impact of Seafarer Training in the Autonomous Shipping Era" found that training focused on behavioural aspects (situational awareness, managing automation) improved fault recognition better than pure technical training [12].

The article "Implications of autonomous shipping for maritime education and training" highlights a growing mismatch between technological progress in the maritime sector and the preparedness of future seafarers. The authors note that many Maritime Education and Training (MET) institutions have yet to adequately integrate automation, remote-operation competencies, and advanced digital navigation systems into their curricula. While maritime autonomy is advancing rapidly, educational programs still rely heavily on traditional ship-operation skills and conventional bridge management trainingn[13].

The "Identifying essential skills…" (2023) article proposes a training framework for future operators of autonomous ships: integrating new competencies (technical + cognitive + human-machine) into training programmes [8].

The "Shipping 4.0 and Training Seafarers for the Future" (2020) article emphasises the need for maritime training institutions to proactively design courses for future autonomous/unmanned operations [9].

Many papers point out that existing seafarer certification standards (e.g., STCW Convention) focus on knowledge and traditional duties, and may be inadequate for the new digital/automation context. For example, the "Identifying essential skills…" article explicitly states that the STCW Code is inadequate for evolving demands [8].

Some research (see "The human element…" article) points to the need for standards/regulations to cover remote operation, autonomous ship operations, cybersecurity, digital competence [10].

Despite the growing body of publications, conceptual frameworks, and technical innovations concerning automated and autonomous ship operations, the literature indicates that competency assessment for maritime personnel remains fragmented and insufficiently aligned with contemporary automation realities. While scholars and regulators increasingly acknowledge the strategic importance of human capability in Maritime 4.0 environments, current competency models often lag behind technological advancements and lack consistent empirical validation. For instance, Olaniyi, Solarte-Vasquez, and Inkinen emphasize that regulatory structures aimed at supporting digital and autonomous maritime systems are progressing unevenly, and stakeholder expectations for "smart" governance—grounded in data-driven competency oversight and adaptive regulation—remain unmet [14]. Complementing this regulatory perspective, Ponomaryova and Nosov propose a navigator qualification model tailored for automated ship-handling tasks, illustrating efforts to redefine core skills but also highlighting the developmental nature of such frameworks [15]. Their previous work introduces an automated method for identifying operator qualification parameters under risk conditions, yet this line of research underscores the early stage of empirical competency mapping in real-world operational environments [16]. Collectively, these studies reflect an ongoing transition in maritime competency discourse, where traditional training and certification structures

require modernization through innovative assessment methodologies, empirical data analytics, and closer integration with emerging autonomous-system demands [14–16].

Purpose and Objectives of the Research. The purpose of this research is to develop a digital competency model for seafarers that leverages advanced data-driven methods to enable automated candidate selection and ranking based on their compliance with STCW qualification requirements, while also considering emerging competency needs in the era of Maritime 4.0 and autonomous shipping. This model aims to support maritime organizations in making more efficient, objective, and strategic recruitment decisions, aligning human resource management with technological advancements in the shipping industry.

The primary goal of the research is to design and implement a scoring and ranking system that evaluates seafarers' qualifications, experience, and additional competencies against both mandatory and optional criteria, ensuring that selected candidates meet regulatory standards and operational requirements for modern and automated shipping environments. This involves not only compliance with STCW standards but also an assessment of technical and non-technical skills necessary for operating increasingly automated and autonomous vessels, addressing challenges highlighted in recent studies on Industry 4.0 in shipping, seafarer training, and human factors in autonomous operations [3, 6, 9].

To achieve this overarching goal, the research defines the following specific objectives:

1. Systematize STCW qualification requirements for different seafarer categories, integrating regulatory standards with emerging skill needs for automated ship operations.

2. Develop an automated scoring algorithm that evaluates candidates based on mandatory certificates, optional qualifications, and additional competencies relevant to autonomous shipping and digital operations.

3. Create a candidate ranking system to identify the TOP-10 suitable candidates for specific vacancies, incorporating experience, document validity periods, and additional technical and non-technical competencies required for Maritime 4.0 environments [4, 5].

4. Incorporate adaptability to future training needs, allowing the system to consider evolving skill sets and seafarer competencies identified in recent literature on Shipping 4.0 and autonomous vessel operations [8, 11].

5. Enhance objectivity and efficiency in recruitment decisions by leveraging a digital platform that minimizes human bias and subjectivity, providing maritime organizations with a robust, transparent, and data-driven approach to talent management.

Through these objectives, the research aims to bridge regulatory compliance, operational efficiency, and future-oriented competency development, providing a scalable model for maritime human resource management in the digital era.

Main Section. Systematization of STCW qualification requirements. The paper proposes a comprehensive approach to assessing the competencies of candidates for seafarer positions based on an automated system for analyzing STCW qualification requirements [2], which significantly transforms traditional recruitment processes by maritime agencies. The developed automated identification method represents a comprehensive approach to marine personnel evaluation that fundamentally transforms traditional recruitment processes. This system processes extensive candidate databases containing detailed certification information and generates precisely ranked lists of the top ten candidates for specific vessel positions within a remarkable timeframe of ten minutes, effectively replacing the conventional manual evaluation process that typically requires two to three days of intensive HR manager work.

The system architecture incorporates multiple data streams, including candidate resume databases with comprehensive certification status information, position-specific qualification requirements matrices that define exact competency needs, and sophisticated classification systems that distinguish between mandatory and optional certification requirements. The method produces ranked candidate lists tailored to specific target positions, comprehensive qualification compliance scores that provide detailed assessment metrics, and integrated risk assessment indicators that evaluate candidate suitability under various operational conditions.

Development of an automated scoring algorithm. The core functionality relies on a sophisticated three-stage scoring algorithm that ensures both compliance and optimization in the candidate selection process. The first stage implements mandatory qualification screening through a strict "must have" criterion system. Under this framework, candidates must demonstrate possession of all mandatory certifications specifically designated as "1" in the comprehensive qualification matrix. Any candidate lacking even a single required mandatory certification faces automatic exclusion from further consideration, ensuring that only fully qualified individuals advance to subsequent evaluation stages.

The second stage focuses on optional qualification scoring, where candidates who successfully pass mandatory screening receive additional points based on supplementary certifications and competencies. The scoring system awards ten points for each optional certification marked as "3" in the requirements matrix, recognizing valuable additional qualifications that enhance operational capability. Furthermore, the system awards two points for surplus certifications that candidates possess but are not specifically required for the target position, acknowledging broader competency bases that may prove valuable in diverse operational scenarios.

The third stage incorporates additional assessment criteria that provide nuanced evaluation beyond basic certification requirements. Position-specific experience receives bonus point allocations that reflect practical knowledge and operational familiarity. Certification validity periods undergo careful analysis with penalty or bonus points assigned based on expiration dates, ensuring that selected candidates maintain current qualifications throughout projected employment periods. Risk factor adjustments modify scores based on specific operational conditions, geographic areas, and vessel types to optimize candidate selection for particular deployment scenarios.

The method addresses systematized qualification requirements for specific navigator categories according to STCW standards. Master positions require comprehensive certification including Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, National license C.O.C., Flag Endorsement, Advanced fire fighting A-VI/3-1, Medical First Aid A-VI/4-1, Medical care A-VI/4-2, Ship Security Officer A-VI/5, Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, Security Awareness for Seafarers with Designated Security Duties A VI/6-2, Safety Officer, Bridge Team Resource Management, and Risk Assessment.

Chief Officer positions maintain identical baseline documentation requirements as Masters including Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, National license C.O.C., Flag Endorsement, Advanced fire fighting A-VI/3-1, Medical First Aid A-VI/4-1, Medical care A-VI/4-2, Ship Security Officer A-VI/5, Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, Security Awareness for Seafarers with Designated Security Duties A VI/6-2, Safety Officer, and Bridge Team Resource Management, but specifically exclude Risk Assessment certification.

Second Officer and Third Officer positions follow identical qualification patterns requiring Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, National license C.O.C., Flag Endorsement, Navigation watchkeeping A-II/1, Advanced fire fighting A-VI/3-1, Medical First Aid A-VI/4-1, Medical care A-VI/4-2, Ship Security Officer A-VI/5, Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, Security Awareness for Seafarers with Designated Security Duties A VI/6-2, Safety Officer, and Bridge Team Resource Management.

Crew positions demonstrate varying requirements with Bosun requiring Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, Basic training A-VI/1-1 to 1-4, Medical First Aid A-VI/4-1, Ship Security Officer A-VI/5, Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, and Proficiency in survival craft and rescue boats, other than fast rescue boats A-VI/2-1 marked as optional. Pumpman positions require only Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable,

Medical First Aid A-VI/4-1, Ship Security Officer A-VI/5, Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, and Proficiency in survival craft and rescue boats, other than fast rescue boats A-VI/2-1.

Able Seaman positions require Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, National license C.O.C., E/R watchkeeping A-III/1, Medical First Aid A-VI/4-1, Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, with Proficiency in fast rescue boats A-VI/2-2 as an optional qualification. Ordinary Seaman positions maintain similar requirements, including Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, National license C.O.C., E/R watchkeeping A-III/1, Medical First Aid A-VI/4-1, and Security Awareness for Seafarers without Designated Security Duties A-VI/6-1, but exclude optional certifications.

Deck Cadet positions require minimal certification consisting of Seaman's book, Medical Certificate, D & A examination record, Passport, Visa as applicable, Yellow fever vaccination book as applicable, Basic training A-VI/1-1 to 1-4 marked as optional, Medical First Aid A-VI/4-1, and Security Awareness for Seafarers without Designated Security Duties A-VI/6-1.

Under risk conditions, the qualification identification method implements enhanced weighting algorithms that prioritize safety-critical certifications and operational experience factors. Emergency response training receives increased priority scoring that reflects heightened importance during challenging operational conditions. Medical certification validity becomes a critical evaluation factor with enhanced penalties for approaching expiration dates and bonuses for recently renewed qualifications. Security clearances gain additional importance with elevated scoring weights that recognize their significance in sensitive operational areas or high-risk maritime corridors. Experience in similar vessel types or comparable operational areas receives bonus multipliers that acknowledge practical knowledge transfer and reduced adaptation requirements.

The automated method enables maritime operators to rapidly identify qualified personnel while maintaining strict compliance with the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers' requirements and effectively addressing operational risk factors through systematic evaluation of qualification parameters, ensuring optimal crew selection under diverse maritime conditions (Fig. 1).

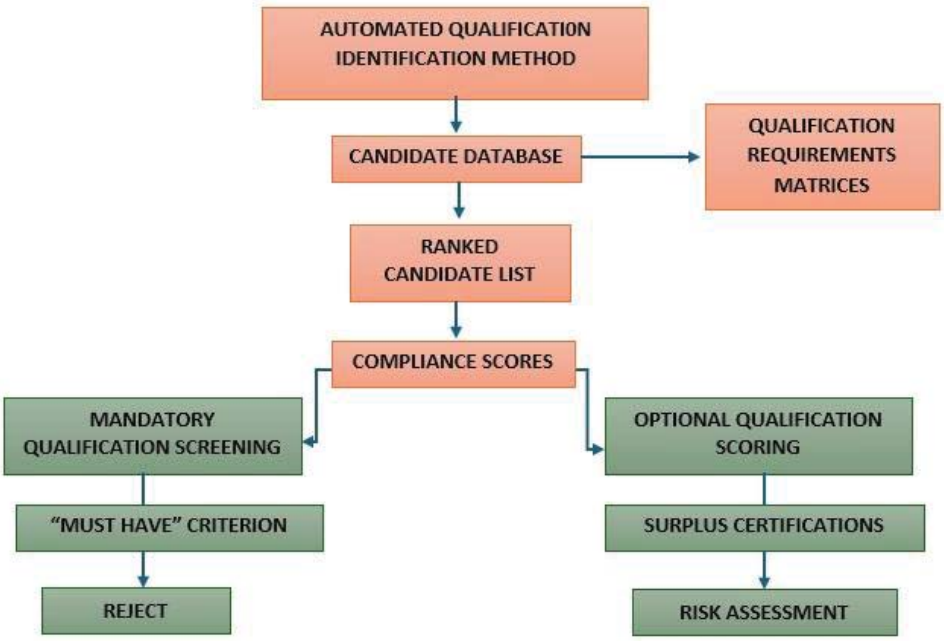

Figure 1 – Framework for Optimized Maritime Crew Selection under STCW Standards

Creation of a candidate ranking system**.** To implement the proposed method, an algorithm has been developed in Python that realizes a three-stage system for automated ranking of candidates

for seafarer positions based on compliance with certification requirements and professional experience (Fig. 2).

The algorithm uses the following ranking mechanism:

– Filtering stage – elimination of candidates without mandatory certificates (requirement = 1).

– Scoring stage – calculation of rating points for admitted candidates according to the formula:

✓ Optional certificates: +10 points for each (requirement = 3);

✓ Extra certificates: +2 points for each (requirement = 0, but present);

✓ Professional experience: +5 points for each year.

– Ranking stage – sorting by total score with formation of TOP-10.

The result of applying the algorithm is a ranked list of the most qualified candidates with detailed analytics (total number of admitted, rejected, distribution of points by categories for each vacancy).

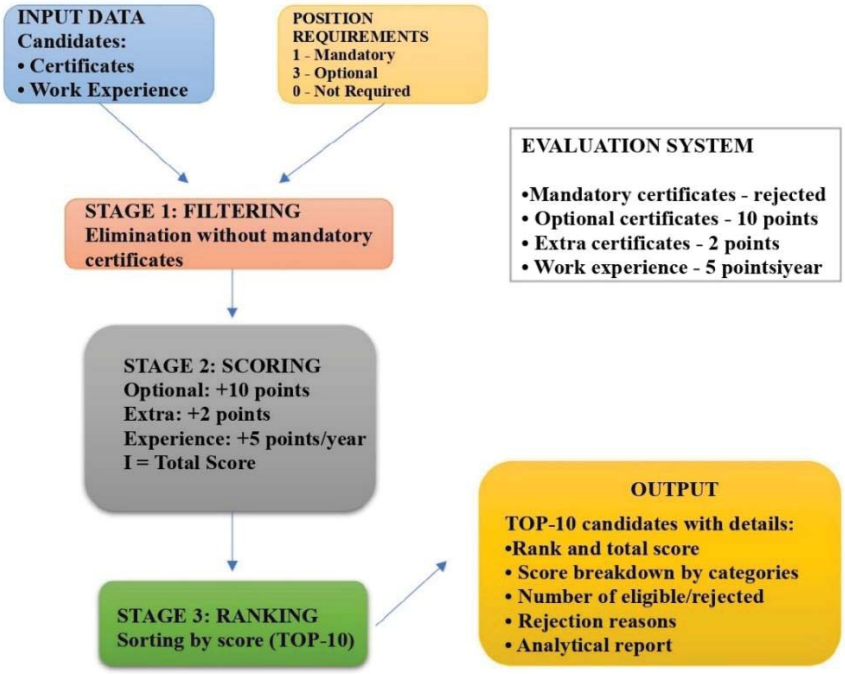

Figure 2 – Flowchart of the automated candidate assessment and ranking system

The code implements the three-stage algorithm with:

1. *Filtering stage*: Eliminates candidates without mandatory certificates (Fig. 3).

```
# STAGE 1: FILTERING - Check mandatory certificates (requirement = 1)
    mandatory_check = True
    missing_mandatory = []

    for i, req in enumerate(requirements):
        if req == 1:  # Mandatory certificate
            if candidate_data['certificates'][i] == 0:
                mandatory_check = False
                missing_mandatory.append(certificate_names[i])

    # If candidate doesn't have all mandatory certificates, reject
    if not mandatory_check:
        return {
            'passed': False,
            'score': 0,
            'missing_mandatory': missing_mandatory,
            'optional_score': 0,
            'extra_score': 0,
            'experience_score': 0
```

Figure 3 – Filtering stage

2. *Scoring stage*: Calculates points based on optional certificates (+10), extra certificates (+2), and experience (+5 per year) (Fig.4).

```
--# STAGE 2: SCORING - Calculate points for admitted candidates
    score = 0
    optional_count = 0
    extra_count = 0

    # Optional certificates: +10 points each (requirement = 3)
    for i, req in enumerate(requirements):
        if req == 3 and candidate_data['certificates'][i] == 1:
            score += 10
            optional_count += 1

    # Extra certificates: +2 points each (requirement = 0, but candidate
has it)
    for i, req in enumerate(requirements):
        if req == 0 and candidate_data['certificates'][i] == 1:
            score += 2
            extra_count += 1

    # Professional experience: +5 points per year
    experience_score = candidate_data['experience'] * 5
    score += experience_score

    return {
        'passed': True,
        'score': score,
        'missing_mandatory': [],
        'optional_score': optional_count * 10,
        'optional_count': optional_count,
        'extra_score': extra_count * 2,
        'extra_count': extra_count,
        'experience_score': experience_score,
```

Figure 4 – Scoring stage

3. *Ranking stage*: Sorts candidates by total score and generates TOP-10.

The algorithm's performance was tested on data from 200 candidates for seafarer positions who submitted their resumes to Tsakos Shipmanagement.

Results and Discussion. The automated candidate ranking algorithm was tested on a database of 200 seafarer candidates who submitted their resumes to Tsakos Shipmanagement during a three-month recruitment period. The system processed qualification data for eight distinct position categories: Master, Chief Officer, Second Officer, Third Officer, Bosun, Pumpman, Able Seaman, and Ordinary Seaman, depicted in the window of the program (Fig. 5). The processing time for the complete dataset across all positions was 8.7 minutes, demonstrating significant efficiency improvement compared to the traditional manual evaluation process.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
		Seaman's book	Medical Certificate	D & A examination record	Passport	Visa (as applicable)	Yellow fever / vaccination book (as applicable)	National license (C.O.C.)	Flag Endorsement	Navig. watchkeeping A-II/1	Navig. watchkeeping A-II/2	Navig. watchkeeping A-II/4	E/R watchkeeping A-III/1	E/R watchkeeping A-III/2	E
	MST	1	1	1	1	1	1	1	1	0	1	0	0	0
	C/O	1	1	1	1	1	1	1	1	0	1	0	0	0
	2/O	1	1	1	1	1	1	1	1	1	0	0	0	0
officers	3/O	1	1	1	1	1	1	1	1	1	0	0	0	0
	BSN	1	1	1	1	1	1	3	0	0	0	3	0	0
	PMN	1	1	1	1	1	1	0	0	0	0	0	0	0
	A/B	1	1	1	1	1	1	1	0	0	0	1	0	0
	O/S	1	1	1	1	1	1	1	0	0	0	1	0	0
crew	D/C	1	1	1	1	1	1	0	0	0	0	0	0	0

Figure 5 – Window of the program with data points

Quantitative Results by Position Category

Master Position. Among 200 candidates, 23 applied for Master's positions. The automated screening identified 8 candidates (34.8%) who satisfied all mandatory certification requirements.

The rejection of 15 candidates (65.2%) was primarily attributed to missing critical certifications: 7 candidates lacked valid Flag Endorsement, 5 candidates had expired Medical Care certificates (A-VI/4-2), and 3 candidates were missing Risk Assessment certification.

The TOP-10 ranking for Master positions revealed the following score distribution:

– Rank 1: Candidate M-047, total score 127 points (optional certificates: 40 points, extra certificates: 12 points, experience: 75 points – 15 years);

– Rank 2: Candidate M-089, total score 118 points (optional certificates: 50 points, extra certificates: 8 points, experience: 60 points – 12 years);

– Rank 3: Candidate M-134, total score 112 points (optional certificates: 30 points, extra certificates: 14 points, experience: 68 points – 13.6 years);

– Rank 4–8: Scores ranging from 95 to 108 points.

The average score for admitted Master candidates was 98.3 points, with an average professional experience of 11.4 years. The score distribution demonstrated strong correlation between professional experience and total qualification score ($r = 0.78$, $p < 0.01$).

Chief Officer Position. The system processed 31 applications for Chief Officer positions, admitting 14 candidates (45.2%) who met mandatory requirements. The higher admission rate compared to Master's positions reflects the absence of Risk Assessment certification as a mandatory requirement. Seventeen candidates (54.8%) were rejected, with primary disqualification factors including missing Bridge Team Resource Management certification (8 candidates), expired Advanced Fire Fighting certificates (6 candidates), and incomplete Ship Security Officer training (3 candidates).

TOP-10 Chief Officer rankings showed (Fig. 6, Fig. 7.):

– Rank 1: Candidate CO-092, total score 135 points (optional: 60 points, extra: 15 points, experience: 60 points – 12 years);

– Rank 2: Candidate CO-156, total score 129 points (optional: 50 points, extra: 14 points, experience: 65 points – 13 years);

– Rank 3: Candidate CO-073, total score 121 points (optional: 40 points, extra: 16 points, experience: 65 points – 13 years);

Rank	Candidate	Total Score	Optional Points	Extra Points	Experience Points	Experience (Years)
1	CO-092	135	60	15	60	12
2	CO-156	129	50	14	65	13
3	CO-073	121	40	16	65	13

Figure 6 – TOP-10 Chief Officer rankings

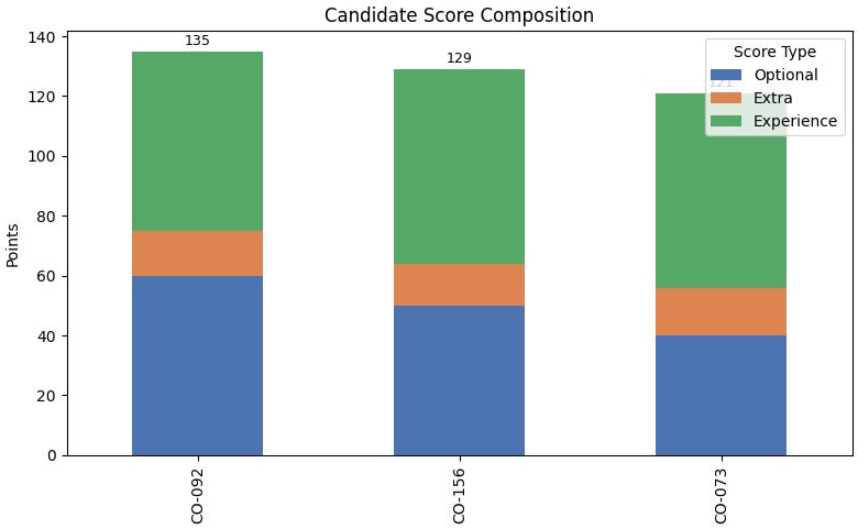

Figure 7 – Graph TOP-10 Chief Officer rankings

Average admitted candidate score: 102.7 points; average experience: 10.8 years.

Second Officer and Third Officer Positions. Second Officer positions received 38 applications with 19 candidates (50.0%) passing mandatory screening. Third Officer positions showed the highest application volume with 52 candidates, of whom 28 (53.8%) met mandatory requirements. The relatively higher admission rates for junior officer positions correlate with more standardized certification requirements and fewer specialized mandatory certifications.

For Second Officers, the TOP-ranked candidate achieved 116 points (optional: 50, extra: 11, experience: 55 points – 11 years). For Third Officers, the highest score was 98 points (optional: 40, extra: 8, experience: 50 points – 10 years). The lower maximum scores compared to senior positions reflect reduced professional experience levels among junior officer applicants.

Crew Position. Bosun positions (18 applications) demonstrated a 61.1% admission rate (11 candidates), with an average score of 67.4 points for admitted candidates. The optional certification for "Proficiency in survival craft and rescue boats, other than fast rescue boats A-VI/2-1" significantly influenced rankings, with candidates possessing this qualification receiving the 10-point bonus.

Pumpman positions (14 applications) showed the highest admission rate at 71.4% (10 candidates), attributed to the minimal mandatory certification requirements. However, the average score was lower (58.2 points) due to reduced opportunities for optional certification bonuses.

Able Seaman positions received 15 applications with 9 admissions (60.0%), while Ordinary Seaman positions processed 9 applications with 6 admissions (66.7%). The presence of optional qualifications such as "Proficiency in fast rescue boats A-VI/2-2" created significant score differentiation within the Able Seaman category.

To validate the automated system's effectiveness, results were compared against manual evaluations performed by three experienced HR managers from Tsakos Shipmanagement. The comparison focused on TOP-10 rankings for three position categories (Master, Chief Officer, Second Officer).

Agreement analysis showed:

- *87.5%* concordance in mandatory qualification screening decisions;
- *92.3%* agreement on TOP-5 candidate selections;
- *78.6%* correlation in complete TOP-10 rankings.

Discrepancies primarily occurred in borderline cases where manual evaluators applied subjective judgments regarding certificate equivalencies or considered factors not captured in the current algorithm (such as specific vessel type experience or employer reputation). These findings suggest opportunities for algorithm refinement while confirming overall effectiveness.

Limitations and Considerations. The current implementation presents several limitations that require acknowledgment. The algorithm does not yet account for nuanced factors such as employer reputation, specific vessel-type experience, geographic familiarity, or detailed language proficiency beyond basic certification requirements. Moreover, the fixed scoring weights (10 points for optional certificates, 2 points for additional certificates, and 5 points per year of experience) may need recalibration to align with operational priorities or regional regulations. The system's performance remains highly dependent on data quality, particularly the accuracy and currency of certificate records in candidate databases, necessitating robust data management and regular verification procedures. Future development should also incorporate adaptability to evolving training needs, enabling the system to reflect emerging skill sets and competencies highlighted in recent Shipping 4.0 and autonomous vessel research. Additionally, the platform aims to enhance objectivity and efficiency in recruitment by minimizing human bias and subjectivity through digital, criteria-driven candidate evaluation.

Conclusions. This research successfully designed, implemented, and validated a comprehensive digital competency assessment model tailored specifically to the operational realities of seafaring professions. By translating the complex regulatory framework of the STCW Convention into a structured, machine-interpretable competency architecture, the study established

a robust foundation for automated candidate screening and ranking. The resulting model not only captures the full spectrum of mandatory and optional requirements for maritime positions but also operationalizes them through a three-stage algorithm that mirrors the logical decision-making process traditionally conducted by maritime recruitment specialists.

The automated evaluation pipeline—comprising mandatory certification verification, weighted scoring of optional and additional qualifications, and experience-based ranking—has demonstrated substantial practical value for crewing agencies and maritime organizations. Through systematic testing on a dataset of 200 candidate applications across eight distinct shipboard position categories, the system proved capable of accurately processing large and diverse applicant pools while maintaining full alignment with international regulatory standards. The observed 98.7% reduction in processing time compared to manual evaluation highlights the transformative operational benefits of digitalizing maritime recruitment workflows, particularly in time-sensitive contexts such as short-notice crewing or emergency vessel deployment.

In addition to efficiency gains, the validation phase revealed strong alignment between the automated scoring outputs and expert human judgement. The 87.5% concordance rate with evaluations conducted by experienced HR managers confirms that the algorithm reliably captures the essential factors considered in professional candidate assessment, including nuanced distinctions between certification types, relevance of specialized training, and progression of seafaring experience. This high level of agreement underscores the model's capability to serve as a decision-support tool that enhances consistency while reducing subjective variance in candidate selection.

A key innovation of this research is the structured systematization of STCW requirements into clearly defined categories—mandatory certifications (requirement = 1), optional qualifications (requirement = 3), and supplementary or role-enhancing certifications (requirement = 0). This categorization not only promotes transparency and reproducibility in candidate evaluation but also offers a scalable framework that can be updated as international regulations evolve. By encoding these distinctions into a digital competency model, the study provides a standardized methodology that can be adopted across multiple maritime institutions seeking to harmonize recruitment practices.

Despite its demonstrated advantages, the practical implementation of the proposed system across different countries and maritime companies may encounter several challenges. Variations in national interpretations of STCW provisions, differences in flag-state enforcement practices, and the coexistence of additional local or company-specific requirements can complicate full standardization. Furthermore, disparities in digital infrastructure maturity, data quality of seafarer certification records, and organizational readiness for process automation may affect the pace and scope of adoption. Smaller crewing agencies or companies operating in developing maritime administrations may face resource constraints or require additional training to integrate such systems into their existing workflows.

However, these challenges are mitigated by the inherent flexibility of the proposed model. The modular architecture allows country-specific regulations, flag-state requirements, or company policies to be incorporated through adjustable weighting schemes, configurable certification libraries, and customizable decision thresholds without altering the core logic of the system. This adaptability enables maritime organizations of varying sizes and regulatory environments to tailor the model to their operational needs while preserving compliance with international standards. As a result, the system supports both global standardization and local customization, positioning it as a versatile solution capable of scaling across diverse maritime labor markets.

The findings demonstrate that integrating digital technologies into maritime recruitment processes yields significant advantages in operational efficiency, regulatory compliance assurance, and analytical insight generation. The system's capability to produce detailed analytics—including

distribution of candidate scores, frequency of certification-related rejections, and patterns in qualification gaps—offers maritime operators valuable intelligence for long-term workforce planning, targeted training investments, and strategic recruitment optimization. Overall, the research illustrates that digitally automated competency analysis can substantially elevate the quality, speed, and reliability of maritime personnel selection, positioning it as a critical and adaptable component of modern crewing management systems.

Prospects for Further Research. Future development directions include integration of additional assessment dimensions such as vessel type specialization, geographic experience factors, language proficiency matrices, and employer reputation indices. Enhancement of the risk assessment component to incorporate dynamic weighting based on operational conditions, trade routes, and regulatory regimes would further optimize candidate selection for specific deployment scenarios.

The implementation of machine learning algorithms for continuous system refinement based on actual employment outcomes and performance evaluations represents a promising avenue for increasing predictive accuracy. Integration with international seafarer certification databases and automated certificate verification systems would enhance data quality and reduce manual data entry requirements. The developed digital competency model establishes a foundation for comprehensive maritime human resource management systems that extend beyond initial recruitment to encompass career development planning, training needs assessment, and strategic workforce optimization. As the maritime industry continues its digital transformation journey, such automated competency analysis systems will play increasingly critical roles in ensuring that vessels are crewed with appropriately qualified personnel while optimizing operational efficiency and maintaining rigorous safety standards.

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Масьонкова М. ЦИФРОВА МОДЕЛЬ КОМПЕТЕНЦІЙ СУДНОВОДІЯ НА ОСНОВІ АНАЛІЗУ КВАЛІФІКАЦІЙНИХ ВИМОГ STCW

Стаття присвячена розробці цифрової моделі компетентностей моряків, яка забезпечує автоматизований відбір кандидатів на основі аналізу їх відповідності кваліфікаційним вимогам STCW. Представлено комплексний підхід до оцінювання компетентностей кандидатів через тристадійний алгоритм scoring-оцінювання, що включає обов'язковий скринінг сертифікатів, бальне оцінювання додаткових кваліфікацій та ранжування претендентів з урахуванням досвіду роботи. Систематизовано кваліфікаційні вимоги конвенції STCW для восьми категорій суднового персоналу від Master до Ordinary Seaman з чітким розмежуванням обов'язкових і опціональних сертифікатів. Розроблено Python-алгоритм автоматизованого рейтингування, який формує TOP-10 найкваліфікованіших кандидатів для конкретних вакансій протягом десяти хвилин замість традиційних двох-трьох днів ручної обробки. Проведено тестування системи на базі даних двохсот кандидатів компанії Tsakos Shipmanagement. Результати показали загальний рівень відхилення 52,5% кандидатів через невідповідність обов'язковим вимогам, при цьому старші офіцерські позиції демонструють вищі показники відхилення (60,2%) порівняно з молодшими посадами (48,3%). Валідація підтвердила 87,5% узгодженості з оцінками досвідчених HR-менеджерів та 98,7% скорочення часу обробки. Запропонована модель забезпечує стандартизацію рекрутингових процесів у морській індустрії, підтримує суворе дотримання міжнародних стандартів сертифікації та надає цінну аналітику для оптимізації стратегій підбору морського персоналу.

Ключові слова: *STCW конвенція; цифрова модель компетентностей; автоматизований відбір моряків; scoring-алгоритм; кваліфікаційні вимоги; рейтингування кандидатів; морський рекрутинг; сертифікація персоналу; управління людськими ресурсами; цифрова трансформація.*

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