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Comparative Study of Shipping Talent Cultivation Models in the Context of Digital Transformation – A Case Study of Universities in China, the United Kingdom, and Singapore

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Abstract: As big data, Artificial Intelligence (AI), and Internet of Things (IoTs) profoundly reshape the global shipping industry, multidisciplinary talents with digital literacy have become a core competitive advantage. This paper aims to explore the systemic changes brought about by digital transformation to global shipping talent cultivation and conducts an in-depth comparative study of the training models of three typical universities: Shanghai Maritime University in China, Plymouth University in the UK, and Nanyang Technological University (NTU) in Singapore, using the Analytic Hierarchy Process (AHP) model. The study is based on four core dimensions: training objectives, curriculum system, practical teaching, and industry-academia-research collaboration. The research concludes that the NTU model performs best in terms of overall weighted performance, demonstrating that the reform of global maritime education must focus on the substantive restructuring of curriculum content and the transformation of practical teaching towards data-driven decision-making simulations, supported by a systematic industry-academia collaboration mechanism, to effectively cultivate "T-shaped" talents who can adapt to and lead the future development of intelligent shipping.

Keywords: Digital Transformation; Maritime Talent; Cultivation Model; Analytic Hierarchy Process (AHP); Comparative Study

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1.Introduction

1.1 Global Context: Technological Disruption and the Reshaping of the Maritime Value Chain

Currently, the wave of the Fourth Industrial Revolution, represented by artificial intelligence, big data, the Internet of Things, and blockchain, is sweeping across the global shipping industry, propelling it towards a new development phase characterized by "green, intelligent, and efficient" operations. The industry's digital transformation has evolved from an option to a necessity for survival and growth. Profound technological changes are systematically reshaping the shipping industry's value chain and ecosystem, imposing disruptive new demands on the knowledge structure and competency of its workforce. In response to these dramatic shifts, the global shipping market is witnessing the emergence of new roles such as "remote-controlled automated terminal technicians," "terminal system optimization specialists," and "model algorithm architects." These positions demand professionals who not only master traditional maritime technologies or shipping management skills but also possess robust data analysis capabilities, IT application literacy, and cross-disciplinary problem-solving competencies.

However, a significant structural disconnect exists between this exponential technological evolution and the existing maritime education and training (MET) system—a so-called "competency gap." Traditional curricula typically center on foundational disciplines such as Marine Engineering, Navigation Technology, International Trade practices, and Shipping Management, while digital-related courses often exist only as supplementary or standalone modules, failing to achieve deep, organic integration with core professional knowledge. This curricular inertia primarily stems from the shipping industry's long-standing strict regulation by standards like the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW). These regulations emphasize ensuring operational safety and compliance but often act as barriers to rapid curriculum innovation [1]. The core competitiveness of future maritime professionals has shifted from the traditional "experience-driven" approach to a "competency-centered" model. This requires solid data analysis skills, information technology application literacy, and comprehensive cross-disciplinary problem-solving capabilities [2].

1.2 Industry Demand Evolution: The Core Competency Requirements for Shipping Professionals in the Digital Transformation Era

The shift to a "competency-centered" signifies a fundamental change in the industry's demand for human resources. Specifically, the digital transformation, exemplified by intelligent ships, smart logistics, and big data decision-making, requires talent to transform from traditional "operators" to comprehensive "digital intelligence enablers." The requirements for digital competency mainly include the following four aspects:

1.2.1 Digital Literacy and Data Analysis Capabilities

Digital literacy constitutes the fundamental ability to comprehend, utilize, and manage digital technologies and data resources. It demands that shipping professionals transcend basic computer operations to develop deep understanding and application of data. For example, they should be able to interpret and utilize the massive amounts of data generated by ship sensors and port logistics; skillfully operate professional systems such as intelligent loading and energy efficiency management; and possess basic cybersecurity awareness to protect critical digital assets.

1.2.2 Interdisciplinary Knowledge and Systems Thinking

Digital transformation breaks down traditional professional barriers, requiring talent to possess a "T-shaped knowledge structure." This means that talent development cannot be limited to a single skill but must be focused on developing versatile, systems-oriented professionals. On the basis of solid professional knowledge in shipping (vertical), they must integrate cross-disciplinary knowledge such as information technology, data science, and even business management (horizontal). Based on this, talent must develop systems thinking, understanding the complex ecosystem composed of ships, ports, and supply chains, and discerning the impact of local operations on overall efficiency and safety.

1.2.3 Human-Machine Collaboration and Complex Situation Decision-Making Capabilities

In intelligent systems, the core value of humans shifts from performing routine operations to handling complex situations that machines cannot handle. This requires talent to possess the ability to collaborate efficiently with AI tools and optimize processes, as well as the ability to think critically and make emergency decisions in system failures or extreme circumstances.

1.2.4 Lifelong Learning and Career Adaptability

The rapid iteration of technology means that any static knowledge will become obsolete. Therefore, the willingness and ability to actively learn new skills, adapt to new positions, and embrace change become the most sustainable core competencies, ensuring that individuals can evolve with the industry.

In summary, these four core competencies collectively outline a new portrait of future shipping talent: no longer isolated technical operators, but "digital-intelligent shipping professional" who can converse with data, collaborate with machines, and solve problems within cross-disciplinary teams.

1.3 Research Objectives

Compared to the idealized portrait of the "digital-intelligent shipping professional" described above, the existing maritime education system still exhibits a significant structural mismatch between talent supply and the industry's emerging demands.

This has become a critical bottleneck constraining the smooth transformation and upgrading of the shipping industry. Therefore, evaluating and optimizing global shipping talent development models while identifying advanced practices is crucial for building a modern maritime education system capable of meeting future challenges.

Although existing comparative studies have yielded substantial findings, further supplementation and improvement are still needed in the following two aspects: firstly, systematic and nuanced comparative analyses of training models across global universities in the context of digital transformation remain relatively scarce; secondly, existing research predominantly focuses on qualitative descriptions, lacking quantitative methods to evaluate the relative importance of different training elements.

Universities are the main body of talent cultivation and the foundation of talent strategy [3]. This paper selects three globally renowned shipping universities as representative examples for analysis: Shanghai Maritime University (SMU) in China, Plymouth University (UoP) in the UK, and Nanyang Technological University (NTU) in Singapore. These three universities represent the world's largest emerging shipping market, the commercially oriented model of a long-established maritime service powerhouse, and the government-led innovation hub model, respectively. The research objectives of this paper are:

A. To systematically compare the strategies and mechanisms adopted by these three universities in responding to digital transformation across four core dimensions: training objectives, curriculum system, practical teaching, and industry-academia-research collaboration.

B. To use the Analytic Hierarchy Process (AHP) to quantitatively prioritize the above four core talent training dimensions to identify the key driving factors of strategic transformation.

C. Based on the quantitative results and analysis of training models, to provide data-driven insights and pathways for the optimization and transformation of university maritime education systems.

2.Literature Review and Establishment of the Analytical Framework

2.1 Existing Research on Shipping Talents Development in the Digital Context

Global maritime education is facing unprecedented technological challenges. Research indicates that new technologies such as artificial intelligence, augmented/virtual reality (AR/VR), digital twins (DTs), and cybersecurity constitute a series of new requirements that maritime education policy design must address [4]. This transformation demands an expansion of the core skills of maritime professionals, particularly in digital literacy [5]. The core competitiveness of shipping talent is undergoing a fundamental shift from "experience is king" to "competence is key," and the demand is evolving from traditional single-skill operational roles to future multi-dimensional, composite roles. Under digital transformation, shipping professionals are no longer holders of single skills, but must be composite individuals with data literacy, systems thinking, human-machine collaboration capabilities, and cross-disciplinary knowledge [6].

In research on the training model for Chinese shipping professionals, research studies are generally characterized by inward reflection and macro-level conceptualization. Specifically, this is reflected in the following aspects: (1) Deep reflection on the current situation: researchers generally believe that the current training model lags behind the development of intelligent shipping [7]; it was also pointed out that there is serious disconnect between practical teaching and industry frontiers [8]; some scholars have also conducted quantitative assessments of seafarers' digital literacy. They also explored the main factors affecting seafarers' digital literacy, finding that familiarity with large language models and internet availability have the greatest impact, and seafarers familiar with large language models demonstrated stronger capabilities in multiple dimensions of digital literacy [9]; (2) Active exploration of reform paths: suggesting the deep integration of cutting-edge technologies such as artificial intelligence and big data into the curriculum [10]; bridging the gap between theory and practice by building an education platform that integrates industry and education, and promotes school-enterprise cooperation [11]; through a systematic literature review, found that skill gaps and insufficient organizational capabilities during digital transformation are key factors restricting the development of the shipping industry, emphasizing that improving digital capabilities is one of the core conditions for achieving industry transformation [12]. (3) Conceptualization of new training models in the new context: calling for the establishment of an interdisciplinary knowledge system to cultivate composite talents with data literacy, systems thinking, and human-computer collaboration capabilities [6].

Against the backdrop of digitalization and intelligence profoundly reshaping the shipping industry, British universities are gradually becoming important hubs for cultivating digital talent in maritime and shipping. Studies by Chinese scholars such as emphasize the characteristics of a “high-end service orientation” and “business management as the core” [12-13]. Existing literature widely believes that digital technology is profoundly changing the skill structure of shipping jobs, prompting higher education institutions and vocational education systems to re-examine curriculum systems, teaching methods, and competency development goals [14-16]. Research by the British government and industry organizations has primarily driven the digital transformation of maritime education from a policy and institutional perspective. The Maritime Skills Commission under Maritime UK noted in its report that digital learning tools, online platforms, and blended learning models have become important development directions for British maritime education, and universities need to address the accelerating pace of technological updates through modular courses and flexible learning paths [14].

At the academic research level, British scholars are more focused on the impact of digitalization on talent skill structures and educational training models. The digital shipping environment requires graduates to possess interdisciplinary skills, particularly in understanding automated systems, cybersecurity awareness, and decision-making abilities in complex human-machine systems, which challenges the traditional shipping education model dominated by operational skills [17]. In terms of specific skill dimensions, based on empirical research on students in shipping and maritime majors at British universities, students have significant shortcomings in key digital skills such as data analysis, basic programming, and cybersecurity, and current curriculum settings have not adequately responded to the needs of digital transformation [18].

At the teaching method level, simulators and immersive technologies are considered important tools for cultivating digital talent in shipping. From the perspective of the simulator teaching continuum, the evolution path from traditional bridge simulators to virtual reality technology in maritime education was analyzed, pointing out that higher education institutions need to establish a clearer teaching logic between technology application and learning effectiveness evaluation [19]. Research further indicates that the effective application of emerging digital teaching technologies in maritime institutions depends on the synergistic improvement of student acceptance, curriculum design rationality, and faculty capabilities [20].

In response to the transformative impact of digital technologies, Singapore has gradually developed a talent cultivation system characterized by government policy guidance, industry demand-driven initiatives, and collaborative education and training. Related research and practices have become important references for the digital development of maritime talent. From a policy perspective, the Maritime and Port Authority of Singapore (MPA) has played a core leading role in the digital transformation of the shipping industry. The MPA’s “Maritime Digitalization Playbook” systematically outlines the overall framework for the digital development of Singapore’s shipping industry, clearly stating that data-driven decision-making, intelligent system operation, and cross-domain collaboration capabilities will become important components of future maritime professionals’ skill sets, and incorporating talent skill enhancement as a crucial part of the maritime digitalization strategy [21]. At the education and training level, research shows that the digital training systems face multiple challenges during implementation, including curriculum adaptation, organizational collaboration, and technological acceptance, emphasizing the importance of institutional design and improved teaching capabilities [22].

Academic research further supports these practical trends from a theoretical perspective, pointing out that, in the context of digitalization and automation, maritime talent is shifting from a single operational role to a complex “technology-data-decision” role, requiring simultaneous adjustments to curriculum structure and teaching priorities in the education and training system [23]. Also, through a systematic literature review and empirical analysis, it was identified that the core competency structure of maritime educators in the digital age, including digital literacy, data analysis awareness, and technological adaptability, verified the significant positive impact of these competencies on teaching effectiveness [24]. Further research shows that the demand for digital skills in Singapore’s shipping industry is shifting from single technical operational capabilities to integrated “technology-management-decision” capabilities, a trend that poses new competency-oriented requirements for higher education and vocational training [25].

2.2 Limitations of Existing Research and Establishment of the Analytical Framework

Although existing research on maritime education reform has diagnosed problems such as outdated curricula and a disconnect between theory and practice, and has proposed ideas such as integrating AI and big data and building industry-education integration platforms, it generally lacks systematic and detailed comparisons within a global context. For example, a study of Southampton Solent University in the UK found that maritime students had significant knowledge gaps in fundamental digital skills such as statistics, computer programming, and cybersecurity, with only a very small number having received relevant training [16]. This indicates that the development of advanced complex decision-making abilities (such as human-machine collaboration) must be predicated on the establishment of fundamental digital literacy. If underlying digital capabilities are lacking, the effectiveness of even high-tech laboratories will be significantly reduced. Therefore, the design of digital content within the curriculum system has an irreplaceable strategic priority compared to other macro factors.

As a result, this paper constructs a four-dimensional analytical framework aimed at deconstructing and comparing the training models of universities in the three countries. For subsequent discussion, these four dimensions are labeled C1 to C4. The specific dimensions are defined as follows:

C1: Training Objectives: The type and specifications of talent positioning (e.g., emphasizing operators, managers, or innovators).

C2: Curriculum System: Integration model of digital content, breadth and depth of interdisciplinary design.

C3: Practical Teaching Model: Cutting-edge nature of practical environments, student role positioning (executor/innovator).

C4: Industry-academia collaboration: Leading force of integration, pathways for knowledge flow.

3.Research Methodology: Quantifying the Priority of Training Elements Using the Analytic Hierarchy Process (AHP)

3.1 Principles and Applicability of the AHP Method

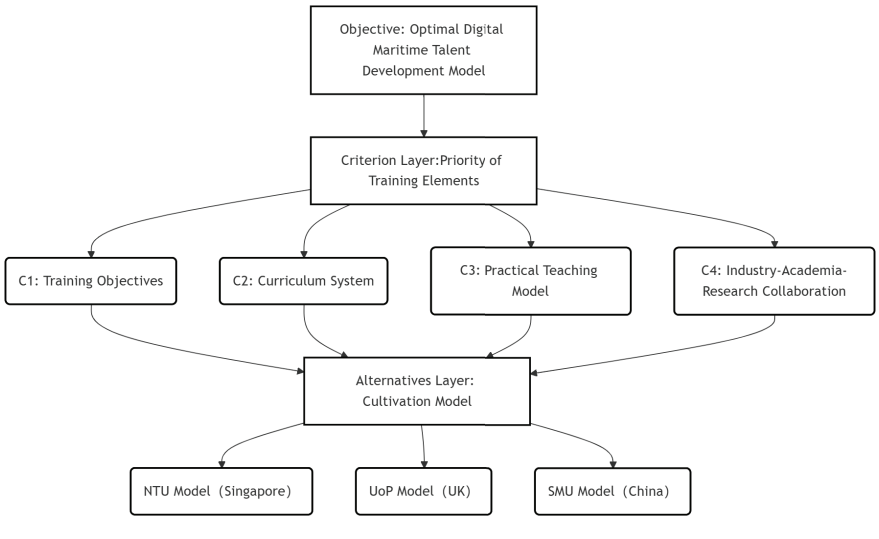
The Analytic Hierarchy Process (AHP) is a structured multi-criteria decision-making (MCDM) analysis method developed by Thomas Saaty in the 1970s. AHP quantifies the relative weights of different criteria by decomposing complex decision problems into hierarchical structures and employing pairwise comparisons based on expert judgments.

Given that comparing maritime training models involve highly qualitative and subjectively judged elements such as training philosophies and strategic positioning, AHP can translate these subjective judgments into operational proportional scales. This provides transparent, mathematically verifiable priority rankings for policy formulation. The method has been widely applied in maritime logistics and education policy making to integrate stakeholder perspectives and assess the criticality of new technologies [26].

3.2 Construction of the AHP Hierarchy and Simulation of Expert Judgments

This study applies the Analytic Hierarchy Process (AHP) to determine the strategic priorities of four key dimensions of talent development in the context of digital transformation in the shipping industry. The hierarchical structure is divided into three levels (as shown in Figure 1):

Figure 1: AHP Hierarchical Structure



Level 1 (Objectives): The optimal talent development model for digital shipping.

Level 2 (Criteria): C1 Training Objectives, C2 Curriculum System, C3 Practical Teaching Model, C4 Industry-Academia-Research Collaboration.

Level 3 (Alternatives): NTU model, UoP model, SMU model.

To determine the weights of the second-level criteria (C1-C4), this paper simulated an expert judgment matrix based on the existing consensus regarding the urgency of maritime talent needs in the digital age. Existing research generally agrees that practical training (C3) is crucial for transforming theoretical knowledge into practical skills [27], and the introduction of new knowledge (C2) is the starting point of this transformation; therefore, C2 and C3 are given higher priority. Particularly considering the aforementioned lack of basic digital literacy (programming, data analysis), the reform of the curriculum system (C2) is considered the most direct and core driving force of the global MET transformation and should be ranked first. Based on this, this paper constructed a simulated pairwise comparison matrix and calculated the weights ω_i for each criterion and the consistency ratio (CR). The calculation results are shown in Table 1. The consistency test results of the matrix satisfy CR < 0.10, indicating that the weight calculation results have good consistency and acceptability.

Table 1: Quantification of Priority Dimensions in Shipping Talent Development (AHP Results)

Development Dimension	Importance Basis in the Digital Era	Simulated AHPWeight (ω_i)	Rank
Curriculum System (C2)	Directly provides new knowledge in AI, data, cybersecurity, etc., achieving interdisciplinary integration.	0.385	1
Practical Teaching Model (C3)	Transforming digital knowledge into actionable professional skills through simulations and real-world projects.	0.280	2
Industry-Academia-Research Integration Mechanism (C4)	Ensures rapid curriculum iteration and provides access to cutting-edge technologies and data resources.	0.190	3
Training Objectives (C1)	Define talent output types to guide curriculum and practice design.	0.145	4

Quantitative results show that the curriculum system (C2) and practical teaching model (C3) account for more than two-thirds of the decisive weight (combined 0.665) in building a shipping talent model adapted to the digital age. This also validates the view that global Maritime Education and Training (MET) reform must be centered on the substantive restructuring of curriculum content and the application-oriented upgrading of practical training [28].

4.Comparative Analysis of Shipping Talent Cultivation Models in Three Countries' Universities

This section conducts an in-depth analysis of the educational models adopted by Shanghai Maritime University (SMU), the University of Plymouth (UoP), and Nanyang Technological University (NTU) in the context of digital transformation, based on the AHP criteria (C1-C4).

4.1 Nanyang Technological University (NTU), Singapore: Triple Helix Innovation Ecosystem

Leveraging its position as a leading global port hub, Singapore has built a "triple helix" ecosystem driven by government strategy and industry demand. The Maritime Studies program within the School of Civil and Environmental Engineering in NTU is a microcosm of this system.

4.1.1 Training Objectives (C1) and Curriculum System (C2)

Singapore's economic core logic is built upon a high degree of reliance on maritime trade, a link that has not only driven its historical development but also shaped its contemporary status as a top global port hub. NTU positions its graduates as "global innovators" and "systems thinkers," and its maritime talent cultivation is based on the integration of interdisciplinary knowledge. By strengthening data analysis, entrepreneurial thinking, and a sustainable perspective, and closely integrating coursework, industry practice, and cutting-edge research, the program aims to cultivate versatile talents with cognitive agility and global leadership capabilities. This is not only a direct response to current industry needs but also a core intellectual investment to drive future innovation in the maritime industry and maintain Singapore's crucial role as a global hub.

NTU's curriculum system (C2) design breaks down disciplinary barriers from the outset, elevating data science and artificial intelligence from "auxiliary tools" to "core foundations" supporting future shipping systems. This program requires students to complete 136 credits, and the course structure is redesigned around "solving systemic problems in future shipping systems." For example, the core curriculum includes an introduction to data science and artificial intelligence. This mandatory interdisciplinary design ensures that business acumen, digital skills, and environmental awareness are integrated into core maritime knowledge, directly meeting the industry's demand for versatile talents. This strategy of treating technology as a core subject rather than an auxiliary tool demonstrates a deep integration advantage in the C2 dimension.

4.1.2 Practical Teaching Model (C3) and Industry-Academia-Research Collaboration (C4)

The practical teaching model in NTU (C3) is a highly structured, pre-professional, and immersive experience. Its mandatory professional internship (MT3920, 10 credits) requires students to undertake "real-world, industry-relevant work tasks," meaning that shipping students are not engaged in peripheral work, but may directly participate in core business activities such as route optimization analysis, ship energy efficiency management, and logistics supply chain modeling, taking on real responsibilities from day one. Students are positioned as "pre-professional talents" and "drivers and co-creators of digital tools," rather than simple observers. Through a "dual-mentorship system" (industry mentors guide daily work, and university mentors ensure theoretical integration), and rigorous assessments of digital literacy and innovation, students' professional identity and skills are maximized.

In terms of industry-academia-research collaboration (C4), Maritime and Port Authority of Singapore (MPA), Singapore Maritime Foundation, and key industry partners conduct top-level strategic design by establishing funds and leading curriculum development. This dual-core driven model, guided by national strategy and driven by the industrial ecosystem, ensures the high internationalization and industry relevance of talent development in NTU. For example, MPA collaborates with top universities such as Imperial College London, bringing together scientists and maritime experts to explore talent development programs focused on cutting-edge areas such as intelligent port systems and cybersecurity solutions, aiming to accelerate the green and digital transformation of the maritime industry. This system-level co-creation mechanism ensures the efficient and deep circulation of knowledge, technology, and talent between academia and industry.

4.2 University of Plymouth (UoP), UK: Business Strategy Empowerment Model

The maritime talent cultivation model in Plymouth University is rooted in the deep commercial traditions of the UK as a global center for maritime finance, law, and arbitration. Its core focus is on shaping industry leaders proficient in business management, maritime law, and global strategy. This reflects the concept of "Strategic Digital Subordination," where digital technology serves as a tool for achieving business and strategic objectives, rather than being an independent technological pursuit.

4.2.1 Training Objectives (C1) and Curriculum System (C2)

The Maritime Business program in University of Plymouth exhibits a distinct focus on business and management. Its objectives (C1) are centered on developing business strategies and industry leaders, emphasizing critical thinking, maritime finance, and global business operations.

The UoP curriculum (C2) is characterized by the integration of "embedded" tools. Digital content is not offered as separate courses, but rather integrated directly into core business courses as methodologies and tools. For example, in the International Logistics Management course, students learn to use optimization algorithm software, essentially "finding digital solutions to business problems." This approach aims to cultivate students into expert users and critical evaluators of digital tools, enabling them to use data analytics to solve complex business scenarios, rather than focusing on technology development itself. While this embedded teaching strategy supports business objectives, it may sacrifice depth in foundational technical disciplines such as programming and data science, which is a significant structural difference compared to the NTU model.

4.2.2 Practical Teaching Model (C3) and Industry-Academia-Research Collaboration (C4)

The University of Plymouth's (UoP) practical teaching model (C3) is essentially a concrete manifestation of its "transformative education" philosophy in the shipping industry. The core strategy of this model lies in systematically bridging the gap between academic training and industry practice through highly realistic environmental design. Its specific approach is reflected in: firstly, using real-world business decisions and industry challenges (such as sustainable shipping and port efficiency optimization) as the foundation for teaching and assessment, ensuring the cutting-edge and practical nature of skills development; secondly, building interdisciplinary collaborative learning spaces (e.g., shipping with engineering, business, and law) to simulate the complex professional collaboration networks in real-world shipping; and thirdly, explicitly integrating cutting-edge technologies (such as artificial intelligence) as enabling tools into the teaching scenarios, potentially allowing students to master core future skills such as AI-driven route optimization and risk management through simulation training. This series of designs collectively points to a clear goal: cultivating industry leaders who can directly address complex real-world challenges, possess cross-disciplinary collaboration capabilities, and have a vision for technological applications, rather than passive knowledge recipients.

Its industry-academia-research integration (C4) is a research-driven systematic engineering process. UoP leverages its excellent research reputation in the marine and maritime fields and its well-established technology transfer system (TTOs) [29] to build a complex technology transfer system centered around the Enterprise Solutions department, the Commercialization Team, and the university's commercial subsidiary (UoPEL). This system promotes the commercial application of the university's research findings, corporate collaborations, and innovation projects. Through long-term participation in the UK government-supported KTP (Knowledge Transfer Partnerships) projects, it facilitates industrial innovation and technology transfer practices, efficiently transforming cutting-edge knowledge into teaching content and commercial applications. For example, by participating in major research projects funded by the European Horizon 2020 research and innovation program (such as Cyber-MAR), the university has established key partnerships with external organizations, ensuring the synchronization of research and industry needs, forming an endogenous driving loop of "knowledge creation → talent cultivation → industrial application."

4.3 Shanghai Maritime University (SMU), China: Exploring the Balance Between Fundamental Expertise and Digital Transformation

Shanghai Maritime University's model demonstrates an exploratory approach to balancing the preservation of traditional disciplinary strengths with the strategic demands of digital transformation, which can be summarized as a dual-track foundational transition model.

4.3.1 Training Objectives (C1) and Curriculum System (C2)

SMU's training objective (C1) is to cultivate well-rounded professionals who are proficient in technology, skilled in management, and capable of serving the shipping industry. Currently, the university offers numerous majors in shipping talent cultivation, mainly divided into maritime and land-based disciplines. In maritime disciplines, the goal is to cultivate "advanced engineering and technical talents" who meet international standards; in land-based disciplines, the focus is on cultivating "senior management talents familiar with shipping and ports."

Its curriculum system (C2) adopts a "dual-track strategy": while retaining core courses of national-level characteristic majors such as International Shipping Management, Ship Principles, and Ship Trade, it introduces new, independent majors such as Big Data Management and Application. In traditional majors, digital courses (such as "Fundamentals and Applications of Artificial Intelligence" and "Python Programming") usually appear as compulsory general education courses or elective professional courses. Although this approach can quickly achieve coverage of digital courses, it faces structural risks: graduates from traditional majors may lack sufficient digital depth, while graduates from new big data majors may lack the necessary professional knowledge in the shipping field, making it difficult to achieve the ideal "T-shaped" talent integration.

Regarding the different integration strategies adopted for digital knowledge (such as AI and data analysis) within the curriculum systems for shipping talent cultivation at three universities, and their potential effects, as shown in Table 2:

Table 2: Comparison of Integration Models of Digital Content in Shipping Courses (C2)

University	Integration Model Overview	Integration Depth and Breadth	Key Risks or Advantages
NTU (Singapore)	Deep Cross-Disciplinary Integration Model	High in depth and breadth. Data science and AI will be elevated to mandatory "core foundation courses" or main subjects for all shipping students, ensuring the compulsory integration of this knowledge.	Advantage: Cultivates true "T-shaped" talent with a digital intelligence foundation.
UoP (UK)	Embedded Tool Enablement Model	Low in depth, high in breadth. Digital content, as a methodology and tool, is embedded in core courses such as business strategy, finance, and logistics.	Risk: Cultivating "critics" rather than "developers" of digital tools, potentially resulting in insufficient technical depth.
SMU (China)	Foundational Dual-Track Model	Imbalance between depth and breadth. Retains traditional major core while establishing a new independent Big Data major. Traditional majors integrate through general education/elective courses.	Risk: Students in traditional majors may lack digital depth, while new major students may lack shipping knowledge, potentially creating a polarized talent structure.

4.3.2 Practical Teaching Model (C3) and Industry-Academia-Research Collaboration (C4)

The advantage of SMU's practical teaching model (C3) lies in its highly realistic practical environment. The university possesses a comprehensive Integrated Bridge System (IBS) laboratory, ship handling simulators, and the 10,000-ton teaching and training vessel "Yuming." This system provides students with progressive, high-fidelity training, from virtual operations to real-world scenarios, greatly ensuring the solidity and safety of students' basic skills training. This model excels in cultivating "standardized process operators" who meet international convention requirements, but its openness needs improvement in supporting students' cutting-edge exploratory practices such as data-driven process optimization or intelligent system innovation validation.

In terms of industry-academia-research integration (C4), SMU's mechanism is project-driven strategic collaboration. The leading forces of integration exhibit diverse and collaborative characteristics, such as strategic cooperation with industry leaders like Shanghai International Port Group (SIPG) based on a shared mission, and the continuous infusion of industry knowledge into the campus through the "Entrepreneurial Mentor" program. Research achievements, such as the "Port Digital Twin Intelligent Management and Control System" and "Methanol-Extended Range Power Ships," have enabled the rapid transfer of technology from the laboratory to the industrial front lines, forming a closed loop of "research for practical application." However, compared to NTU's ecosystem led by a government statutory board (MPA), SMU's cooperation model focuses more on large-scale projects and localized applications, and there is still room for improvement in the breadth of knowledge flow and resource integration. Table 3 below shows the analysis of which force plays the primary "driving role" in the flow of knowledge, technology, and talent among the three universities, as well as their industrial alignment.

Table 3: Comparison of Industry-Academia-Research Integration Ecosystems (C4)

University	Dominant Driving Model	Core Driving Force	Knowledge Flow Pathways
NTU (Singapore)	Triple Helix Ecosystem	Government (MPA) Strategic Leadership + Industry Ecosystem Promotion. The government implements top-level design through policy, funding, and standard-setting.	Knowledge, talent, and technology circulate efficiently and mandatorily between government, academia, and industry.
University of Plymouth (UK)	Research-Driven Systems Engineering	University research reputation (Research Excellence) and Technology Transfer Offices (TTOs) system.	Knowledge transformation as the primary focus. Cutting-edge research outcomes are transformed into teaching content, commercial applications, research commercialization, and technology transfer.
SMU (China)	Project-Driven Strategic Synergy	Strategic needs of industry leaders (e.g., Shanghai International Port Group) + major project missions.	Research for practical application. Rapid validation and deployment of research outcomes (e.g., digital twin systems) from laboratories to industrial frontlines.

5.Results and Analysis: AHP-driven Performance Evaluation

5.1 Interpretation of AHP Criteria Weights

The AHP weight analysis results (see Table 1) show that, in the context of digitalization, curriculum system (C2) and practical teaching models (C3) are the two most influential strategic levers for maritime universities to achieve their talent cultivation goals. The highest weight of C2 (0.385) also validates the academic community's judgment on the urgency of basic digital literacy: any advanced innovation and decision-making capabilities must be built on a solid foundation of underlying digital knowledge (such as programming languages and algorithms, computational thinking, data literacy, and critical thinking). If the curriculum content (C2) is not substantially restructured, even if the goals (C1) and external cooperation (C4) are well-positioned, the quality of talent cultivation will still be limited. C3 has the second highest weight (0.280), emphasizing the principle of "learning by doing." The value of digital skills is reflected in their application and decision-making in complex situations. Traditional practical teaching, which mainly focuses on verifying established procedures, must shift to a core focus on data-driven process optimization and innovative exploration to match the new knowledge introduced in C2.

5.2 Performance Scoring and Weighted Evaluation of Universities

Based on the qualitative analysis in Chapter 4, this section scores the performance of the three universities across the four AHP criteria (very high, high, medium-high, medium), and applies AHP weights for a comprehensive quantitative evaluation. See Table 4:

Table 4. University Performance Scoring Matrix (Based on AHP Weighted Criteria)

University/ Model	C1: Training Objectives (0.145)	C2: Curriculum System (0.385)	C3: Practical Teaching Model (0.280)	C4: Industry-Academia-Research Collaboration (0.190)	Total Weighted Score (Simulation)
NTU (Singapore)	High (Innovation/ Strategy)	High (Deep Interdisciplinary Integration)	High (Structured Professional Internships)	Very High (Triple Helix, MPA-led)	High (approx. 0.91)
UoP (UK)	High (Business Leadership)	Mid-High (Embedded, Applied)	Mid-high (Decision Simulation, Multidisciplinary)	High (Research-Driven, Technology Transfer)	Mid-High (approx. 0.76)
SMU (China)	Medium (Comprehensive/Transitional)	Medium (dual-track system, separate majors)	Mid-high (high-fidelity physical simulation)	Medium (Project-driven, regionalized)	Medium (approx. 0.56)

5.3 Comparing Structural Strengths and Gaps Among Universities

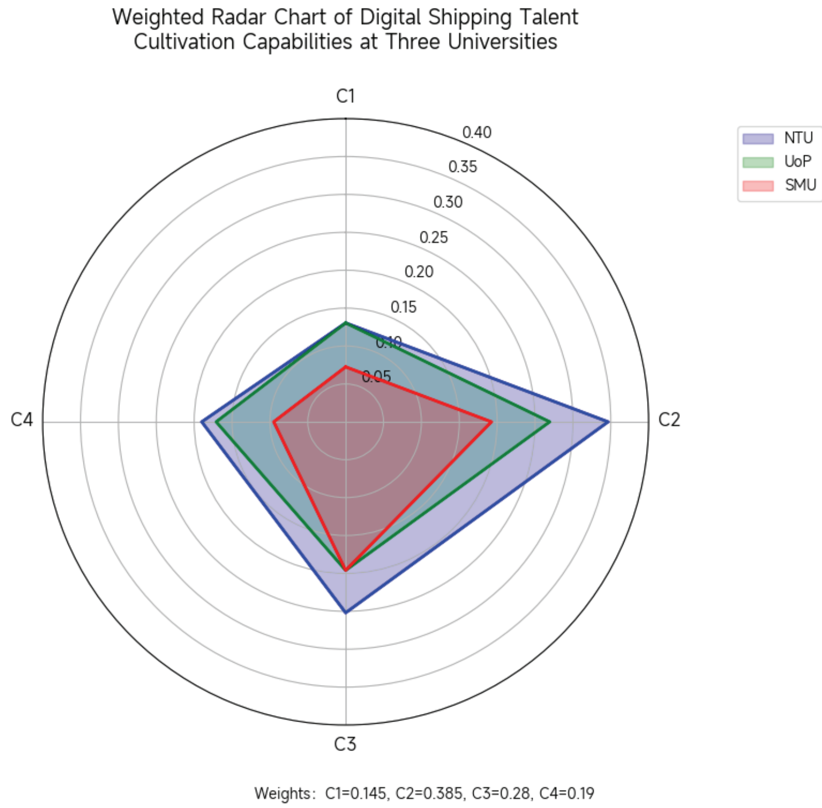
5.3.1 Graphical Analysis of Structural Advantages

To more intuitively illustrate the comparison of digital shipping talent development across the three universities, this section presents a radar chart based on the analysis above, as shown in Figure 2. This chart uses a quadrilateral radar diagram with four criteria (C1, C2, C3, C4) as axes, visualizing the weighted scores of NTU, UoP, and SMU across these four dimensions to compare their relative strengths. NTU has the largest area, with particularly strong scores on the C2, C3, and C4 axes; UoP performs strongly on the C1 and C4 axes (with only small differences compared to NTU on the corresponding axes); while SMU maintains high competitiveness on the C3 axis (practical ability).

Table 5: Radar Chart Structure Description

Model	Structural Characteristics	Primary Characteristics
NTU (Singapore)	Largest radar area with highest scores on axes C2, C3, and C4.	Comprehensive and deeply integrated. Achieves overall leadership through government/industry-led (C4) promotion of deep interdisciplinary integration of curriculum (C2) and practical capabilities (C3).
UoP (UK)	Strong performance on C4 and C1 axes, followed by C3.	Business strategy-driven. Clear educational objectives and research focus (C1/ C4), with digital skills embedded as business tools, though relatively conservative in deep technology integration.
SMU (China)	Excels on the C3 axis (practical teaching) but has the smallest overall footprint.	Foundational dual-track transition. Strong in traditional high-fidelity practice (C3), but still in exploratory phase for high-weight dimensions C2 (curriculum integration depth) and C4 (integration breadth).

Figure 2: Radar Chart of Digital Shipping Talent Cultivation Capabilities Among Universities in Three Countries



As shown in Figure 2, the NTU model performs best in terms of overall weighted performance, primarily due to its excellent performance in the three high-weighted dimensions: curriculum system (C2), practical teaching (C3), and industry-academia-research collaboration (C4). Through the mandatory driving forces of government strategy and the industrial ecosystem (C3 and C4), NTU successfully ensured deep interdisciplinary integration of its curriculum (C2), thus forming a self-reinforcing virtuous cycle.

5.3.2 Balancing Depth and Breadth in Curriculum Design

The cases of UoP and SMU reveal the strategic trade-offs between depth and breadth in curriculum design.

UoP's "embedded" strategy, which applies digital technology as a business tool (breadth), effectively supports its goal of cultivating business leadership (C1). However, this model may lack sufficient depth in specialized technical skills, making it difficult to cultivate digital technology talents capable of complex algorithm design or system development.

In contrast, SMU's "dual-track" strategy (such as establishing a separate big data major) provides in-depth technical training for specific students, but graduates from its traditional majors may face a lack of breadth in digital literacy. If not handled properly, this strategy may lead to a polarization of talent structure, where professional and digital talents fail to truly integrate into T-shaped composite talents. This contrasts sharply with NTU's mandatory, comprehensive interdisciplinary core curriculum design. The AHP results emphasize the high priority of C2, indirectly supporting the model adopted by NTU, which elevates digital knowledge to the level of fundamental science and integrates it into all majors. This approach better aligns with the urgent need for composite talents in the digital age.

6.Conclusions and Implications

6.1 Conclusion Summary

This study compares and analyzes the maritime talent cultivation models of Shanghai Maritime University (China), Plymouth University (UK), and Nanyang Technological University (Singapore) in the context of digital transformation. Using the Analytic Hierarchy Process (AHP), the study quantifies the strategic priorities of key cultivation elements and draws the following conclusions:

1. Model Diversity: Global maritime education has developed diverse strategic models with different functions to address

the challenges of digitalization: such as the comprehensive ecosystem model represented by NTU; the strategic business empowerment model represented by UoP; and the basic dual-track transition model represented by SMU.

2. Transformation Drivers: The AHP analysis clearly shows that curriculum restructuring (C2) and practical teaching upgrades (C3) are key actionable levers affecting the quality of talent cultivation, with their combined weight exceeding two-thirds. While strategic direction and external cooperation (C1, C4) are important, they must be implemented through C2 and C3 to have a substantial impact on students' skills.

3. Success Mechanism: Stemming from the Singaporean government's high priority on national shipping development, the success of the NTU model lies in its efficient industry-academia-research integration mechanism (C4), where the strategic guidance of the government regulatory agency (MPA) and high industry participation effectively promote deep interdisciplinary integration of the curriculum (C2) and pre-professionalization of practical teaching (C3), forming a rapid, efficient, and sustainable talent cultivation closed loop.

6.2 Insights and Recommendations

Based on the comparative analysis and quantitative results above, this paper proposes the following recommendations for the reform of global maritime education institutions:

1. Core Curriculum and Deep Integration (Focus on C2): Maritime education schools and institutions should avoid treating digital skills as elective or supplementary courses. Following NTU's strategy, foundational data science, computational thinking, data literacy, and critical thinking should be elevated to mandatory core courses for all shipping majors. Curriculum design should be oriented towards solving interdisciplinary problems, rather than teaching technologies in isolation, to overcome the "structural disconnect" between traditional curriculum systems and intelligent shipping practices.

2. Shifting Practice Towards Decision-Making and Innovation (Focus on C3): Practical teaching should move beyond traditional physical skill verification and operational compliance training, shifting towards data-driven decision-making simulations in complex scenarios. Universities should increase investment in digital twin and VR/AR technologies to build exploratory practical environments that allow students to optimize processes and validate innovative solutions, transforming students from "operational executors" to "data analysts and process innovators."

3. Building a Systematic Industry-Academia-Research Collaboration Ecosystem (Focus on C4): Universities should be encouraged to adopt Singapore's "triple helix" training model, establishing institutionalized strategic co-creation mechanisms with government regulatory agencies and leading industry companies. This mechanism should ensure that industry data and cutting-edge technologies flow quickly into classrooms and research platforms; that universities participate in the development of industry standards; and that students are provided with structured, high-standard professional internships to minimize the time lag between talent development and industry needs.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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