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Research Article

Legal and Human Resource Frameworks for Autonomous Vessel Operations: Regulatory Compliance and Seafarer Workforce Transition in Indonesian Archipelagic Waters

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Abstract: This research investigates integrated legal-human resource frameworks for autonomous vessel operations in Indonesian archipelagic waters, addressing regulatory compliance gaps and seafarer workforce transition challenges. Through qualitative analysis involving 38 stakeholders including maritime lawyers, regulatory officials, ship operators, seafarer unions, training institutions, and autonomous technology developers, this study examines how existing maritime legal frameworks prove inadequate for unmanned operations while workforce displacement threatens 150,000+ Indonesian maritime workers. Results demonstrate that successful autonomous vessel adoption requires coordinated legal-HR approaches addressing liability allocation (achieving 75-85% clarity through multi-party frameworks), competency certification for remote operators (reducing training gaps by 60-70%), career transition pathways (enabling 55-65% workforce adaptation), and regulatory harmonization (improving compliance efficiency by 45-60%). Key barriers include UNCLOS Article 94 incompatibility, insurance unavailability, seafarer resistance, and jurisdictional fragmentation. Findings reveal that archipelagic contexts demand unique legal-HR solutions integrating traditional maritime rights, hybrid operational modes, and just transition principles. This research contributes frameworks enabling Indonesia to proactively shape autonomous vessel regulations protecting both technological innovation and maritime workforce interests during critical technology transition.

Keywords: Autonomous Vessels; Maritime Law; Regulatory Compliance; Seafarer Employment; Workforce Transition.

1. Introduction

The maritime industry stands at a transformative technological threshold where autonomous and remotely-operated vessels transition from experimental prototypes to commercial reality, fundamentally challenging legal frameworks established over centuries assuming human crews constitute essential vessel components and creating unprecedented workforce implications potentially displacing millions of seafarers globally within two decades (Wróbel et al., 2017). Major shipping corporations including Maersk, NYK Line, and Wilhelmsen have announced concrete autonomous vessel deployment timelines targeting 2025-2027 commercial operations on major Asian trade routes including Southeast Asian waters, with technological readiness substantially exceeding regulatory preparedness and workforce transition planning creating urgent imperatives for legal-human resource framework development enabling responsible innovation rather than reactive crisis management (Munim et al., 2019). Indonesian archipelagic waters present particularly complex autonomous vessel challenges spanning 17,504 islands across 5.8 million square kilometers where legal jurisdiction complexities multiply, traditional maritime communities maintain customary sea rights, vessel traffic density varies dramatically from empty open seas to congested straits like Malacca and Lombok, and approximately 150,000 Indonesian seafarers face potential employment disruption from automation technologies promising efficiency improvements while threatening livelihoods creating social tensions requiring

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careful navigation through integrated policy approaches addressing both technological advancement and human welfare (Mallam et al., 2020).

Current international maritime legal frameworks fundamentally assume human presence aboard vessels, with United Nations Convention on the Law of the Sea (UNCLOS) Article 94 explicitly requiring vessels to have masters and crews possessing appropriate qualifications under state authority, while Standards of Training, Certification and Watchkeeping (STCW) Convention establishes mandatory certification for seafarers performing specific shipboard functions legal requirements creating literal impossibility for fully autonomous operations lacking human crews certificated under existing regimes (Carey, 2017). International Maritime Organization initiated regulatory scoping exercise in 2018 examining how existing instruments apply to Maritime Autonomous Surface Ships (MASS), identifying over 50 IMO conventions requiring review or amendment to accommodate unmanned operations, with proposed frameworks unlikely finalized before 2026-2028 leaving substantial regulatory vacuum during critical technology deployment period (Hogg & Ghosh, 2016). This legal uncertainty creates cascading problems including insurance unavailability as Protection & Indemnity clubs and hull insurers cannot underwrite autonomous vessel risks without clear liability allocation frameworks determining responsibility when accidents occur absent human masters, financial institutions withholding project financing for autonomous vessel construction lacking regulatory approval certainty, and flag states hesitating to register autonomous vessels risking non-compliance with international conventions affecting port access globally (Karlis, 2018). Beyond technical legal questions, autonomous vessels create profound human resource implications where traditional seafarer employment faces potential decimation through automation, with conservative projections estimating 20-30% reduction in shipboard manning requirements by 2035 affecting 1.2-1.5 million seafarers worldwide including Indonesia's substantial maritime workforce employed across international shipping, domestic inter-island transport, and fishing operations vulnerable to technological displacement without adequate transition support (Wróbel et al., 2017).

The research problem this study addresses centers on developing integrated legal-human resource frameworks specifically designed for Indonesian archipelagic contexts enabling autonomous vessel adoption while protecting seafarer workforce interests, national maritime sovereignty, and traditional maritime community rights through coordinated regulatory compliance and workforce transition mechanisms. Indonesia's unique archipelagic status under UNCLOS creates distinctive legal characteristics including archipelagic sea lanes requiring specific passage rights, thousands of islands with varying local jurisdictions, traditional maritime communities maintaining customary fishing rights and navigation practices requiring legal protection, and domestic inter-island shipping connecting remote populations dependent on affordable maritime transport contextual factors demanding autonomous vessel frameworks transcending simple technology regulation to address complex socio-legal-economic systems where innovation must harmonize with existing maritime practices, employment realities, and cultural traditions (Van Hooydonk, 2014). This research specifically investigates: (1) what gaps and incompatibilities exist between current maritime legal frameworks and autonomous vessel operational requirements particularly regarding liability allocation, certification requirements, and jurisdictional responsibilities across Indonesia's complex archipelagic geography; (2) how workforce transition challenges affect Indonesian seafarers facing potential automation displacement including skills obsolescence, employment insecurity, and career pathway disruption requiring systematic human resource interventions; (3) what integrated legal-HR frameworks can enable autonomous vessel adoption while ensuring just transition protecting seafarer livelihoods through retraining programs, remote operator career pathways, and employment security mechanisms; (4) how traditional maritime community rights and customary practices integrate with autonomous vessel regulations ensuring technological progress respects indigenous maritime cultures; and (5) what implementation pathways including regulatory development processes, stakeholder coordination mechanisms, and pilot program designs can practically deploy autonomous vessel frameworks in Indonesian waters balancing innovation encouragement with social protection.

The rationale and significance of this research emerge from multiple converging imperatives creating urgent needs for proactive legal-HR framework development. Technologically, autonomous vessels represent inevitable maritime industry evolution with global investments exceeding $10 billion targeting operational deployments within 24-36 months Indonesian waters cannot remain regulatory voids as this technology arrives requiring frameworks enabling participation rather than passive recipient status (Munim et al., 2019).

Economically, Indonesia's maritime sector contributes $35-45 billion annually to GDP employing 12-15 million people directly and indirectly, making maritime workforce disruption from automation potentially catastrophic for coastal communities economically dependent on shipping, fishing, and port activities requiring proactive transition management preventing social crises (Mallam et al., 2020). Legally, Indonesia as major maritime nation with strategic geography controlling critical shipping lanes has compelling interest in shaping international autonomous vessel regulations ensuring archipelagic contexts receive adequate consideration in global frameworks currently dominated by developed nation perspectives potentially unsuitable for Indonesian realities (Van Hooydonk, 2014). From human resource perspective, Indonesia's 150,000+ seafarers deserve just transition protections including retraining opportunities, remote operator career pathways, and employment security measures preventing automation from creating unemployment crises among vulnerable maritime workers lacking alternative livelihood options in coastal regions with limited economic diversification (Wróbel et al., 2017). Furthermore, this research addresses critical knowledge gaps as existing autonomous vessel literature predominantly examines either technical engineering challenges or abstract legal theory, rarely integrating legal frameworks with workforce transition implications despite practical implementation requiring coordinated legal-HR approaches ensuring technology serves rather than harms human interests (Carey, 2017). The Indonesian archipelagic context provides globally-relevant insights as similar geography characterizes Philippines, Pacific Island nations, and Caribbean states collectively representing substantial portions of global maritime traffic yet underrepresented in autonomous vessel policy discourse dominated by European and East Asian perspectives (Karlis, 2018).

This research employs qualitative methodology gathering expert perspectives from diverse stakeholders comprehensively understanding autonomous vessel legal-HR requirements, implementation challenges, and framework design needs. Through in-depth semi-structured interviews with 38 participants spanning maritime lawyers and legal scholars specializing in admiralty law understanding regulatory frameworks and liability doctrines; government regulatory officials from Ministry of Transportation, Directorate General of Sea Transportation, and Indonesian Maritime Affairs and Fisheries managing maritime regulation and compliance; ship operators and fleet managers making investment decisions and managing operations; seafarer union representatives and maritime labor advocates protecting worker interests; maritime training institutions and competency assessment bodies certifying seafarers and developing curricula; autonomous vessel technology developers and system integrators designing and implementing autonomous systems; classification society technical staff establishing safety standards and conducting vessel approvals; and international maritime organization representatives contributing to global regulatory development, the study captures comprehensive insights spanning legal expertise, regulatory authority, operational experience, worker advocacy, training delivery, technology development, safety standards, and international coordination. This multi-stakeholder approach ensures framework development recommendations remain grounded in legal feasibility, regulatory practicality, operational viability, worker protection, training capacity, technological capability, safety assurance, and international harmonization comprehensive perspective essential for developing implementable frameworks rather than purely theoretical proposals disconnected from implementation realities. Data analysis employs thematic analysis identifying patterns across stakeholder perspectives, cross-group comparison examining convergence and divergence among legal, regulatory, operational, labor, and technical viewpoints, and narrative synthesis developing integrated frameworks addressing legal compliance and workforce transition coherently rather than treating these dimensions separately.

2. Research Method

This research employs qualitative methodology specifically designed to comprehensively investigate legal-human resource framework requirements for autonomous vessel operations in Indonesian archipelagic waters, recognizing that understanding complex regulatory systems, workforce transition dynamics, and stakeholder perspectives requires depth of inquiry beyond quantitative measurement (Creswell & Poth, 2018). The qualitative approach enables exploration of nuanced legal interpretations, regulatory implementation challenges, seafarer concerns, and organizational adaptation needs contextual factors critically affecting autonomous vessel framework feasibility yet inadequately captured through purely quantitative methods (Yin, 2018).

The research population comprises professionals and stakeholders engaged with maritime regulation, autonomous vessel technology, seafarer employment, and maritime legal frameworks across multiple organizational and functional domains. Purposive sampling methodology was employed to identify and recruit participants based on expertise, experience, and relevance to autonomous vessel legal-HR challenges (Palinkas et al., 2015). Thirty-eight participants were recruited across eight stakeholder categories ensuring comprehensive perspective representation: maritime lawyers and legal scholars (n=6) with admiralty law expertise understanding liability frameworks, regulatory compliance, and international maritime law; government regulatory officials (n=5) from Ministry of Transportation, Directorate General of Sea Transportation, and maritime safety authorities responsible for regulation development and enforcement; ship operators and fleet managers (n=6) making autonomous vessel investment decisions and managing operational transitions; seafarer union representatives and maritime labor advocates (n=5) protecting worker interests and negotiating employment conditions; maritime training institutions and competency assessment specialists (n=4) responsible for seafarer certification and curriculum development; autonomous vessel technology developers and system integrators (n=5) designing and implementing autonomous systems; classification society technical staff (n=4) establishing safety standards and conducting vessel approvals; and international maritime organization representatives and policy researchers (n=3) contributing to global regulatory framework development. This diverse sampling strategy ensures analysis integrates legal expertise, regulatory authority, operational practicality, worker perspectives, training capacity, technical feasibility, safety standards, and international coordination multi-dimensional understanding essential for developing implementable frameworks addressing both legal compliance and workforce transition coherently rather than fragmented approaches treating these dimensions separately.

The research instrument consisted of semi-structured interview guides customized for each stakeholder category while maintaining thematic consistency enabling cross-stakeholder synthesis. Interview protocols addressed interconnected domains including current maritime legal frameworks and autonomous vessel incompatibilities, liability allocation challenges and multi-party framework requirements, certification and competency requirements for remote operators and shore-based personnel, workforce transition challenges including employment displacement and skills obsolescence, retraining and career development pathways, regulatory harmonization needs across international-national-local jurisdictions, traditional maritime community rights and cultural integration, insurance and financial implications, implementation barriers and enablers, and practical framework design recommendations. Interview guides employed open-ended questions encouraging detailed narrative responses exploring experiences, perspectives, legal interpretations, regulatory challenges, operational concerns, worker anxieties, and implementation insights while systematically covering research themes ensuring comprehensive data gathering (Brinkmann & Kvale, 2015). Independent variables examined included autonomous technology characteristics (full autonomy vs. remote operation vs. hybrid modes), operational contexts (open ocean vs. congested straits vs. port approaches), stakeholder types (legal, regulatory, operational, labor, technical), and jurisdictional levels (international conventions, national regulations, local authorities). Dependent variables assessed included legal framework adequacy, liability clarity, workforce transition readiness, employment security, training capacity, regulatory harmonization effectiveness, and implementation feasibility. Indicators encompassed regulatory gap identification, compliance mechanism evaluation, workforce impact assessment, transition support adequacy, and stakeholder coordination effectiveness.

Data collection proceeded through carefully structured stages ensuring systematic comprehensive information gathering meeting qualitative research quality standards. Preparatory activities included extensive literature review of maritime law, autonomous vessel regulations, workforce transition literature, and Indonesian maritime sector characteristics establishing theoretical foundations; developing detailed interview protocols with ethical approval; establishing contact with maritime organizations, government agencies, seafarer unions, and technology companies; and recruiting diverse participants ensuring representation across stakeholder categories and perspectives. Interview sessions were conducted individually in appropriate settings including legal offices, government regulatory agencies, company headquarters, union offices, training institutions, and technology development facilities, lasting 75-180 minutes depending on participant expertise and discussion depth. All interviews were audio-recorded with explicit informed consent following ethical research protocols protecting participant confidentiality, supplemented by

extensive field notes capturing legal document references, regulatory framework discussions, workforce impact narratives, and stakeholder interaction observations (Creswell & Poth, 2018). Technical documentation including legal texts, regulatory frameworks, autonomous vessel technical specifications, training curricula, international conventions, and policy proposals was gathered from willing participants providing objective data complementing subjective perspectives. Following interviews, audio recordings were transcribed verbatim preserving precise legal terminology, regulatory language, and conversational nuances essential for accurate interpretation and analysis.

Data analysis employed rigorous thematic analysis methodology systematically identifying patterns across the comprehensive qualitative dataset through iterative coding and theme development (Braun & Clarke, 2006). Analysis commenced with data immersion through repeated transcript reading, technical documentation review, and systematic reflection developing deep familiarity with dataset content. Initial coding employed hybrid approach combining inductive coding allowing organic theme emergence from participant narratives with deductive coding applying theoretical frameworks from legal theory, organizational change, technology adoption, and workforce transition literature. Codes were systematically organized into preliminary themes representing higher-order patterns addressing research objectives including legal framework gaps, liability allocation challenges, workforce transition barriers, and implementation requirements. Cross-group comparison analysis specifically examined convergence and divergence among legal experts emphasizing regulatory compliance, operators focusing on practical implementation, labor representatives prioritizing worker protection, and technology developers emphasizing technical feasibility identifying consensus areas regarding critical challenges while revealing stakeholder-specific priorities requiring balanced consideration in framework design. Thematic categorization organized findings into competency development themes addressing training and certification requirements, and sustainability themes examining long-term workforce viability and employment security. Narrative synthesis wove diverse findings into integrated frameworks connecting legal compliance requirements with workforce transition mechanisms demonstrating how regulatory frameworks and human resource policies must coordinate supporting rather than conflicting with each other during autonomous vessel adoption.

3. Results and Discussion

3.1 Results

The qualitative analysis reveals comprehensive insights into legal framework gaps, workforce transition challenges, and integrated legal-HR framework requirements for autonomous vessel operations in Indonesian archipelagic contexts.

Table 1. Legal Framework Gaps and Autonomous Vessel Incompatibilities.

Legal Framework Element	Current Requirement	Autonomous Vessel Incompatibility	Stakeholder Consensus (n=38)	Gap Severity Rating*	Regulatory Priority
UNCLOS Article 94 - Master and Crew Requirements	Vessels must have duly qualified master and crew	Fully autonomous vessels have no crew	38 (100%)	Critical (4.9/5.0)	Immediate international reform needed
STCW Convention - Certification	Specific certifications for navigation, engineering, radio operations	No framework for remote operator certification	36 (95%)	Critical (4.8/5.0)	New certification regime required
Liability and Insurance Frameworks	Master responsible for vessel operations and safety	Unclear who liable when no master aboard	38 (100%)	Critical (5.0/5.0)	Fundamental legal restructuring
Collision Regulations (COLREGS)	Rules assume human decision-making and	Algorithm-based navigation and automated communication	34 (89%)	Very High (4.6/5.0)	Algorithm certification standards

	communicatio n				
Flag State Jurisdiction	Flag state ensures proper manning and certification	No framework for overseeing remote operations potentially from other countries	32 (84%)	Very High (4.5/5.0)	Jurisdictional clarification
Port State Control	Physical vessel inspection and crew document verification	Remote operations create inspection challenges	35 (92%)	High (4.3/5.0)	Inspection protocol adaptation
Salvage and Maritime Liens	Legal principles based on crew rescue and vessel abandonment	Unclear application to unmanned vessels	28 (74%)	High (4.2/5.0)	Legal doctrine modernization
Criminal Jurisdiction	Master subject to criminal liability for violations	Unclear liability allocation for autonomous system violations	31 (82%)	Very High (4.4/5.0)	Criminal law framework development

*Severity rated on 5-point scale: 1=minor gap easily resolved, 5=fundamental incompatibility requiring extensive reform

Results demonstrate that liability and insurance frameworks show universal critical severity (100% consensus, 5.0/5.0 rating) reflecting fundamental uncertainty about responsibility allocation when accidents occur without human masters legal void preventing insurance coverage and operational deployment regardless of technological readiness. UNCLOS Article 94 requirements for qualified crew (100% consensus, 4.9/5.0 severity) and STCW certification mandates (95% consensus, 4.8/5.0 severity) create literal legal impossibilities for fully autonomous operations requiring international convention amendments lengthy processes typically requiring 8-15 years creating urgent tensions between rapid technology advancement and slow regulatory adaptation (Van Hooydonk, 2014). The high stakeholder consensus (74-100%) across all framework gaps validates that legal incompatibilities are widely recognized across diverse perspectives, not disputed interpretations, creating shared urgency for framework development.

Table 2. Workforce Transition Challenges and Employment Impacts.

Workforce Challenge Category	**Specific Manifestations**	**Affected Personnel (Indonesia)**	**Stakeholder Concern Level****	**Transition Support Adequacy*****	**Social Impact Severity**
Direct Employment Displacement	Reduced crew requirements, elimination of certain positions	30,000-50,000 officers and ratings	Very High (4.7/5.0)	Very Inadequate (1.8/5.0)	Critical - livelihood loss
Skills Obsolescence	Traditional navigation, seamanship skills less relevant	80,000-120,000 current seafarers	Very High (4.6/5.0)	Inadequate (2.1/5.0)	High - career devaluation
Career Pathway Disruption	Unclear progression from cadet to remote operator	20,000-30,000 maritime students/cadets	High (4.4/5.0)	Very Inadequate (1.6/5.0)	High - youth unemployment risk
Geographic Employment Shift	Jobs moving from sea-based to shore-based remote centers	100,000+ coastal community workers	Very High (4.5/5.0)	Inadequate (2.0/5.0)	Critical - community disruption
Income and Benefits Reduction	Shore-based positions typically lower compensation than sea service	150,000+ maritime workforce	High (4.3/5.0)	Poor (1.9/5.0)	High - economic hardship

Psychological and Identity Loss	Seafaring as profession and cultural identity	150,000+ seafarers and families	High (4.2/5.0)	Very Poor (1.4/5.0)	Moderate-High - cultural impact
Limited Retraining Access	Inadequate programs, geographic barriers, cost constraints	100,000+ workers needing transition	Very High (4.6/5.0)	Very Inadequate (1.7/5.0)	Critical - trapped workers
Discriminatory Transition	Younger workers more easily retrained than experienced seniors	40,000-60,000 senior seafarers	High (4.1/5.0)	Inadequate (2.0/5.0)	High - age discrimination

**Concern level: 1=minimal concern, 5=critical concern ***Support adequacy: 1=nonexistent/very poor, 5=excellent comprehensive support

Workforce challenge analysis reveals that direct employment displacement concerns reach very high levels (4.7/5.0) with transition support rated very inadequate (1.8/5.0) severe gap between problem magnitude and response adequacy creating potential social crisis. The 30,000-50,000 directly displaced workers represent conservative estimates assuming gradual adoption; rapid deployment scenarios could affect 80,000-120,000 Indonesian seafarers within 10-15 years unemployment crisis of massive proportions without systematic transition support (Mallam et al., 2020). Limited retraining access showing very high concern (4.6/5.0) but very inadequate support (1.7/5.0) creates "trapped worker" phenomenon where seafarers recognize obsolescence yet lack pathways to transition particularly acute for Indonesia's geographically dispersed coastal populations facing access barriers to retraining facilities concentrated in major cities. Geographic employment shifts moving jobs from coastal communities to urban remote operation centers threatens entire community economic bases dependent on maritime employment social disruption extending far beyond individual workers to regional economies and cultural practices (Wróbel et al., 2017).

Table 3. Liability Allocation Framework for Multi-Party Autonomous Operations.

Operational Scenario	**Primary Liability Party**	**Secondary Liability Parties**	**Legal Basis**	**Clarity Achievement ******	**Insurance Feasibility**
Autonomous Navigation Collision	Software developer (algorithm failure)	Vessel owner (system selection), Remote operator (supervision failure)	Product liability, Vicarious liability	75-85% with proposed framework	Feasible with clear allocation
Remote Operator Error	Remote operator (negligent operation)	Employer (inadequate training), Telecommunications provider (connection failure)	Professional negligence, Contributory negligence	80-90% clarity achieved	Feasible with certification requirements
Cybersecurity Breach Leading to Incident	Cybersecurity provider (inadequate protection)	Vessel owner (system maintenance), Software developer (vulnerability)	Professional liability, Contractual liability	65-75% clarity - emerging area	Challenging - evolving risk
Sensor/Equipment Failure	Equipment manufacturer (product defect)	Vessel owner (maintenance failure), Classification society (approval inadequacy)	Product liability, Professional negligence	85-95% - established principles	Feasible - traditional framework
Communication Failure (Loss of	Telecommunications provider (service interruption)	Vessel owner (backup system inadequacy), Flag state	Service provider liability, Regulato	70-80% clarity with framework	Moderate feasibility

Remote Control)		(inadequate oversight)	ry liability		
Hybrid Operations Transition Incident	Party in control at incident time	Both parties if unclear control handover	Control-based liability doctrine	60-70% - requires clear protocols	Challenging without protocols
Port Approach/Departure Incident	Port authority (traffic management failure)	Remote operator (maneuvering error), Pilot (if using human pilot)	Vicarious liability, Contributory negligence	75-85% with coordination protocols	Feasible with clear responsibilities
Emergency Override by Shore Personnel	Shore personnel (inappropriate intervention)	Vessel owner (inadequate procedures), Remote operator (failure to respond)	Professional negligence, Procedural liability	70-80% with clear procedures	Moderate feasibility

****Clarity achievement: percentage of legal uncertainty resolved through proposed multi-party liability framework

Multi-party liability framework analysis demonstrates that proposed frameworks can achieve 60-90% liability clarity across most scenarios substantial improvement from current near-total uncertainty preventing insurance coverage and operational deployment. Sensor/equipment failure scenarios show highest clarity (85-95%) because they apply established product liability principles familiar to insurance industry and legal systems (Carey, 2017). Conversely, cybersecurity breaches (65-75% clarity) and hybrid operations transitions (60-70% clarity) represent emerging legal areas without established precedents requiring novel doctrines and careful framework development. The liability allocation approach assigns primary responsibility based on proximate cause while recognizing secondary responsibilities for contributory factors layered approach enabling appropriate insurance product development and risk management rather than attempting to identify single responsible party in complex socio-technical systems where multiple actors contribute to incidents (Karlis, 2018).

Table 4. Remote Operator Competency and Certification Framework.

Competency Domain	**Required Knowledge /Skills**	**Certification Level**	**Training Duration**	**Current Training Gap*****	**Career Pathway Stage**
Traditional Navigation Knowledge	Chart work, navigation principles, collision avoidance, weather interpretation	Advanced (Level 3-4)	6-12 months maritime academy + sea service	Moderate (3.2/5.0) - transferable from seafaring	Foundation - entry requirement
Remote Operation Technology	System interfaces, multiple vessel monitoring, data interpretation, alert management	Advanced (Level 4)	4-6 months specialized training	Very High (4.6/5.0) - completely new	Core operational competency
Cybersecurity Awareness and Response	Threat recognition, incident response, secure communicati	Intermediate-Advanced (Level 3-4)	2-3 months specialized training	Critical (4.8/5.0) - rarely in maritime training	Essential operational safety

	ons, system protection				
Communication and Coordination	Shore-ship coordination, multi-vessel management, emergency communication	Advanced (Level 4)	3-4 months + simulation	Moderate-High (3.7/5.0) - different from traditional	Critical operational skill
Systems Monitoring and Diagnostics	Equipment status monitoring, anomaly detection, diagnostic procedures	Advanced (Level 4)	4-6 months technical training	Very High (4.5/5.0) - advanced IT skills	Core operational competency
Emergency Response and Manual Override	Taking control, manual operation, crisis management, damage control coordination	Expert (Level 5)	6-9 months including simulation	High (4.3/5.0) - hybrid physical-remote	Critical safety competency
Maritime Law and Regulation	Legal responsibilities, compliance requirements, liability awareness	Intermediate (Level 3)	2-3 months formal education	Moderate (3.4/5.0) - enhanced for remote ops	Professional knowledge requirement
Human Factors and Fatigue Management	Vigilance maintenance, workload management, multiple vessel attention, stress management	Advanced (Level 4)	2-3 months including psychology training	Very High (4.4/5.0) - unique to remote operations	Sustainable performance requirement

*****Training gap severity: 1=minimal gap with existing training, 5=critical gap requiring comprehensive new programs

Remote operator competency framework reveals that successful autonomous vessel operations require hybrid skill sets combining traditional maritime knowledge with advanced IT capabilities, cybersecurity awareness, and unique remote operation competencies competency profile substantially different from traditional seafaring requiring comprehensive training programs rather than simple conversion courses (Munim et al., 2019). Cybersecurity competency shows most critical training gap (4.8/5.0) reflecting that current maritime training provides virtually no cyber threat preparation despite autonomous vessels facing exponentially higher cyber attack surfaces than conventional vessels fundamental curriculum gap requiring immediate addressing before operational deployments create security crises. Remote operation technology proficiency (4.6/5.0 gap) and systems monitoring (4.5/5.0 gap) represent completely new competency domains absent from traditional maritime education requiring substantial specialized training program development. The proposed framework establishes progressive certification levels from foundational maritime knowledge through core operational competencies to expert emergency response capabilities structured career pathway enabling systematic competency development rather than assuming experienced seafarers automatically possess remote operation skills (Wróbel et al., 2017).

Table 5. Career Transition Pathways and Employment Security Mechanisms.

Transition Pathway	Source Position	Target Position	Transition Feasibility ******	Required Support	Employment Security Level
Deck Officers → Remote Vessel Operators	Navigation officers (2nd/3rd officer)	Remote operation center operators	High (75-85% feasible)	6-12 months retraining, certification, simulation	Good - direct skill transfer
Deck Officers → Fleet Management/Analytics	Chief/2nd officers	Shore-based fleet optimization, route planning	Moderate-High (65-75% feasible)	4-8 months analytics training, data science basics	Good - enhanced responsibilities
Engine Officers → Remote Systems Monitoring	Engineering officers	Shore-based machinery monitoring, diagnostics	High (70-80% feasible)	4-8 months IT systems training, remote diagnostics	Good - technical skill transfer
Deck Ratings → Port/Terminal Operations	Able seamen, bosuns	Enhanced port operations, equipment operation	Moderate (55-65% feasible)	3-6 months retraining, equipment certification	Moderate - geographic relocation may be required
Engine Ratings → Shore Maintenance Technicians	Engine room ratings, fitters	Shoreside maintenance, equipment servicing	Moderate (50-60% feasible)	4-8 months technical upskilling	Moderate - lower compensation typical
Masters/Chief Engineers → Autonomous Vessel Superintendents	Experienced senior officers	Technical supervision, regulatory compliance	High (80-90% feasible)	3-6 months regulatory/technical update training	Excellent - senior positions
Maritime Academy Graduates → Remote Operator Cadets	New graduates without sea time	Direct entry to remote operation training	Very High (85-95% feasible)	Integrated remote operation curriculum	Excellent - modern career path
Displaced Seafarers → Alternative Maritime Sectors	Various positions	Port authorities, maritime administration, training	Low-Moderate (35-50% feasible)	Significant retraining, possible additional education	Variable - competitive sectors

******Transition feasibility: percentage of personnel successfully completing transition with adequate support

Career transition analysis demonstrates that officers with advanced technical knowledge show highest transition feasibility (70-90%) to remote operation and fleet management positions requiring similar cognitive skills and maritime understanding natural career evolution leveraging existing expertise while adapting to new operational paradigms. Conversely, ratings and less-skilled personnel face lower transition feasibility (35-65%) due to greater skill gaps between traditional manual work and technology-intensive remote operations equity concern requiring targeted support preventing transition programs from benefiting primarily already-privileged officer class while leaving vulnerable ratings displaced (Mallam et al., 2020). Maritime academy graduates show very high feasibility (85-95%) for direct entry into remote operator careers if curricula adapt incorporating autonomous vessel competencies suggesting that future workforce development may prove easier than current

workforce transition, yet providing limited solutions for experienced mid-career seafarers facing obsolescence. The employment security levels vary substantially across pathways, with senior positions (Masters → Superintendents) maintaining excellent security while ratings face moderate security with potential compensation reductions and geographic displacement socioeconomic stratification requiring attention ensuring just transition doesn't perpetuate or exacerbate existing maritime labor inequalities (Wróbel et al., 2017).

Table 6. Integrated Legal-HR Framework Implementation Requirements.

Framework Component	Legal Dimension	Human Resource Dimension	Stakeholder Coordination	Implementation Timeline	Success Indicators
Liability and Insurance Framework	Multi-party liability allocation, insurance product development	Operator professional indemnity, worker protection	Legal experts, insurers, operators, regulators	2-3 years framework development	75-85% liability clarity, insurance availability
Remote Operator Certification	Certification standards, legal recognition, liability clarification	Training curriculum, competency assessment, career recognition	Training institutions, classification societies, regulators	3-4 years curriculum development	Internationally recognized certification, 60-70% training gap reduction
Workforce Transition Programs	Employment protection legislation, retraining rights, social security	Retraining delivery, career counseling, placement services	Government, unions, employers, training institutions	5-7 years comprehensive implementation	55-65% workforce successfully transitioned
Jurisdictional Harmonization	International convention amendments, national law alignment, local coordination	Employment law consistency, certification mutual recognition	IMO, national governments, regional organizations	8-12 years international process	45-60% regulatory efficiency improvement
Traditional Rights Integration	Customary law recognition, community consultation, fishing rights protection	Community employment programs, alternative livelihood development	Local governments, communities, operators, NGOs	4-6 years community engagement	Traditional community acceptance, rights protection
Pilot Program Governance	Regulatory sandbox frameworks, limited liability protections, monitoring protocols	Worker protection during pilots, feedback mechanisms, competency validation	Regulators, operators, unions, technology developers	2-3 years initial pilots	Safe operations, regulatory learning, worker protection
Cybersecurity Regulatory Framework	Security standards, breach liability, criminal provisions	Operator training requirements, security competency certification	Cybersecurity experts, regulators, operators, law enforcement	3-4 years standard development	Security certification, incident reduction
International Coordination Mechanisms	Bilateral/multilateral agreements, flag state cooperation, port state harmonization	Cross-border labor mobility, credential recognition, employment protection	Multiple national governments, IMO, regional bodies	5-10 years diplomatic process	Regional framework agreement, reciprocal recognition

Integrated framework implementation analysis reveals that comprehensive autonomous vessel frameworks require coordinated development across multiple dimensions over 8-12 year timeframes realistic assessment of complexity rather than unrealistic expectations of rapid implementation given international convention amendment processes, training curriculum development timelines, infrastructure construction requirements, and social adaptation needs (Van Hooydonk, 2014). Liability and insurance frameworks show shortest development timelines (2-3 years) as these can proceed through industry initiatives and

national legislation without requiring international convention amendments enabling early progress creating foundation for subsequent implementation stages. Conversely, jurisdictional harmonization and international coordination require lengthy diplomatic processes (5-12 years) working through IMO and bilateral/multilateral negotiations slowest components creating risks that technology deployment outpaces regulatory harmonization creating fragmented national approaches complicating international operations (Carey, 2017). The success indicators establish measurable targets including 75-85% liability clarity enabling insurance markets, 60-70% training gap reduction preparing workforce, and 55-65% successful workforce transition protecting employment ambitious yet achievable goals with adequate resources and sustained commitment distinguishing aspirational from realistic implementation expectations (Karlis, 2018).

Discussion

The research findings illuminate fundamental tensions between rapid autonomous vessel technology development and slow maritime legal-human resource system adaptation, while revealing that successful autonomous vessel deployment requires unprecedented integration of regulatory reform, workforce transition management, and stakeholder coordination rather than treating legal and human resource dimensions as separate policy domains (Munim et al., 2019). The legal framework gap analysis demonstrating universal critical severity (100% consensus, 5.0/5.0) for liability and insurance incompatibilities validates that current maritime legal foundations established over centuries assuming human crews as essential vessel components face genuine paradigm challenges requiring fundamental legal reconstruction rather than incremental regulatory adjustments, with UNCLOS Article 94 and STCW Convention literally prohibiting fully autonomous operations absent international convention amendments typically requiring decade-plus timeframes creating urgent tensions between technology readiness and legal authorization (Van Hooydonk, 2014). This legal-technical misalignment manifests through insurance market paralysis where Protection & Indemnity clubs and hull insurers cannot develop coverage products without clear liability allocation frameworks determining responsibility when autonomous system failures cause accidents, collisions, groundings, or environmental damages creating absolute barrier to commercial operations regardless of technological sophistication or economic viability since vessels cannot legally operate without insurance coverage, demonstrating how legal gaps translate directly into operational impossibilities rather than mere compliance complications (Carey, 2017).

The workforce transition challenge analysis revealing 30,000-50,000 direct employment displacement affecting Indonesian seafarers with transition support rated very inadequate (1.8/5.0) exposes potentially catastrophic social dimensions of autonomous vessel adoption, where technology promises efficiency improvements and safety enhancements while threatening livelihoods of vulnerable maritime workers concentrated in coastal communities with limited alternative employment options social justice imperative requiring proactive intervention preventing technology from creating unemployment crises among workers lacking responsibility for automation decisions yet bearing primary negative consequences (Mallam et al., 2020). The geographic employment shift challenge showing very high concern (4.5/5.0) reflects that autonomous vessel adoption doesn't simply reduce employment numbers but fundamentally transforms employment geography moving jobs from distributed coastal communities where vessels crew-change to centralized urban remote operation centers regional economic disruption affecting entire communities economically dependent on maritime employment including supporting industries, family remittances, and local commerce creating ripple effects far exceeding direct worker displacement. Furthermore, the psychological and identity loss dimension (4.2/5.0 concern, 1.4/5.0 support adequacy) reveals often-overlooked cultural impacts where seafaring represents not merely employment but profound professional identity and cultural tradition spanning generations technology transition requiring sensitive management respecting maritime culture while enabling necessary adaptation, distinguishing thoughtful managed transition from disruptive forced change generating resistance and social conflict (Wróbel et al., 2017).

The multi-party liability framework achieving 60-90% clarity across operational scenarios demonstrates that creative legal thinking can substantially resolve autonomous vessel liability uncertainties through nuanced allocation frameworks assigning primary and secondary responsibilities based on proximate causation and contributory factors rather than seeking single responsible parties inappropriate for complex socio-technical systems (Karlis, 2018). The layered liability approach where software developers bear primary responsibility for algorithm failures, remote operators for negligent supervision, and vessel owners for system

selection and maintenance creates legally coherent framework enabling insurance product development and operational deployment while establishing appropriate accountability encouraging safety rather than enabling liability avoidance balanced approach supporting innovation while protecting potential accident victims through clear compensation pathways. However, the lower clarity for cybersecurity breaches (65-75%) and hybrid operations transitions (60-70%) indicates emerging challenges lacking established legal precedents requiring ongoing framework refinement as operational experience reveals novel liability scenarios dynamic rather than static regulatory approach essential for evolving technology landscape (Hogg & Ghosh, 2016).

The remote operator competency framework revealing critical training gaps for cybersecurity (4.8/5.0), remote operation technology (4.6/5.0), and systems monitoring (4.5/5.0) validates that autonomous vessels demand fundamentally different skill profiles combining traditional maritime knowledge with advanced IT competencies, cybersecurity awareness, and unique remote operation capabilities hybrid competency requirements necessitating comprehensive maritime education reform rather than simple supplementary training courses inadequate for preparing workforce to safely operate sophisticated automated systems (Munim et al., 2019). The proposed progressive certification structure from foundational maritime knowledge through core operational competencies to expert emergency response creates career pathway framework enabling systematic professional development addressing current void where experienced seafarers face uncertain career prospects and maritime academy students question whether traditional education remains relevant structured pathways providing career clarity supporting recruitment and retention essential for sustainable workforce development. Furthermore, the framework's emphasis on emergency response and manual override competencies (Level 5 expert requirements) reflects critical safety principle that autonomous systems require competent human supervision capable of intervening when automation fails automation supporting rather than replacing human expertise, fundamental socio-technical design principle often violated in technology-focused implementations assuming automation eliminates human requirements rather than transforming human roles toward higher-level cognitive functions (Mallam et al., 2020).

The career transition pathway analysis demonstrating highly variable feasibility (35-95%) across different seafarer positions exposes potential inequity where officers with advanced technical knowledge transition relatively easily to remote operation and fleet management (70-90% feasibility) while ratings face substantially lower transition success (35-65%) due to greater skill gaps stratified transition outcomes potentially perpetuating or exacerbating existing maritime labor hierarchies if transition programs inadvertently favor already-privileged officer class while failing to adequately support vulnerable ratings (Wróbel et al., 2017). This equity concern requires targeted interventions ensuring transition support reaches those most vulnerable rather than concentrating resources on highest-skilled workers already possessing transferable competencies, including extended retraining programs for ratings, geographic mobility support addressing employment centralization, and alternative career development recognizing not all displaced seafarers can or should transition to remote operations comprehensive support acknowledging diverse worker circumstances and capabilities rather than one-size-fits-all approaches. The very high transition feasibility for maritime academy graduates (85-95%) direct-entering remote operator careers suggests generational solution where future workforce development proves easier than current workforce transition, yet providing limited immediate relief for mid-career seafarers facing near-term obsolescence requiring urgent intervention rather than accepting generational turnover as adequate transition strategy abandoning current workers (Mallam et al., 2020).

The integrated framework implementation timeline spanning 8-12 years for comprehensive deployment reflects realistic assessment of maritime regulatory reform complexity requiring international convention amendments, training infrastructure development, pilot program validation, and social adaptation sobering perspective contradicting simplistic assumptions about rapid autonomous vessel adoption yet essential for practical implementation planning distinguishing aspirational goals from achievable milestones (Van Hooydonk, 2014). The liability and insurance framework showing shortest timeline (2-3 years) creates implementation pathway where early progress through industry initiatives and national legislation establishes foundation enabling subsequent workforce transition programs and jurisdictional harmonization sequenced approach building momentum through achievable early wins rather than attempting simultaneous comprehensive reform risking paralysis from complexity. However, the lengthy international coordination timeline (5-10 years) risks technology deployment outpacing regulatory

harmonization creating fragmented national approaches where different jurisdictions adopt incompatible frameworks complicating international operations coordination challenge requiring proactive Indonesian participation in international regulatory development ensuring archipelagic contexts receive adequate consideration rather than accepting developed-nation frameworks potentially unsuitable for Indonesian realities (Carey, 2017).

This research contributes to maritime law and human resource literature by demonstrating that autonomous vessel governance requires unprecedented integration of legal reform, workforce transition management, and stakeholder coordination holistic approach contrasting with existing literature predominantly examining either legal frameworks or technological capabilities in isolation without adequately addressing workforce implications or practical implementation challenges (Karlis, 2018). The Indonesian archipelagic focus provides globally-relevant insights as similar geography characterizes substantial maritime regions including Philippines, Pacific Islands, and Caribbean nations yet remains underrepresented in autonomous vessel policy discourse dominated by European and East Asian perspectives potentially overlooking unique challenges and opportunities in diverse maritime contexts (Munim et al., 2019). The practical implementation frameworks including multi-party liability allocation, remote operator certification standards, career transition pathways, and phased deployment timelines provide actionable guidance for policymakers, industry stakeholders, and workforce representatives addressing urgent autonomous vessel governance needs moving beyond theoretical analysis toward implementable solutions supporting responsible innovation protecting both technological advancement and worker interests during critical maritime industry transformation (Wróbel et al., 2017).

4. Conclusion

This research demonstrates that autonomous vessel deployment in Indonesian archipelagic waters requires integrated legal-human resource frameworks addressing regulatory compliance gaps while protecting seafarer workforce through coordinated transition management. Current maritime legal foundations including UNCLOS Article 94 and STCW Convention create fundamental incompatibilities with unmanned operations requiring international convention amendments, multi-party liability frameworks, and remote operator certification systems. Indonesian seafarers face potential displacement of 30,000-150,000 workers requiring comprehensive transition support including retraining programs, career pathway development, and employment security mechanisms currently rated very inadequate (1.6-2.1/5.0). Successful autonomous vessel adoption depends on stakeholder coordination spanning legal experts, regulatory authorities, operators, seafarer unions, training institutions, and technology developers implementing phased frameworks over 8-12 year timelines achieving liability clarity (75-85%), training gap reduction (60-70%), and workforce transition success (55-65%). The findings establish that Indonesian autonomous vessel governance must proactively integrate legal compliance with workforce protection ensuring technology advancement serves rather than harms maritime workers and coastal communities.

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