

Crew Availability Ratio in Indonesian-Flagged Vessels: A Discrete Model Analysis of Sign-On–Sign-Off Cycle Effects on Sustainable Ship Operations

Moejiono^{1*}, Agus Dwi Santosa², Lusia Permata Sari Hartanti³, Indah Ayu Johanda Putri⁴, Romanda Annas Amrullah⁵

¹ Politeknik Pelayaran Surabaya E-mail: moejiono12@gmail.com

² Politeknik Pelayaran Surabaya

³ Universitas Katolik Widya Mandala Surabaya

⁴ Politeknik Pelayaran Surabaya

⁵ Politeknik Pelayaran Surabaya

*Corresponding Author: moejiono12@gmail.com

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ABSTRACT

This study analyzes the influence of the sign-on–sign-off (SoSo) cycle on sustainable operational continuity of Indonesian-flagged vessels using the Discrete Crew Availability Ratio Model. Grounded in IMO Resolution A.1047(27), SOLAS 1974, MLC 2006, and Indonesia's Ministerial Regulation PM No. 26 of 2022, the research applies a quantitative approach to 26,757 active Indonesian-flagged merchant vessels identified via Vessel Finder (AIS). Vessels are stratified into five gross tonnage (GT) categories—GT >10,000; GT 3,000–10,000; GT 1,500–3,000; GT 500–1,500; and GT <500—and classified as cargo or passenger ships. The discrete model computes crew group allocation using duty-cycle ratios and ceiling functions, incorporating attrition modeling through probabilistic outflow estimation. Under the baseline cycle of T=10 months on board and L=1 month leave, results indicate a total crew requirement of 327,120 seafarers, of whom 297,299 (90.9%) are on board and 29,821 (9.1%) are on leave. Attrition modeling at a rate of 0.30%/month yields an additional buffer demand of approximately 2,899 seafarers/year, increasing total requirements to 330,019 persons. Sensitivity analysis across 14 cycle scenarios (T=6 to T=12; L=1 to L=2) reveals the T10/L1 cycle as the optimal sustainable balance point across three Triple Bottom Line (TBL) dimensions: economic efficiency, seafarer social welfare, and environmental safety compliance. The study delivers evidence-based policy recommendations for regulators, shipping companies, and maritime education institutions aligned with SDGs 8, 9, and 14.

Keywords: crew availability ratio; sign-on sign-off cycle; discrete model; safe manning; Indonesian-flagged vessels; maritime sustainability; attrition model; MLC 2006.

INTRODUCTION

Global Maritime Context and the Sustainability Imperative

The global shipping industry underpins more than 98% of international trade by volume (BIMCO/ISF, 2020). As global fleet capacity continues to expand, the demand for qualified seafarers at all rank levels—officers and ratings alike—intensifies correspondingly (Patchiapane & Rengamani, 2018). Concurrently, the maritime sector faces mounting pressure to align with the United Nations Sustainable Development Goals (SDGs), particularly

SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 14 (Life Below Water), reflecting the interconnected economic, social, and environmental dimensions of maritime operations.

Elkington's (1997) Triple Bottom Line (TBL) framework—people, planet, and profit—provides a foundational lens through which sustainable ship operation can be evaluated. Applied to maritime human resource management, this framework emphasizes that crew welfare, environmental protection, and operational profitability are not competing objectives but mutually reinforcing pillars of long-term industry viability.

The Seafarer Supply-Demand Challenge

Global seafarer attrition has been identified as a persistent structural challenge. The decline in maritime career attractiveness, driven by family separation, psychosocial burdens, and increasingly competitive shore-based employment opportunities, contributes to measurable workforce erosion (Livingstone Divine Caesar, 2016). Miroshnik (2012) warned that shortages of experienced officers pose direct threats to operational safety and navigational integrity. BIMCO/ISF (2020) reports that the global imbalance between seafarer supply and demand represents one of the most critical systemic risks in international shipping.

The preparation pipeline for maritime officers—from cadet enrollment through certification as a competent officer—spans many years, rendering workforce shortfalls difficult to remedy in the short term. This structural lag underscores the necessity for rigorous, quantitative crew planning methodologies.

The Indonesian Maritime Context

As the world's largest archipelagic state, comprising more than 17,000 islands, Indonesia depends fundamentally on maritime connectivity for national integration, food security, logistics distribution, and geopolitical positioning as the Poros Maritim Dunia (Global Maritime Nexus). The sustainability of Indonesian-flagged vessel operations is therefore a strategic national priority.

The Indonesian government, through Ministerial Regulation PM No. 26 of 2022 on Merchant Ship Manning, has established minimum crew requirements aligned with IMO Resolution A.1047(27) on Principles of Safe Manning, SOLAS 1974, and MLC 2006. However, regulatory compliance alone does not guarantee operational sustainability; the dynamic interplay of sign-on–sign-off (SoSo) cycles—determining the proportion of crew members simultaneously active at sea versus on leave—critically shapes total workforce requirements across the national fleet.

Research Gap and Objectives

Despite the centrality of crew rotation management to operational sustainability, no comprehensive, quantitative national-level analysis has been conducted for Indonesian-flagged vessels that systematically models the relationship between SoSo cycle parameters and total crew availability requirements, inclusive of attrition effects. Existing literature predominantly addresses single-company fleet optimization (Lin et al., 2018; Zhen et al., 2019; Wang et al., 2022) or global aggregate seafarer supply-demand assessments (BIMCO/ISF, 2020), leaving a significant gap in national-fleet-level discrete modeling.

This study addresses four research questions: (1) How does the SoSo cycle ratio quantitatively influence crew availability at the national fleet level?, (2) What is the total crew requirement across all Indonesian-flagged vessel categories under varying cycle scenarios?, (3) Which SoSo cycle configuration optimizes the TBL sustainability balance?, (4) What policy recommendations emerge for sustainable maritime human resource management?

LITERATURE REVIEW

Sustainability in Maritime Operations

The TBL framework, introduced by Elkington (1997) and operationalized in the maritime context by subsequent researchers, delineates three interdependent sustainability dimensions:

Economic sustainability

Operational continuity, cost efficiency, and revenue protection through adequate safe manning and minimization of vessel idle time (SDG 9).

Social sustainability

Fulfillment of seafarer rights under MLC 2006, including regulated rest hours, equitable leave entitlements, and protection against chronic fatigue (SDG 8).

Environmental sustainability

Prevention of marine pollution, navigational safety, and mitigation of human-error-induced incidents through appropriate crew levels (SDG 14).

Research confirms the causal cascade linking these dimensions: imbalanced SoSo cycles precipitate crew fatigue (social dimension), which elevates accident risk (environmental dimension), which in turn generates economic losses through incident costs and operational disruptions (Moejiono et al., 2025).

Maritime Labour Convention 2006 and Working Hour Standards

MLC 2006, effective August 2013, constitutes the "fourth pillar" of international maritime law alongside SOLAS, MARPOL, and STCW. It mandates maximum working hours of 14 hours per 24-hour period and 72 hours per 7-day period, with corresponding minimum rest requirements of 10 hours per 24-hour period and 77 hours per 7-day period. The convention establishes a maximum contract duration of 12 months, with a minimum leave entitlement of 2.5 days per month of service—parameters that directly constrain the design space for SoSo cycle optimization.

Safe Manning Frameworks

IMO Resolution A.1047(27) articulates the principles governing minimum safe manning determinations, requiring flag state administrations to consider the vessel's operational profile, trade patterns, and crew rest requirements. PM No. 26 of 2022 translates these principles into enforceable national standards, specifying minimum crew complements by GT category, propulsion power (kW), and vessel type.

Crew Scheduling Optimization: Quantitative Approaches

The operations research literature provides methodological foundations for crew scheduling optimization. Hillier and Lieberman (2015) establish integer programming as the canonical tool for workforce scheduling with continuous operational requirements. Kelso (2018) extends this to duty-cycle-based models applicable to rotating shift systems. In the maritime domain, Lin et al. (2018) demonstrated that crew rotation optimization must integrate competency requirements, operational periods, and rest constraints. Zhen et al. (2019) specifically addressed rest-hour compliance in crew scheduling, while Wang et al. (2022) incorporated competency certification requirements. Hyeon and Park (2018) examined optimal crew size considerations for maritime transport efficiency. Rehmat and Lee (2019) advocated for systematic, model-based approaches to maritime crew management. Collectively, this body of work validates the discrete ceiling-function approach adopted in the present study, while no prior research has applied this framework at national fleet scale with integrated attrition modeling.

Seafarer Attrition

Attrition in maritime human resources encompasses retirement, mortality, career transition to shore-based employment, permanent medical disqualification, and certification failure (Livingstone Divine Caesar, 2016; BIMCO/ISF, 2020). Aggregate global attrition rates are estimated at 2.0–3.5% annually (IMO estimates), with higher rates in developing country fleets (3.0–5.0%; ILO reports) and among specialized vessel types (BIMCO/ISF, 2020). Failure to incorporate attrition in crew planning produces systematically underestimated workforce requirements, threatening operational sustainability.

METHODOLOGY

Research Design

This study employs a quantitative secondary-data case study methodology, combining fleet census data with regulatory standards and analytical modeling. The analytical unit is the Indonesian-flagged merchant fleet, stratified by vessel category and type.

Data Sources

Source	Data Type	Application
Vessel Finder (AIS/IMO No.)	Active fleet count by category	Variable N (vessel count)
PM No. 26/2022	Minimum crew by GT/kW	ABK per vessel
MLC 2006	Contract and leave standards	Parameters T and L
IMO Resolution A.1047(27)	Safe manning principles	Model validation
SOLAS 1974	Safety standards	Operational safety framing
BIMCO/ISF (2020); ILO; IMO	Attrition rate benchmarks	Attrition modeling
Lin et al. (2018); Zhen et al. (2019); Wang et al. (2022)	Scheduling theory	Model foundation

Fleet data were retrieved from Vessel Finder (2024) for all vessels displaying Indonesian flag registration with active AIS transponders and verified IMO numbers.

Vessel Classification

Vessels were stratified into five GT categories consistent with PM No. 26/2022 structures:

- GT > 10,000 / Engine Power > 7,500 kW
- GT 3,000–10,000 / Power 3,000–7,500 kW
- GT 1,500–3,000 / Power 750–3,000 kW
- GT 500–1,500 / Power < 750 kW
- GT < 500

Each category was further differentiated by vessel type: cargo and passenger.

Discrete Crew Availability Model

Availability Ratio

For a rotation cycle comprising T months on board and L months on leave, the availability ratio of one crew group is:

$$\text{Availability} = \frac{T}{T+L}$$

Required Number of Crew Groups

To ensure N vessels maintain full complement at all times:

$$G \geq \frac{N}{\frac{T}{T+L}} = N \cdot \frac{T+L}{T}$$

Since G must be an integer (discrete model):

$$G = \left\lceil N \cdot \frac{T+L}{T} \right\rceil$$

Total Crew Calculation

$$Z = G \times \text{crew per vessel}$$

$$\text{Hob} = N \times \text{ABK per vessel (on board crew)}$$

$$\text{Hc} = Z - \text{Hob (crew on leave)}$$

$$Z = \text{Hc} + \text{Hob}$$

Attrition Model

Total attrition rate p (monthly, probabilistic):

$$P = p_{\text{pen}} + p_{\text{md}}$$

Where

p_{pen} covers retirement, illness, career change, and other separations;

p_{md} covers mortality.

Expected monthly crew outflow:

$$\lambda = (\text{Hob} + \text{Hc}) \times p$$

Buffer crew required (accounting for lead time L_r and overlap handover period L_o):

$$\beta = \lambda \cdot (L_r + L_o) = [(Z \times p) \times (L_r + L_o)]$$

Total crew requirement including attrition buffer:

$$H_{tot} = Z + \beta$$

Parameter Assumptions

Parameter	Value	Basis
Baseline T (on board)	10 months	MLC 2006 compliance; industry practice
Baseline L (leave)	1 month	PM No. 26/2022; MLC 2006
Monthly attrition rate (p)	0.30%	BIMCO/ISF 2020; ILO; IMO estimates
Lead time (L_r)	3 months	1 month recruitment + 1 training + 1 certification
Overlap/handover (L_o)	0.25 months	1-week vessel familiarization

Sensitivity Analysis

To assess sustainability implications across the TBL dimensions, 14 SoSo cycle scenarios were evaluated: $T \in \{6, 7, 8, 9, 10, 11, 12\}$ months $\times L \in \{1, 2\}$ months, computing availability ratio, total crew requirement, monthly outflow, and buffer demand for each scenario.

RESULTS AND DISCUSSION

Fleet Data and Minimum Crew Standards

Table 1 presents the consolidated fleet data derived from Vessel Finder (2024) and minimum crew complements from PM No. 26/2022.

Table 1. Fleet inventory and minimum crew per vessel by category

Vessel Category	Power (kW)	Type	N (vessels)	crews/vessel
GT > 10,000	> 7,500	Cargo	557	21
GT > 10,000	> 7,500	Passenger	14	28
GT 3,000–10,000	3,000–7,500	Cargo	1,077	20
GT 3,000–10,000	3,000–7,500	Passenger	11	23
GT 1,500–3,000	750–3,000	Cargo	928	19
GT 1,500–3,000	750–3,000	Passenger	13	17
GT 500–1,500	< 750	Cargo	1,916	12
GT 500–1,500	< 750	Passenger	54	13
GT < 500	—	Cargo	21,933	10
GT < 500	—	Passenger	254	10
Total			26,757	

Source: Vessel Finder (2024); PM No. 26/2022

Baseline Crew Availability Matrix (T10, L1)

For the baseline cycle, the availability ratio is:

$$G \geq \frac{N}{T+L} = N \cdot \frac{T+L}{T} \dots\dots\dots(2)$$

Illustrative calculation based on table 1, (GT > 10,000 cargo vessels; N = 557, ABK = 21):

$$G = 557 \times \frac{10+1}{10} = 612,7 \text{ groups}$$

$$G = \left[557 \times \frac{10+1}{1} = 612,7 \right] = 613 \text{ groups}$$

$$Z = 613 \times 21 = 12,873 \text{ Persons}$$

$$Z = 613 \times 21 = 12,873 \text{ persons}$$

$$H_{ob} = 557 \times 21 = 11,697 \text{ (on board, 90.9\%)}$$

$$H_c = 12,873 - 11,697 = 1,176 \text{ (on leave, 9.1\%)}$$

Table 2. Crew Availability Matrix — Indonesian-Flagged Fleet (T=10 months, L=1 month)

Category	Type	N	ABK	T	L	G	On Board	On Leave	Total (Z)
GT>10,000	Cargo	557	21	10	1	613	11,697	1,176	12,873
GT>10,000	Passenger	14	28	10	1	16	392	56	448
GT 3,000–10,000	Cargo	1,077	20	10	1	1,185	21,540	2,160	23,700
GT 3,000–10,000	Passenger	11	23	10	1	13	253	46	299
GT 1,500–3,000	Cargo	928	19	10	1	1,021	17,632	1,767	19,399
GT 1,500–3,000	Passenger	13	17	10	1	15	221	34	255
GT 500–1,500	Cargo	1,916	12	10	1	2,108	22,992	2,304	25,296
GT 500–1,500	Passenger	54	13	10	1	60	702	78	780
GT <500	Cargo	21,933	10	10	1	24,127	219,330	21,940	241,270
GT <500	Passenger	254	10	10	1	280	2,540	260	2,800
TOTAL		26,757				29,438	297,299	29,821	327,120

Source: Authors' calculations based on Vessel Finder (2024) and PM No. 26/2022

Table 2 presents the complete crew availability matrix for all vessel categories. The results demonstrate that sustaining 26,757 active Indonesian-flagged vessels under a T10/L1 rotation requires 327,120 total seafarers, with 297,299 (90.9%) actively on board and 29,821 (9.1%) on concurrent leave at any given time. The GT <500 cargo segment dominates the requirement (73.8% of total Z), reflecting Indonesia's high volume of small inter-island cargo vessels.

Attrition Modeling

The global maritime attrition benchmark of $p = 0.30\%/month$ (3.6%/year) is consistent with estimates from BIMCO/ISF (2020) for Southeast Asian fleets (2.5–4.0%/year) and ILO reports for developing country fleets (3.0–5.0%/year). The monthly rate is decomposed as: retirement/career change/illness ($p_{pen} \pm 0.25\%/month$) and mortality ($p_{md} \pm 0.05\%/month$).

Applying the attrition model to the aggregate fleet:

$$\lambda = 327,120 \times 0.003 = 981.4 = 981 \text{ persons/month}$$

$$\beta = 981 \times (3 + 0.25) = 981 \times 3.25 = 3,188 = 3,189 \text{ persons}$$

$$H_{tot} = 327,120 + 3,189 = 330,309 = 330,019 \text{ persons}$$

Table 3. National fleet crew requirement summary with attrition buffer

Parameter	Value
Minimum on-board requirement (H_0)	297,299 persons
Total crew (rotation, T10/L1, no attrition)	327,120 persons
Attrition rate (monthly)	0.30%
Expected monthly outflow (λ)	± 981 persons/month
Lead time gap ($L_r + L_o$)	3.25 months
Annual buffer requirement (β)	$\pm 2,899$ –3,189 persons/year
Total with attrition buffer (H_{tot})	$\sim 330,019$ persons

These findings indicate that Indonesian maritime HRM planners must factor an annual recruitment pipeline of approximately 3,000 new qualified seafarers merely to replace attrition losses—beyond the base recruitment required to maintain rotational balance. Failure to incorporate this buffer creates accumulative operational deficits consistent with the supply-demand gaps documented by BIMCO/ISF (2020).

Sensitivity Analysis: TBL Implications of SoSo Cycle Variation

Table 4 presents results across 14 cycle scenarios.

Table 4. Sensitivity matrix: crew requirements and attrition metrics by SoSo cycle

Cycle	T (mo)	L (mo)	Availability	Total Crew	On Board	On Leave	Groups	λ /month	β (buffer)
T6/L1	6	1	85.7%	346,925	297,364	49,561	31,217	1,041	3,383
T6/L2	6	2	75.0%	396,454	297,341	99,114	35,676	1,189	3,865
T7/L1	7	1	87.5%	339,824	297,346	42,478	30,579	1,019	3,313
T7/L2	7	2	77.8%	382,329	297,367	84,962	34,402	1,147	3,728

T8/L1	8	1	88.9%	334,520	297,351	37,169	30,102	1,004	3,262
T8/L2	8	2	80.0%	371,706	297,365	74,341	33,446	1,115	3,624
T9/L1	9	1	90.0%	330,407	297,366	33,041	29,730	991	3,221
T9/L2	9	2	81.8%	363,446	297,365	66,081	32,703	1,090	3,544
T10/L1	10	1	90.9%	327,120	297,382	29,738	29,433	981	3,189
T10/L2	10	2	83.3%	356,840	297,367	59,473	32,108	1,071	3,479
T11/L1	11	1	91.7%	324,403	297,369	27,034	29,189	973	3,163
T11/L2	11	2	84.6%	351,421	297,356	54,065	31,622	1,054	3,426
T12/L1	12	1	92.3%	322,166	297,384	24,782	28,987	966	3,141
T12/L2	12	2	85.7%	346,925	297,364	49,561	31,217	1,041	3,383

Source: Authors' calculations

TBL Dimension Analysis

Economic Dimension (SDG 9)

The T12/L1 cycle minimizes total crew deployment at 322,166 persons—approximately 4,954 fewer than the T10/L1 baseline, representing a marginal $\sim 1.5\%$ cost reduction. However, this efficiency gain is accompanied by elevated fatigue risk and reduced regulatory compliance margins. The T6/L2 cycle, by contrast, demands 396,454 persons—a 21.2% increase over T10/L1—substantially inflating recruitment, training, and salary expenditures. The relationship between leave duration and total crew requirement is non-linear: doubling leave duration from L1 to L2 increases total crew requirements by an average of 7.4–16.1% across T-values, with proportionally greater impacts at shorter on-board periods.

Social Dimension (SDG 8)

Shorter on-board periods (T6) maximize seafarer family contact frequency, potentially improving mental health outcomes and recruitment attractiveness. However, this welfare gain must be weighed against the substantial resource burden imposed on shipping companies. The T10/L1 cycle satisfies MLC 2006 requirements (12-month maximum contract; minimum 2.5 days leave per month of service = 25 days for 10 months, aligning with the 1-month leave parameter) while maintaining operational feasibility. Critically, all modeled cycles with $T \leq 12$ comply with MLC 2006's maximum contract duration, preserving legal compliance across the sensitivity range.

Environmental Dimension (SDG 14)

Extended on-board periods approaching the 12-month maximum are associated with progressive fatigue accumulation, documented to increase human error probability (Zhen et al., 2019; Moejiono et al., 2025). Human error remains the primary causative factor in 75–96% of maritime accidents (IMO estimates), with direct implications for marine pollution incidents, oil spills, and navigational casualties. The T10/L1 cycle represents a pragmatic boundary condition: sufficiently short to maintain alertness levels within acceptable safety margins, while sufficiently long to minimize the rotational overhead that drives recruitment costs.

Optimal Cycle Identification

The T10/L1 configuration emerges as the TBL sustainable balance point, satisfying the following criteria simultaneously:

MLC 2006 compliance ($T < 12$ months; leave ≥ 2.5 days/month)

Economic near-optimality (only 1.5% above minimum-cost T12/L1 cycle)

Fatigue risk mitigation (adequate leave frequency for physiological recovery)

Operational feasibility (availability ratio 90.9%, exceeding the recommended $\geq 90\%$ threshold)

The marginal crew cost differential between T10/L1 (327,120) and T12/L1 (322,166) is approximately 4,954 persons—a relatively small sacrifice in economic efficiency that yields substantial gains in seafarer welfare and safety performance, consistent with TBL optimization principles.

Comparative Discussion with Existing Literature

The total Indonesian fleet crew requirement of 297,299 on-board seafarers substantially exceeds individual fleet studies but aligns with BIMCO/ISF (2020) projections for Southeast Asian seafarer demand. The attrition buffer of $\sim 3,000$ persons/year is consistent with ILO (developing country fleet, 3.0–5.0%/year applied to Indonesia's fleet), validating the model's parameterization against independent benchmarks.

The discrete ceiling-function approach extends the methodology of Hillier and Lieberman (2015) and Kelso (2018) to a national-fleet context, filling the gap identified in prior literature where scheduling optimization was conducted at company or route level (Lin et al., 2018; Zhen et al., 2019; Wang et al., 2022). The integration of attrition modeling with rotational scheduling represents a methodological contribution beyond existing maritime workforce literature.

CONCLUSIONS

This study presents the first national-scale quantitative analysis of crew availability requirements for Indonesian-flagged vessels using a discrete duty-cycle model with integrated attrition modeling. The principal findings are:

- A total of 327,120 seafarers are required to sustain all 26,757 active Indonesian-flagged vessels under the recommended T10/L1 rotation cycle, with 297,299 (90.9%) simultaneously on board and 29,821 (9.1%) on leave.
- An additional attrition buffer of approximately 2,899–3,189 persons/year is required to compensate for seafarer separations from retirement, mortality, and career transition, raising the effective total requirement to approximately 330,019 persons.
- The T10/L1 cycle is identified as the optimal TBL sustainable balance point, achieving near-maximum economic efficiency ($\approx 1.5\%$ above minimum cost), MLC 2006 compliance, fatigue risk mitigation, and a 90.9% crew availability ratio satisfying safe manning requirements.
- Sensitivity analysis across 14 SoSo scenarios reveals that cycle design decisions generate total crew requirement variations of 18.7% (from 322,166 to 396,454 persons), with profound implications for cost structures, seafarer welfare, and operational safety. Longer leave periods (L2) consistently increase total requirements by 7–16% relative to L1 at equivalent on-board durations.
- This research contributes a replicable quantitative methodology applicable to other archipelagic and developing maritime nations facing analogous crew management sustainability challenges, directly supporting progress toward SDGs 8, 9, and 14 in national maritime sectors.

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