Prescriptive Intelligence for the Blue Economy: Transforming Ship Maintenance toward Smart and Sustainable Operations

Workshop “Blue Economy and Partnership for Sustainable Development of Ukraine’s Maritime Sector”

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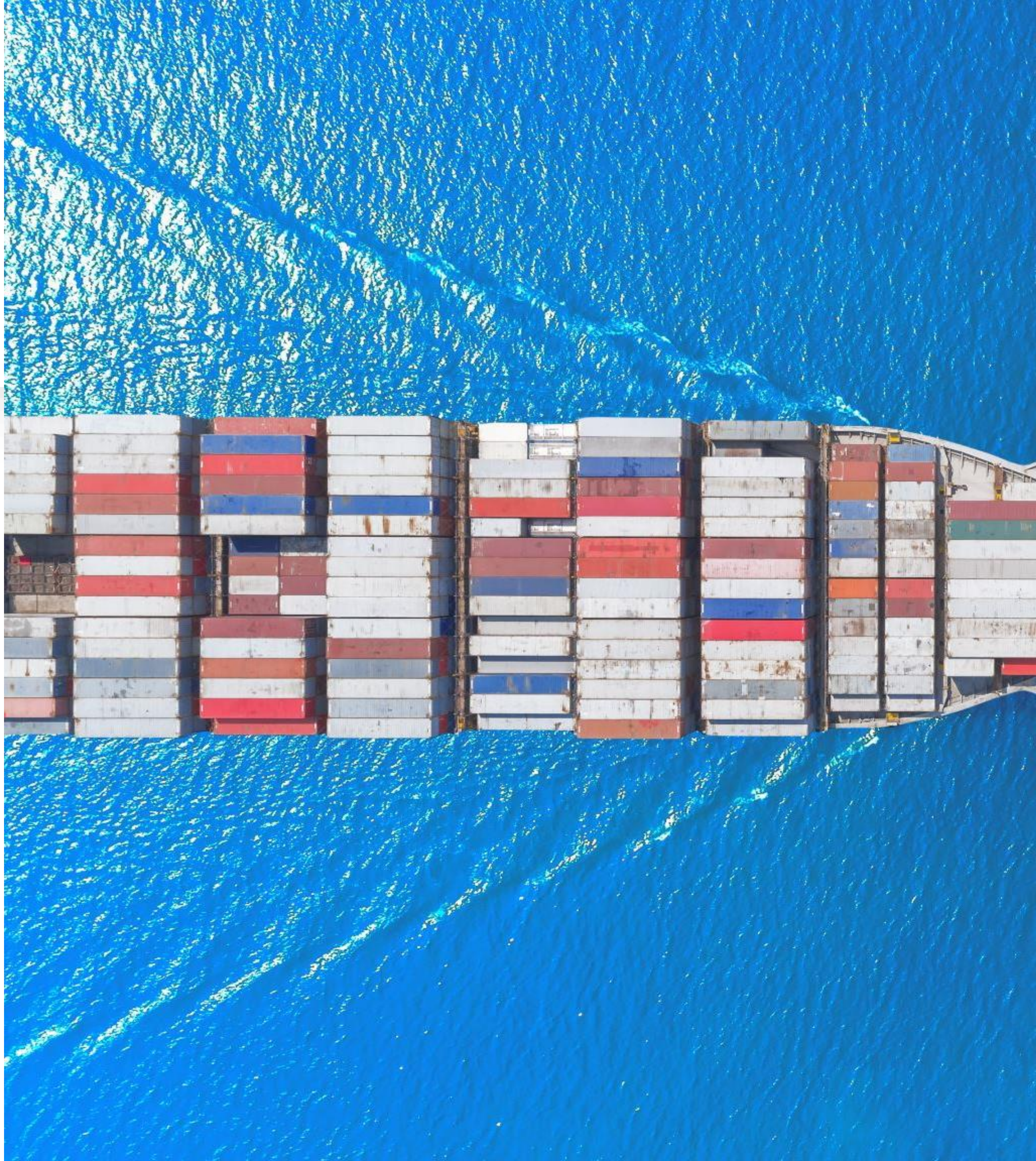
Purpose & Objectives

- Present the concept and methodology of prescriptive intelligence for smart ship maintenance
- Support Blue Economy & Green Shipping goals
- Demonstrate the digital system CPMS integrating ACMS and ShipDiMRO
- Validate real applications toward low-carbon operations
- Outline the roadmap for future smart ship operations



Outline

MOTIVATION IN BLUE ECONOMY CONTEXT

EVOLUTION TOWARD SMART MAINTENANCE

DIGITAL ECOSYSTEM FOR SUSTAINABILITY

CASE STUDY & VALIDATION

FUTURE ROADMAP 2035

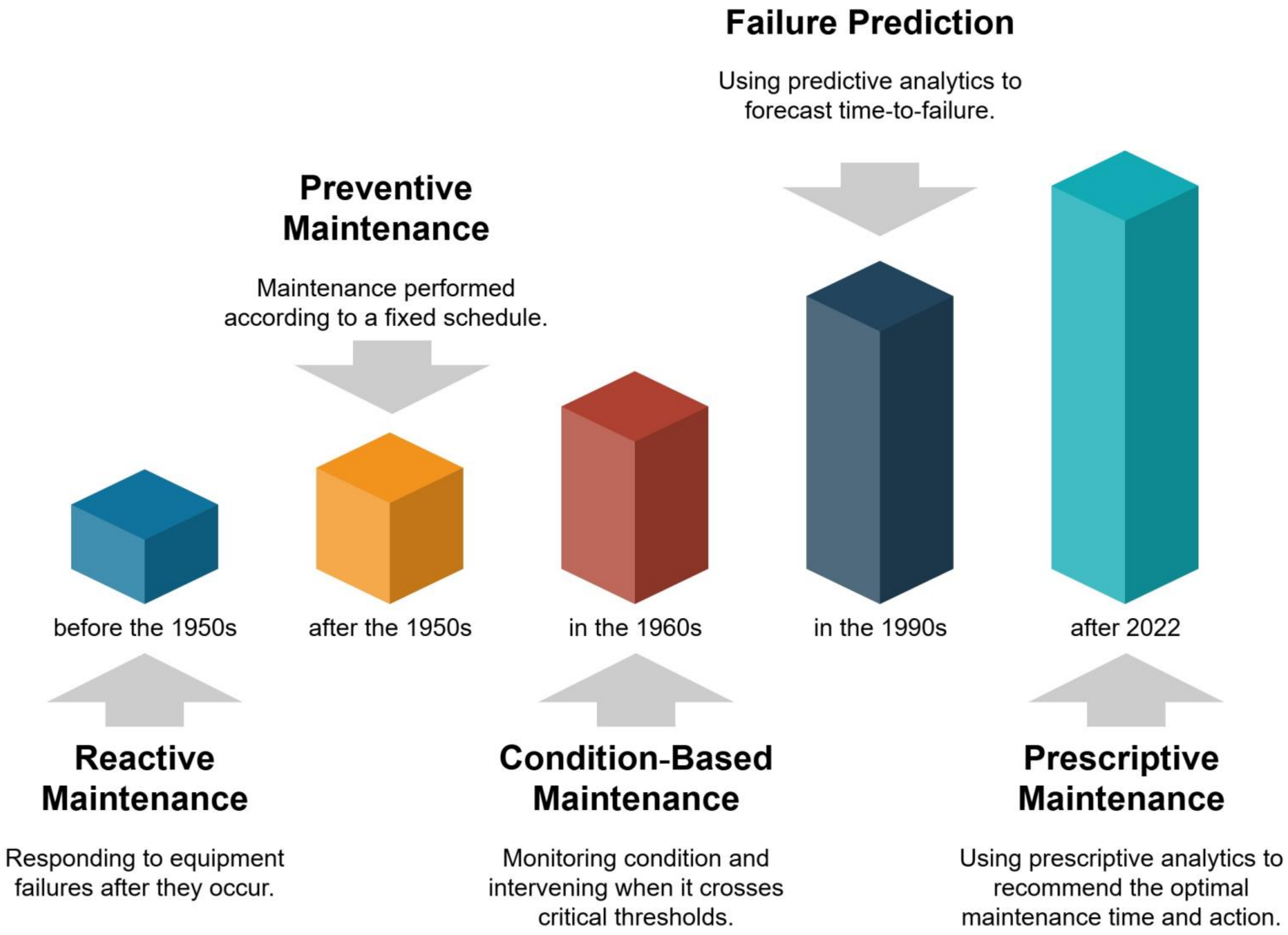
Motivation: Blue Economy & Maritime Sustainability

DIGITALIZATION ENABLES SUSTAINABLE GROWTH

GREEN SHIPPING SUPPORTS THE BLUE ECONOMY

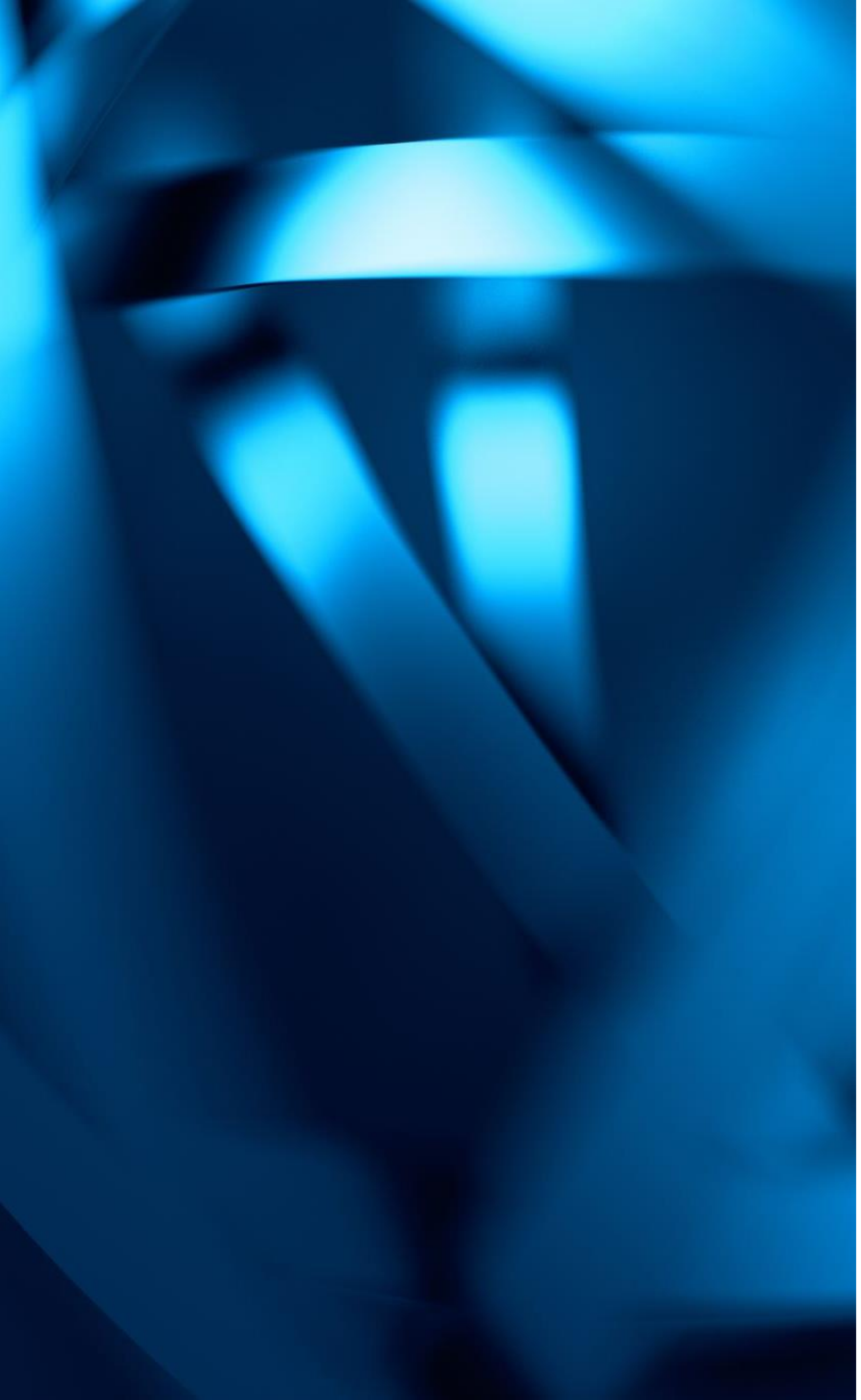
NEED FOR INTELLIGENT, PREDICTIVE, AND PRESCRIPTIVE SHIP SYSTEMS

From Reactive to Prescriptive Maintenance: The Green Transition



Challenges in the Blue Economy Transition

- Fragmented monitoring and control systems
- Lack of integration between technical and ecological performance
- Limited integration between onboard and cloud services
- Need for unified prescriptive maintenance platform



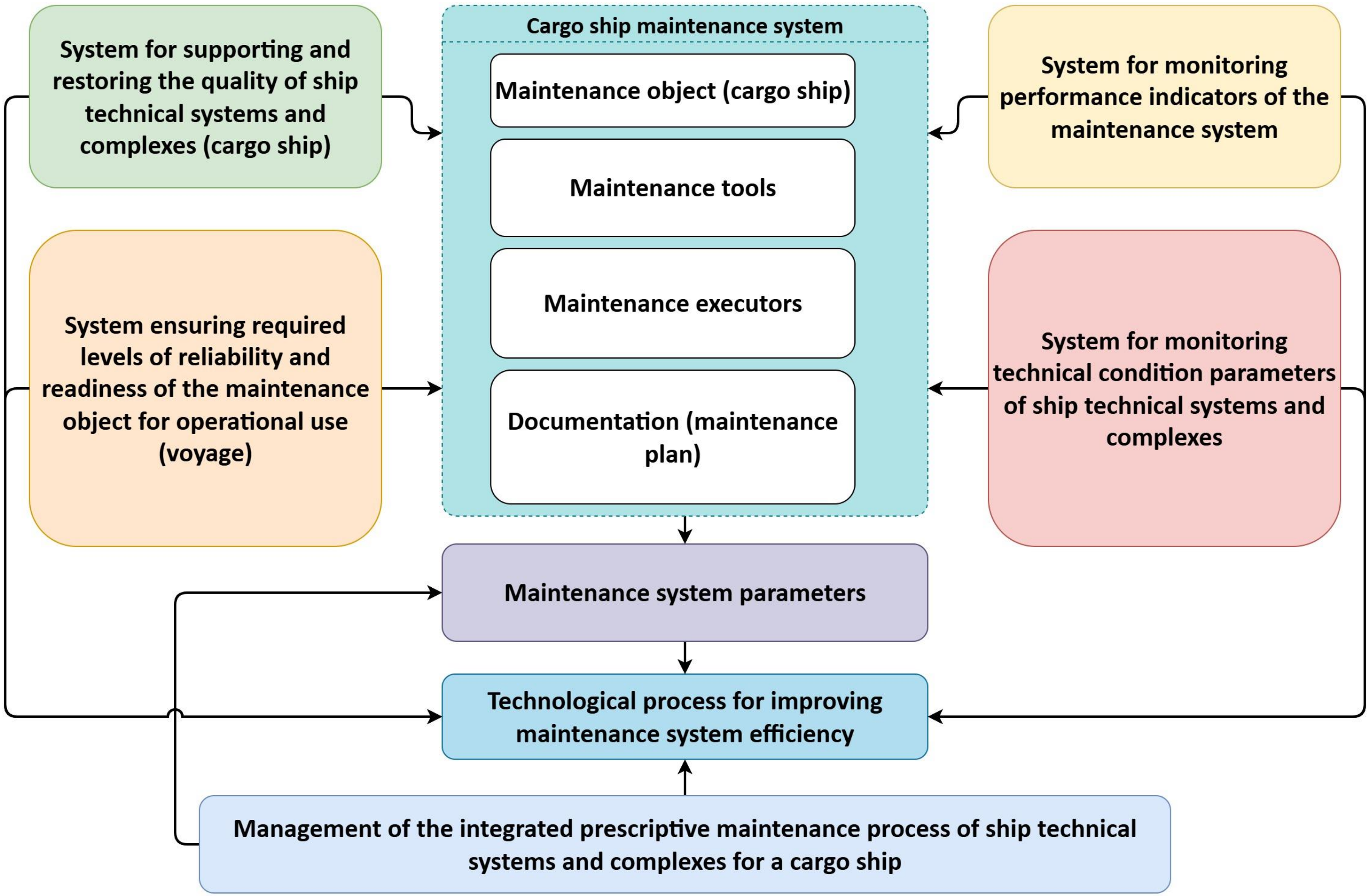
Research Focus & Relevance to Blue Growth

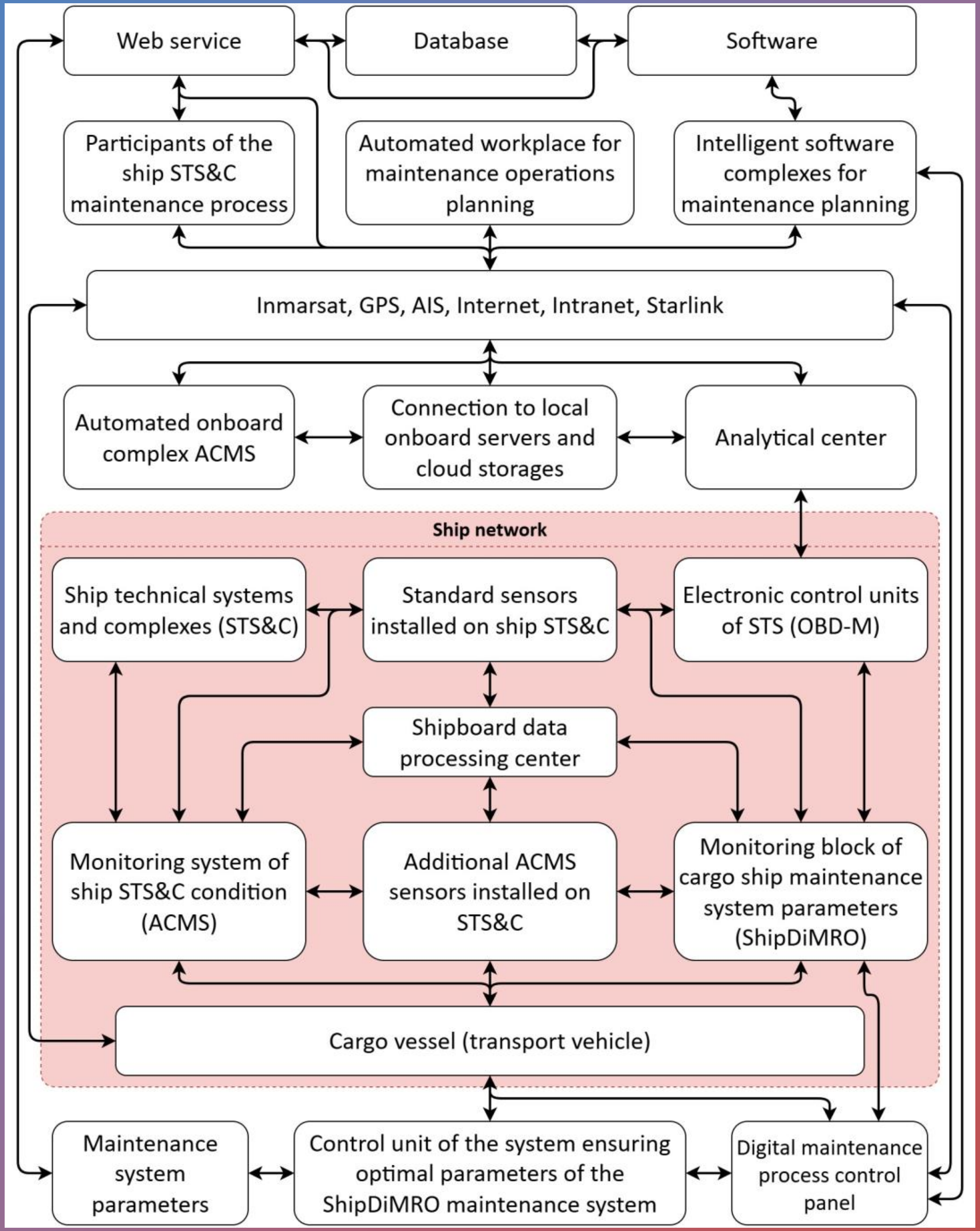
Eco-efficiency-driven maintenance strategies

ACMS and ShipDiMRO systems for validation

Supporting circular and sustainable ship operations

Conceptual Framework: CPMS



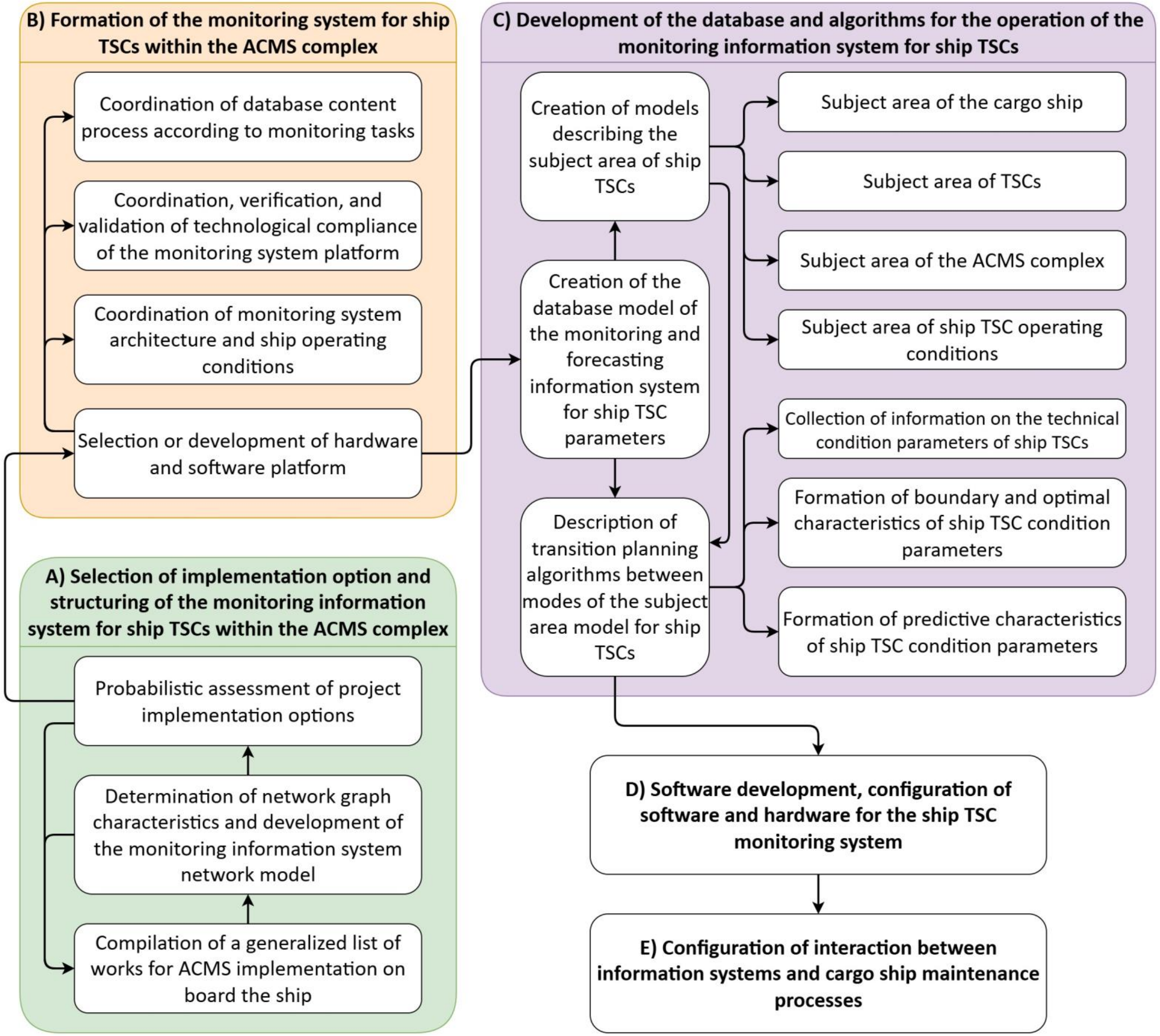


Digital Ecosystem for the Blue Economy

- ACMS: Onboard Intelligence
- ShipDiMRO: Cloud Sustainability Analytics
- shipmonitoring.org: Collaborative Platform

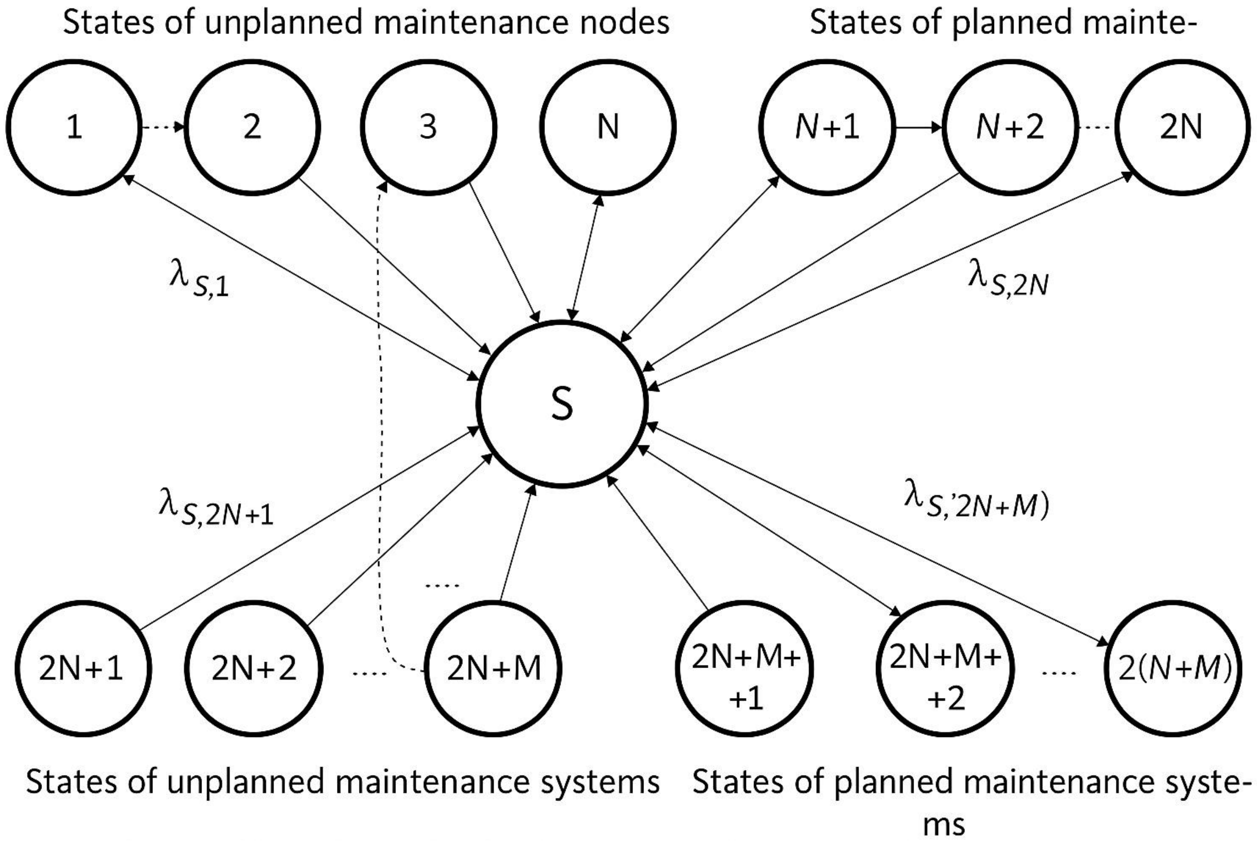
Methodology for Sustainable Maritime Analytics

- System approach: reliability, probability, safety, ML integration
- Tools: mathematical programming, statistics, graph theory
- Validation: parametric identification + experiments



Simulation Models Supporting Eco-efficiency

State graph of a ship's technical equipment (using the main engine as an example)



System of differential equations for calculating the probabilities of corresponding states

$$
\begin{cases}
\frac{dP_1(t)}{dt} = -\mu_{1,S} \cdot P_1(t) + \lambda_{S,1} \cdot P_S(t) + \lambda_{2,1} \cdot P_2(t) \\
\frac{dP_2(t)}{dt} = -\mu_{2,S} \cdot P_2(t) + \lambda_{S,2} \cdot P_S(t) - \lambda_{2,1} \cdot P_2(t) \\
\frac{dP_3(t)}{dt} = -\mu_{3,S} \cdot P_3(t) + \lambda_{S,3} \cdot P_S(t) + \lambda_{(2N+3),3} \cdot P_{2N+3}(t) \\
\dots\dots\dots\dots\dots \\
\frac{dP_{2N+3}(t)}{dt} = -\mu_{(2N+3),S} \cdot P_{2N+3}(t) + \lambda_{S,3} \cdot P_S(t) - \lambda_{(2N+3),3} \cdot P_{2N+3}(t) \\
\dots\dots\dots\dots\dots \\
\frac{dP_i(t)}{dt} = -\mu_{i,S} \cdot P_i(t) + \lambda_{S,i} \cdot P_S(t) \\
\frac{dP_s(t)}{dt} = \sum_{i=1}^{M+N} \mu_{i,S} \cdot P_i(t) - P_S(t) \sum_{i=1}^{M+N} \lambda_{S,i}
\end{cases}
$$

Morphological Matrix:
Digital Strategies toward Green Transformation

id	Name	Number	Name of the group of feature	Number	Name of feature
1	The data topology underlying the digital strategy	11	Digital model	-	-
		12	Digital shadow	-	-
		13	Digital twin	-	-
2	Predictive analytics methods	21	Machine learning / intelligent data analysis method	2101	Random search
				2102	Decision tree
				2103	Clustering-based heuristics
				2104	Image recognition
				2105	Random forest
				2106	Gaussian process
				2107	Conditional conclusion tree
				2108	Support vector method
				2109	Ensemble training
				2110	Artificial neural network
				2111	k-nearest neighbors method
				2112	Kernel methods
				2113	Multilayer perceptron
				2114	Gradient-boosted tree
		22	Statistical analysis method	2201	Linear regression
				2202	Multiple linear regression
				2203	Rank regression
				2204	Autoregressive integrated moving average
				2205	Logistic regression
				2206	Multivariate logistic regression
				2207	Density assessment
				2208	Regression by support vectors
		23	Probabilistic models	2301	Hidden Markov model
				2302	Bayesian network
				2303	Monte Carlo Markov chains

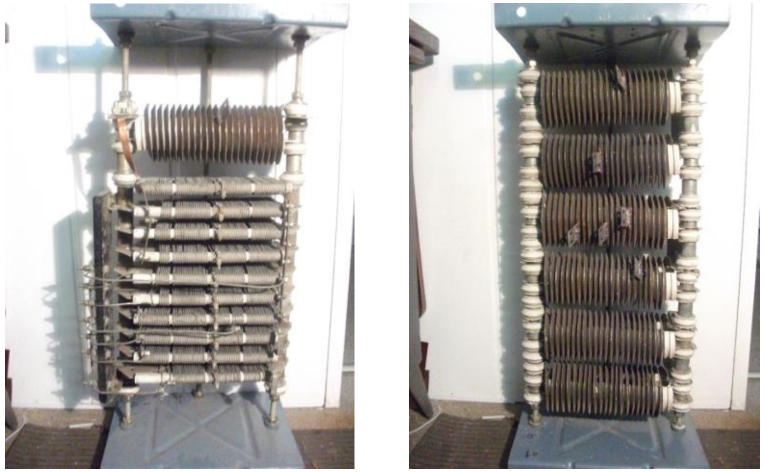
Experimental Setup for Sustainable Performance Testing

Ship auxiliary engine (diesel generator)

LN-2FC Signal Frequency Calculator

Alternating current generator

Active load elements



Power cables, AC generator busbars

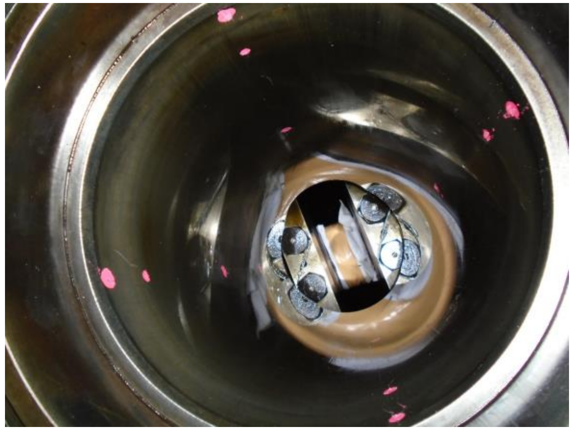
Results: Improving Efficiency and Reducing Environmental Impact

Pistons without rings

The diesel generator piston with new rings is installed in the cylinder.

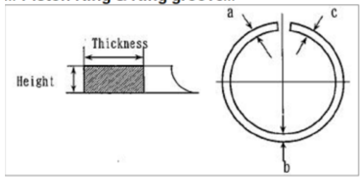
Diesel generator pistons with new rings

Cylinder liner for diesel generator



Inspection report for rings and grooves, cylinder 1

/// Piston Ring & Ring groove///



<<< Standard Data >>> — **Unit : 1/100mm**

Ring	Piston ring				Clearance Ring and Groove	
	Height		Thickness			
	Standard	Limit	Standard	Limit	Standard	Limit
1	5				0.13-0.17	0.3
2	5				0.09-0.13	0.3
3	5				0.08-0.12	0.3
4	7				0.04-0.08	0.2
5	7				0.04-0.08	0.2

No.1 Cylinder

Position	Piston ring						Clearance between Ring and Groove				Remark
	Thickness			Height			with New Piston Ring				Piston rings renewed.
	a	b	c	a	b	c	F	A	P	S	
1	7.69	7.67	7.67	4.9	4.91	4.89	0.31	0.32	0.32	0.31	
2	7.73	7.56	7.61	4.96	4.91	4.97	0.15	0.15	0.15	0.15	
3	7.65	7.63	7.65	4.93	4.89	4.91	0.15	0.15	0.15	0.15	
4	5.2	5.19	5.17	6.74	6.86	6.81	0.07	0.06	0.07	0.07	
5	5.20	5.17	5.21	6.88	6.82	6.92	0.06	0.06	0.06	0.06	

Cylinder liner inspection report

D/E Inspection Record (Cylinder Liner,Piston & Rings)

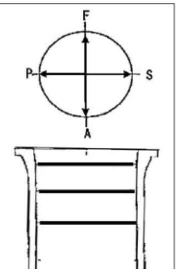
Vessel Name :	Tianjin Highway	Engine Type :	8DK-20
2nd Engineer :		Chief Engineer :	

Date	Place	Machine No	Total Working Hrs	Working Hrs since last O.H
24.July.2023	At Sea	1	63127	9057

/// Cylinder Liner ///

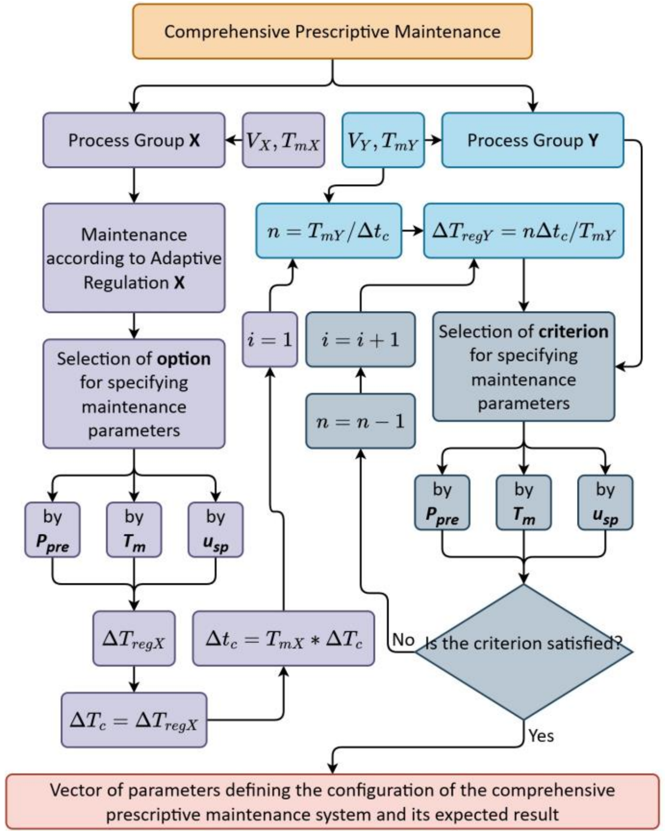
*** Measurment position by Ship's point gauge — Unit : 1/100mm

Cyl No	Direction	Dimension of cylinder liner					Working Hrs since last O/H	Working Hrs since last renew
		Original : 200 mm				Max wear down		
		Limit : 1 mm						
		B1	B2	B3	B4			
1	F - A	200.43	200.13	200.13	200.15	0.43	9057	63127
	P - S	200.4	200.18	200.09	200.1	0.4		
2	F - A	200.35	200.15	200.12	200.11	0.35	9057	63127
	P - S	200.45	200.11	200.11	200.08	0.45		
3	F - A	200.42	200.15	200.1	200.11	0.42	9057	63127
	P - S	200.33	200.1	200.08	200.12	0.33		
4	F - A	200.35	200.15	200.12	200.15	0.35	9057	63127
	P - S	200.47	200.13	200.09	200.17	0.47		
5	F - A	200.5	200.21	200.13	200.1	0.5	9057	63127
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		



Adaptive and Circular Maintenance Cycle

Algorithm for adapting the parameters of the CPMS



Excerpt from the maintenance plan generated by the CPMS

Component / Object	Job ID	Job Interval	Dept.	Work Date Last	Work Date Due	Month 1	2	3	4	5	6	7	8	9	10	11	12
Year : **2023**																	
RENEW LO - LIFT CAR ENGINE	215-18_LO-16	Month	ENGINE	04-04-22	04-04-23				D								
MOBILE LIFTER CAR	210-06-36_PC C_LFTCR	Month	DECK	02-11-22	02-05-23					D							
373 - OPEN VENTILATION SYSTEM FOR CAR HOLDS																	
MAINTENANCE CAR DECK VENTILATOR	210-01-05_PC C_HLDVENT	Month	DECK	11-12-22	11-03-23			D									
381.730 - PORTABLE FLAMMABLE GAS DETECTOR																	
TEST OF GAS DETECTOR	381_GASDET ECT	Month	DECK	27-02-23	27-03-23			D									
CALIBRATION OF FLAMABLE GAS DETECTOR	381_GASDET ECT-1	Month	DECK	28-09-22	28-03-23			D									
381.750 - PORTABLE O2 METER																	
TEST PORTABLE O2 METER	381_O2MTR	Month	DECK	27-02-23	27-03-23			D									
401.001 - RUDDER																	
CHECK RUDDER	401.001_RUD DER	Month	DECK	05-01-21	05-07-23							D					
402.031 - NECK BUSH / LOWER PINTLE BUSH																	
RENEW LO - RUDDER CARRIER	215-18_LO-25	Month	ENGINE	02-02-21	02-08-23								D				
STEERING GEAR - RECORED WEAR DOWN	220-01-04_402 .031	Month	ENGINE	10-02-21	10-08-23								D				
403.201 - STEERING GEAR COMPONENTS																	
FILL & APPLY GREASE - STEERING GEAR	215-18_GREA SE-03	Month	ENGINE	06-01-23	06-07-23							D					
STEERING GEAR - CLEAN LINE FILTER & SAFETY DEVICE TEST	220-01-02_403 .201	Month	ENGINE	09-02-23	09-08-23								D				

Integration Benefits for the Blue Economy

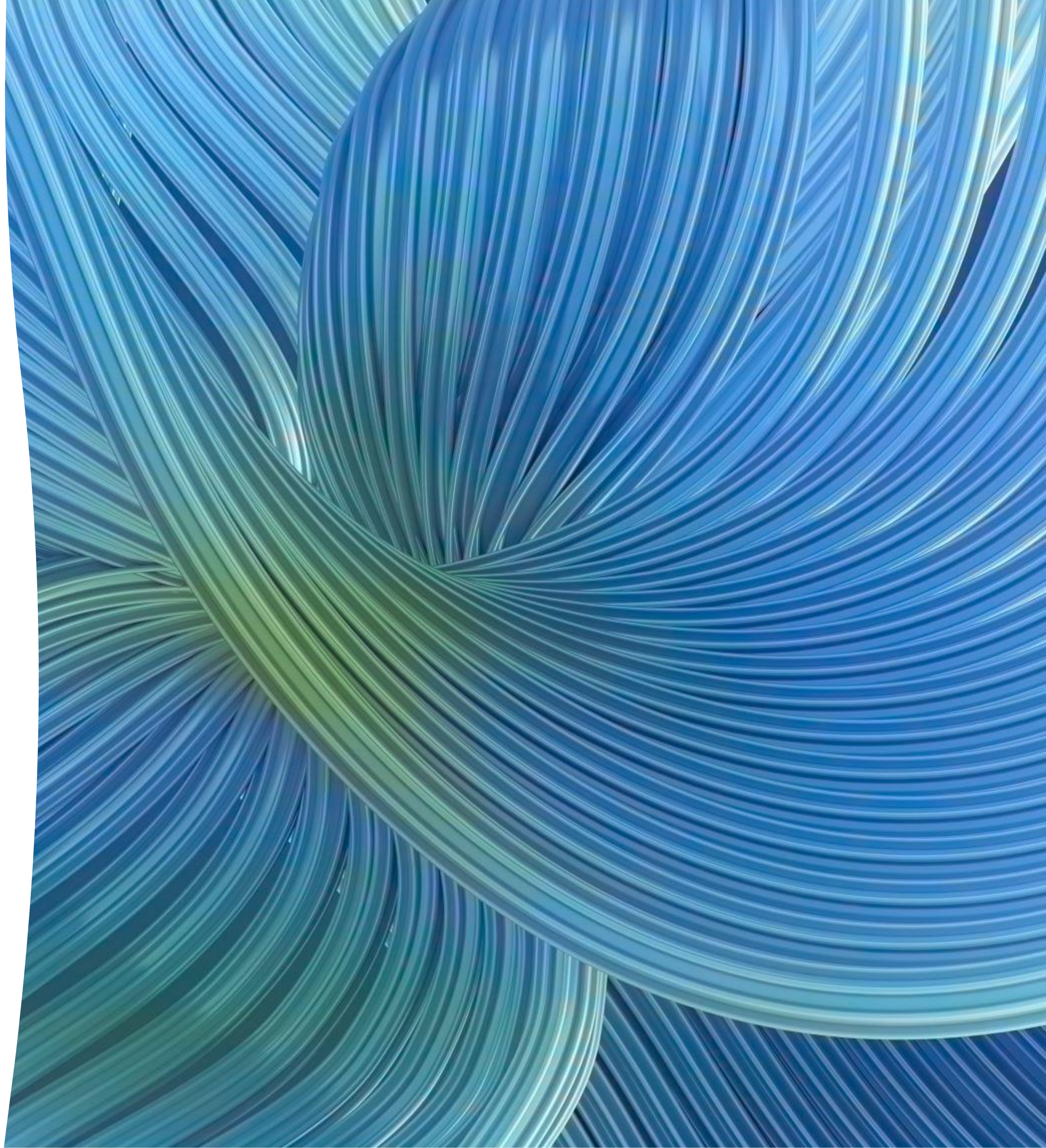
- Energy and resource savings
- Reduced emissions and improved lifecycle performance
- Compliance with IMO digitalization goals
- Prescriptive maintenance = sustainability enabler

Roadmap: Prescriptive Intelligence in Blue Growth 2035

2030: Smart Integration

2032: AI-driven eco-optimization

2035: Low emission smart fleet



Conclusions

From data to action →
From smart to sustainable

Concept validated through modeling and experiments

Demonstrated industrial applications in multiple enterprises

Pathway toward intelligent, sustainable ship operation

Thank you for your attention!

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Advances in Sustainable Transportation and Energy Systems

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energies

IMPACT FACTOR 3.2

CITESCORE 7.3