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Research Article

Evaluating Nippon Yusen Kaisha's Remote Diagnostic Center: An Analysis of End-User Perspectives Among Engine Management-Level Officers

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ABSTRACT

The integration of shore-based diagnostics in maritime operations is reshaping shipboard maintenance and decision-making practices. This study evaluated Nippon Yusen Kaisha's Remote Diagnostic Center (RDC) from the perspectives of engine management-level officers onboard its vessels. Specifically, it assessed the RDC's usefulness, clarity, reliability, ease of use, influence on decision-making, and challenges in shipboard integration.

A total of 214 respondents, equally divided between Chief Engineers and Second Engineers, participated through a structured survey analysed using descriptive statistics. Findings revealed that the RDC is moderately useful in enhancing data-driven decisions and supporting the Planned Maintenance System (PMS). It assists in detecting abnormalities and promoting condition-based maintenance, though its reports remain supplementary to firsthand inspections. Reports were generally viewed as clear and accessible, but their influence on major decisions was moderate.

The study concludes that NYK's RDC is a reliable support tool with room for improvement. Enhancements in scope, usability, and real-time responsiveness are recommended to maximize operational value in maritime practice.

Keywords*: Remote diagnostics, Maritime digitalization, Decision-making, Condition-based maintenance, NYK, Technology adoption*

Background

The global maritime industry is undergoing rapid digital transformation, characterized by the adoption of automation, real-time data analytics, and remote monitoring systems to improve safety, efficiency, and sustainability in ship operations. Remote condition monitoring has become integral to modern ship management. Prior studies highlight its value: Kristiansen (2022) and the American Bureau of Shipping (ABS, 2021) demonstrated that shore-based diagnostic centers enhance machinery fault detection and enable proactive maintenance. Similarly, DNV's Remote Monitoring

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Services and Rolls Royce's Intelligent Asset Management illustrate how centralized analytics hubs strengthen collaboration between onboard and shore-based teams, leading to more informed operational decisions (DNV, 2022; Rolls Royce, 2021).

Within this context, Nippon Yusen Kaisha (NYK)—one of the world's largest shipping companies—established the Remote Diagnostic Center (RDC) as part of its commitment to smarter and more sustainable vessel operations. The RDC is a shore-based facility that delivers real-time monitoring, diagnostics, and predictive maintenance support to selected NYK vessels. Using satellite communications, it continuously collects and analyzes data on critical engine parameters. RDC experts then assess this information to detect anomalies, evaluate machinery health, and forecast potential failures, with findings transmitted to Chief Engineers and Second Engineers for decision-making and maintenance planning.

This study evaluates the RDC from the perspectives of engine management-level officers. Specifically, it examines perceptions of the system's usefulness, clarity, and reliability, along with its contributions to troubleshooting, maintenance planning, and operational decision-making. By identifying strengths and areas for improvement, the findings provide practical recommendations to enhance the RDC's usability and operational value. More broadly, the study supports NYK and the maritime sector in advancing safer, more efficient, and sustainable ship operations, aligned with United Nations Sustainable Development Goal (SDG) 9: Industry, Innovation, and Infrastructure (Ahola et al., 2021).

Methods

This study employed a quantitative-descriptive research design to evaluate the NYK Remote Diagnostic Center (RDC) from the perspectives of engine management-level officers onboard NYK-operated vessels. The study aimed to assess how these officers evaluated the RDC in terms of usefulness, clarity, reliability, and ease of use, and how RDC-generated information supported decision-making, troubleshooting, and maintenance activities.

A structured survey questionnaire served as the primary data-gathering instrument. The variables measured included perceived usefulness, clarity, reliability, ease of use, influence on decision-making, contributions to troubleshooting and maintenance, and challenges encountered during the integration of RDC outputs into shipboard operations (Berg et al., 2024).

Respondents of the Study

The respondents of this study were engine management-level officers, specifically Chief Engineers and Second Engineers, who served as the direct recipients and primary users of RDC-generated reports. The Chief Engineer holds overall responsibility for engine department operations, including machinery performance, safety, and maintenance. The Second Engineer oversees day-to-day engine room operations and is directly engaged in maintenance, troubleshooting, and the implementation of technical instructions. Their combined expertise made them essential participants in evaluating how RDC information supports real-time decision-making and operational efficiency.

A total of 214 engine management-level officers were selected as respondents. They were proportionally stratified from a population of 460 officers assigned across 230 NYK-operated vessels with active Remote Diagnostic Center (RDC) monitoring. The sample size was determined using Slovin's formula at a 95% confidence level and a 5% margin of error, ensuring statistical validity and representation across vessel types.

The stratified distribution of the 214 respondents across vessel types is presented in Table 1.

Table 1. Stratified Distribution of Respondents by Vessel Type and Sample Size

TYPE OF VESSEL WITH RDC MONITORING	NUMBER OF VESSELS WITH RDC MONITORING	TOTAL ENGINE MANAGEMENT LEVEL OFFICERS	TOTAL SAMPLE SIZE REQUIRED
BULK CARRIERS	87	174	81
PURE CAR CARRIERS	58	116	54
CONTAINERS	41	82	38
CRUDE AND CHEMICAL TANKERS	24	48	22
LPG TANKERS	10	20	9
LNG TANKERS	6	12	6
RORO	4	8	4
TOTAL	**230**	**460**	**214**

Note. This table presents the stratified distribution of respondents by vessel type and sample size for vessels with RDC monitoring. The sample size was determined proportionally based on the total number of engine management-level officers per vessel type.

The respondents' exposure to and operational use of RDC reports provided critical insights into the system's usefulness, clarity, reliability, and integration into shipboard practices. Their feedback served as the core data source for this research and guided the formulation of practical recommendations for optimizing NYK's RDC system.

A structured survey questionnaire served as the primary data collection tool, aligned with the Statement of the Problem. The questionnaire consisted of two parts: (1) socio-demographic information and (2) structured items related to the research variables. Demographic data included rank, vessel type, years of experience in current rank, total seafaring experience, duration of current contract, number of RDC reports received, and prior training in the use of RDC reports. These details provided context for interpreting responses and enabled trend analysis based on personal and professional backgrounds.

The structured portion of the questionnaire covered perceived usefulness, clarity, reliability, and ease of use of RDC-generated reports; the system's contributions to troubleshooting and machinery maintenance; challenges in integrating RDC insights into daily operations; and perceived limitations of the system. An open-ended item was also included to capture qualitative suggestions for system improvement. All close-ended items used a 4-point Likert scale: 1 – Strongly Disagree, 2 – Disagree, 3 – Agree, 4 – Strongly Agree. This scale was selected to encourage definitive responses and support reliable quantitative analysis.

Data collected from the questionnaires were processed and analyzed using Microsoft Excel. Descriptive statistical tools—including frequency counts, percentage distribution, and mean—were applied to summarize and interpret the responses of engine management-level officers. The analysis focused on officers' evaluation of the RDC in terms of report clarity, reliability, usefulness, and ease of use, as well as the RDC's contributions to troubleshooting and maintenance. Challenges and perceived weaknesses encountered during integration into shipboard operations were also examined.

Results were presented in tabular form to clearly illustrate findings and support conclusions. This methodological approach provided a data-driven foundation for evaluating how the RDC influences efficiency, safety, and decision-making in maritime operations (Chin et al., 2023).

Result and Discussion

Profile of the Survey Respondents

Table 2 summarizes the demographic profile of the 214 respondents, equally divided between Chief Engineers (50.47%) and Second Engineers (49.53%). This balance ensured perspectives from both management-level ranks.

Table 2. Distribution of Respondents by Demographic Profile

DEMOGRAPHICS	f	%
Rank		
Chief Engineer	108	50.47%
Second Engineer	106	49.53%
Total	214	100.00%
Type of Vessel		
Bulk Carriers	81	37.85%
Pure Car Carriers	54	25.23%
Containers	38	17.76%
Crude and Chemical Tankers	22	10.28%
LPG Tankers	9	4.21%
LNG Tankers	6	2.80%
Ro-ro	4	1.87%
Total	214	100.00%
Years of Experience in Current Rank for C/E		
1-3	19	17.59%
4-6	47	43.52%
7-9	25	23.15%
more than 10 years	17	15.74%
Total	108	100.00%
Years of Experience in Current Rank for 2/E		
1-3	47	44.34%
4-6	29	27.36%
7-9	28	26.42%
more than 10 years	2	1.89%
Total	106	100.00%
Total Years of Seafaring Experience for C/E		
6-10	1	0.93%
11-15	5	4.63%
16-20	29	26.85%
21-25	30	27.78%
26-30	40	37.04%
31-35	3	2.78%
Total	108	100.00%
Total Years of Seafaring Experience for 2/E		
6-10	7	6.60%
11-15	23	21.70%
16-20	30	28.30%
21-25	24	22.64%

DEMOGRAPHICS	f	%
26-30	22	20.75%
31-35	0	0.00%
Total	106	100.00%
Current Contract Duration		
4 months	177	82.71%
6 months	37	17.29%
Total	214	100.00%
Number of RDC Reports Received During the Contract		
1 report	52	24.30%
2 reports	120	56.07%
3 reports	40	18.69%
4 reports	2	0.93%
Total	214	100.00%
Have you attended any RDC training/seminar?		
Yes	214	100.00%
No	0	0.00%
Total	214	100.00%

Note. Percentages are based on the total number of respondents (N = 214). C/E = Chief Engineer; 2/E = Second Engineer. Data reflect the rank, vessel type, years of experience, contract duration, RDC report frequency, and training attendance of participating engine management-level officers

The majority served on bulk carriers (37.85%), followed by car carriers (25.23%) and container ships (17.76%), reflecting NYK's operational focus on dry cargo logistics as noted in the NYK Fact Book (2023). Fewer respondents were assigned to tankers, LNG, LPG, and Ro-Ro vessels, consistent with the company's smaller liquid cargo segment managed partly through subsidiaries.

Chief Engineers generally accumulated more than two decades of sea service before promotion, often serving longer in rank, which indicates a slower progression beyond C/E. By contrast, Second Engineers advanced more quickly, typically achieving promotion within 5–9 years, with sea service levels comparable to those of current C/Es.

Most respondents (82.71%) were under four-month contracts, aligning with NYK's crewing policies designed to reduce fatigue and maintain performance. RDC engagement was moderate, with over half receiving two reports per contract, while all respondents had attended at least one RDC training or seminar. This ensured their feedback was based on both operational practice and formal instruction.

Overall, the demographic profile shows that respondents possessed extensive professional experience across vessel types and ranks, reinforcing the reliability of their evaluations of the RDC.

The Nippon Yusen Kaisha's Remote Diagnostic Center (RDC) As Assessed by the Respondents

This section presents the respondents' assessment of the Remote Diagnostic Center (RDC) developed by Nippon Yusen Kaisha (NYK). The evaluation focuses on four key dimensions: usefulness, clarity, reliability, and ease of use of the RDC reports and services. These dimensions reflect how well the RDC supports Engine Management-Level Officers in monitoring equipment conditions, planning maintenance, and making data-driven decisions onboard. The responses are measured using a 4-point Likert scale, and the results are discussed per indicator, supported by corresponding weighted mean values and qualitative interpretations.

Usefulness

As presented in Table 3, all indicators assessing the usefulness of the RDC obtained weighted means ranging from 3.33 to 3.37, with an overall weighted mean of 3.35, interpreted as Moderately Useful. This indicates that respondents generally agreed that RDC-generated reports support their engine-related decisions and maintenance tasks.

Table 3. Respondents' Assessment of RDC in terms of Usefulness

Indicators	WM	Description	Interpretation
1. The RDC supports the prioritization of maintenance tasks.	3.37	*Agree*	*Moderately Useful*
2. The RDC helps in making accurate engine-related decisions.	3.36	*Agree*	*Moderately Useful*
3. The RDC identifies performance trends before failures occur.	3.36	*Agree*	*Moderately Useful*
4. The RDC minimizes unnecessary inspections or interventions.	3.35	*Agree*	*Moderately Useful*
5. The RDC increases my awareness of machinery performance.	3.33	*Agree*	*Moderately Useful*
OVERALL WEIGHTED MEAN	**3.35**	***Agree***	***Moderately Useful***

Legend: 3.50 – 4.00 — Strongly Agree (Highly Useful); 2.50 – 3.49 — Agree (Moderately Useful); 1.50 – 2.49 — Disagree (Slightly Useful); 1.00 – 1.49 — Strongly Disagree (Not Useful at All)

These findings directly answer Research Question 1.1 (Usefulness). While the RDC is perceived as supportive in task prioritization, decision-making, and trend identification, it has not yet been regarded as indispensable.

From the Technology Acceptance Model (TAM), this indicates that although officers perceive the RDC as useful, this perception has not translated into strong behavioral intent to fully rely on the system. Under the Diffusion of Innovations (DOI) framework, the RDC shows relative advantage and compatibility with existing practices but lacks trialability and observability, which slows its deeper adoption as an indispensable decision-support tool.

The results align with Perera et al. (2019), who emphasize that remote diagnostics significantly support situational awareness and maintenance decision-making when reports are structured and context specific. Similarly, Fischer et al. (2020) report a 32% reduction in emergency repairs due to predictive diagnostics, reinforcing the practical value also perceived by NYK's officers. The recognition of usefulness in planning and prioritization is consistent with DNV (2023) and IMO (2021), both of which stress that remote monitoring systems must provide actionable, real-time insights to be operationally effective.

The absence of ratings in the Highly Useful range (≥ 3.50) highlights a gap between the RDC's potential and its perceived impact. Mallam et al. (2020) caution that digital systems may underperform if their interface or outputs lack operational clarity, particularly under high-stress conditions. This concern resonates with the slightly lower rating for "increasing awareness of machinery performance" (WM = 3.33), suggesting that engineers may find it difficult to fully grasp certain insights. Likewise, Ahola et al. (2021) identify technostress and digital fatigue as barriers to full adoption, particularly when outputs are frequent but not intuitively applicable.

Within NYK's organizational context, RDC reports are reviewed by shore-based experts before transmission to vessels (NYK Line, 2022). While this ensures data accuracy, it may also delay information flow, reducing the immediacy of support for onboard decision-making.

Clarity

As shown in Table 4, all indicators assessing the clarity of RDC reports received weighted means between 3.32 and 3.42, with an overall weighted mean of 3.37, interpreted as Mostly Clear. This indicates general agreement among respondents that RDC reports are understandable and easy to interpret.

Table 4. Respondents' Assessment of RDC in terms of Clarity

Indicators	WM	Description	VI
1. The reports clearly distinguish between normal and abnormal values.	3.42	*Agree*	*Mostly Clear*
2. The technical terms used in RDC reports are understandable.	3.37	*Agree*	*Mostly Clear*
3. The contents of the RDC reports are easy to interpret.	3.36	*Agree*	*Mostly Clear*
4. The recommendations in the reports are easy to follow.	3.36	*Agree*	*Mostly Clear*
5. The visuals (graphs, tables) in the RDC reports are clear.	3.32	*Agree*	*Mostly Clear*
OVERALL WEIGHTED MEAN	**3.37**	***Agree***	***Mostly Clear***

Legend:.50 – 4.00 — Strongly Agree (Very Clear); 2.50 – 3.49 — Agree (Mostly Clear); 1.50 – 2.49 — Disagree (Somewhat Unclear); 1.00 – 1.49 — Strongly Disagree (Not Clear at All)

These findings directly answer Research Question 1.2 (Clarity), showing that while RDC reports are generally understandable, their clarity is not yet at the level of being "Very Clear."

Within TAM, this reflects partial satisfaction with perceived ease of use, as users still report challenges in interpreting visuals. From a DOI perspective, clarity gaps reduce compatibility with daily workflows and slow the rate of adoption among diverse crews.

The highest-rated item, "The reports clearly distinguish between normal and abnormal values" (WM = 3.42), suggests that deviation detection is effectively communicated — a critical factor for rapid decision-making in shipboard contexts. Conversely, the lowest-rated indicator, "The visuals (graphs, tables) in the RDC reports are clear" (WM = 3.32), highlights challenges in visual presentation, which may hinder quick interpretation during time-sensitive operations.

These results align with Perera et al. (2019), who found that clarity in technical reports enhances situational awareness and reduces cognitive load for engineers. Similarly, DNV (2023) recommended standardized report formats to ensure consistent interpretation across multinational crews. This echoes the positions of the IMO (2021) and ICS (2023), which advocate for user-centered design in digital maritime tools to improve comprehension and decision-making.

However, the absence of ratings in the Very Clear category (≥ 3.50) points to limitations. Mallam et al. (2020) cautioned that ambiguous visuals and poorly designed human–machine interfaces can cause misinterpretations even among experienced officers. Likewise, Theotokatos et al. (2022) noted that language barriers and inconsistent formatting in diagnostic reports may compromise usability for multicultural crews — a concern directly relevant to NYK's global fleet operations.

Reliability

Table 5 presents the respondents' assessment of the RDC's reliability. All indicators received weighted means between 3.35 and 3.43, with an overall weighted mean of 3.38, interpreted as Generally Reliable. This reflects agreement among respondents that the RDC provides dependable information for engine management-level officers.

Table 5. Respondents' Assessment of RDC in terms of Reliability

Indicators	WM	Description	Interpretation
1. RDC reports are consistent across successive data sets.	3.43	*Agree*	*Generally Reliable*
2. I consider the assessments provided by RDC experts to be reliable.	3.38	*Agree*	*Generally Reliable*
3. The data transmitted to the RDC is complete	3.38	*Agree*	*Generally Reliable*
4. There are few instances of false alarms or inaccurate readings.	3.35	*Agree*	*Generally Reliable*
5. RDC findings align with observed equipment conditions onboard.	3.35	*Agree*	*Generally Reliable*
OVERALL WEIGHTED MEAN	**3.38**	***Agree***	***Generally Reliable***

Legend: 3.50 – 4.00 — Strongly Agree (Highly Reliable); 2.50 – 3.49 — Agree (Generally Reliable); 1.50 – 2.49 — Disagree (Occasionally Reliable); 1.00 – 1.49 — Strongly Disagree (Not Reliable at All)

These findings directly answer Research Question 1.3 (Reliability), showing that while respondents view the RDC as dependable, its perceived reliability has not yet reached the Highly Reliable level.

From the Technology Acceptance Model (TAM), respondents perceive the RDC as reliable enough to encourage adoption, but occasional mismatches prevent stronger behavioural intent. From the Diffusion of Innovations (DOI) perspective, the system shows relative advantage and compatibility, but gaps in consistency limit observability, which slows its adoption as a fully dependable decision-making tool.

The highest-rated item, "RDC reports are consistent across successive data sets" (WM = 3.43), indicates strong trust in the stability of data readings. By contrast, the lowest-rated indicators—false alarms and alignment with onboard conditions (both WM = 3.35)—suggest occasional discrepancies between shore-based diagnostics and real-time shipboard observations. This reflects a general appreciation for the RDC's consistency but also cautiousness in fully relying on it.

These findings align with IMO (2021) and ICS (2023), which emphasize that reliability is critical for building seafarers' trust in remote systems. NYK Line (2022) also notes that its internal verification process ensures reports undergo expert review before transmission, a practice reflected in the respondents' favorable ratings of data consistency.

Nonetheless, the absence of any indicator in the Highly Reliable range underscores an important gap. Ahola et al. (2021) reported that inconsistencies in diagnostic outputs can create technostress or hesitation, especially when feedback does not match officers' firsthand observations. Theotokatos et al. (2022) further highlighted that in multicultural crews, variations in interpretation and language clarity may reduce perceived reliability even when the data is technically sound. Similarly, Mallam et al. (2020) stressed that user trust in automated systems grows with consistent, context-rich outputs but erodes when misalignment with operational realities occurs.

Overall, while the RDC is regarded as a reliable support tool, occasional discrepancies and communication barriers limit its full acceptance as a highly dependable system.

Ease of Use

Table 6 presents the respondents' assessment of the RDC in terms of ease of use. All indicators received weighted means between 3.31 and 3.37, with an overall weighted mean of 3.34, interpreted as Generally Easy to Use. This indicates that engine management-level officers find the RDC reports accessible, understandable, and reasonably user-friendly.

Table 6. Respondents' Assessment of RDC in terms of Ease of Use

Indicators	WM	Description	Interpretation
1. The RDC reports are easily accessible onboard.	3.37	*Agree*	*Generally Easy to Use*
2. The coordination with the RDC team for clarifications is easy.	3.36	*Agree*	*Generally Easy to Use*
3. The report format is user-friendly.	3.34	*Agree*	*Generally Easy to Use*
4. The content of the reports requires minimal effort to understand.	3.33	*Agree*	*Generally Easy to Use*
5. The reports can be integrated smoothly into daily routines.	3.31	*Agree*	*Generally Easy to Use*
OVERALL WEIGHTED MEAN	**3.34**	***Agree***	***Generally Easy to Use***

Legend: 3.50 – 4.00 — Strongly Agree (Very Easy to Use); 2.50 – 3.49 — Agree (Generally Easy to Use); 1.50 – 2.49 — Disagree (Somewhat Difficult to Use); 1.00 – 1.49 — Strongly Disagree (Very Difficult to Use)

These findings directly answer Research Question 1.4 (Ease of Use), indicating that while the RDC is generally considered user-friendly, it is not yet perceived as very easy to use or seamlessly integrated into officers' daily routines.

From the Technology Acceptance Model (TAM), officers perceive the RDC as easy to use, but the lack of seamless integration into daily routines limits stronger behavioural intent to rely on it consistently. From the Diffusion of Innovations (DOI) perspective, the system demonstrates compatibility and relative advantage, yet weak trialability and limited embedding in workflows slow its full adoption in engine operations.

The highest-rated item, "The RDC reports are easily accessible onboard" (WM = 3.37), confirms that officers do not encounter major issues retrieving or viewing the reports, reflecting the system's technical availability across NYK vessels. In contrast, the lowest-rated item, "The reports can be integrated smoothly into daily routines" (WM = 3.31), suggests gaps in embedding RDC outputs into everyday workflows.

These results are consistent with ICS (2023), which stresses that user-centered digital systems must support rather than disrupt operational duties. DNV (2023) similarly advocates for diagnostic tools to prioritize simplicity and navigability, particularly for multicultural crews in demanding environments. NYK has attempted to address usability concerns through standardized templates and formatting (NYK Line, 2022), though these efforts appear only moderately effective given the uniform but modest ratings.

The lack of any Very Easy to Use ratings (≥ 3.50) implies further optimization is needed. Mallam, Nazir, and Renganayagalu (2020) caution that even well-designed systems may fail if not aligned with seafarers' operational rhythms, which may explain the lower score for daily routine integration. Likewise, Ahola et al. (2021) describe technostress as a barrier when digital tools are not fully embedded in workflow, a factor that may also account for the slightly reduced ease-of-use perception among some respondents.

Influence of RDC Reports on the Decision-Making Process of the Respondents

Table 7 shows that the respondents perceive the RDC as a moderately influential factor in their operational decision-making. Weighted means ranged from 3.32 to 3.37, with an overall weighted mean of 3.35, interpreted as Moderately Influences Decisions. This indicates that while the RDC provides relevant information that supports engine-related decisions, it does not serve as the sole basis for them.

Table 7. Influence of RDC Reports on Respondents' Decision-Making

Indicators	WM	Description	Interpretation
1. The RDC strengthens data-based decision-making onboard.	3.37	*Agree*	*Moderately Influences Decisions*
2. I consult RDC reports before making major engine-related decisions.	3.36	*Agree*	*Moderately Influences Decisions*
3. I adjust engine parameters based on RDC insights.	3.36	*Agree*	*Moderately Influences Decisions*
4. I use RDC reports to verify onboard readings.	3.32	*Agree*	*Moderately Influences Decisions*
5. I rely on RDC trends when planning maintenance interventions.	3.32	*Agree*	*Moderately Influences Decisions*
OVERALL WEIGHTED MEAN	**3.35**	***Agree***	***Moderately Influences Decisions***

Legend: 3.50 – 4.00 — Strongly Agree (Strongly Influences Decisions); 2.50 – 3.49 — Agree (Moderately Influences Decisions); 1.50 – 2.49 — Disagree (Slightly Influences Decisions); 1.00 – 1.49 — Strongly Disagree (Does Not Influence Decisions).

These results directly answer Research Question 2, which asked how RDC information influenced officers' decision-making. The findings confirm that while the RDC supports evidence-based judgments, it is not yet regarded as decisive or indispensable.

From the Technology Acceptance Model (TAM), this reflects that while officers perceive RDC reports as useful for decision support, this perception has not generated strong behavioral intent to fully depend on them, as experiential judgment remains dominant. From the Diffusion of Innovations (DOI) perspective, the RDC shows relative advantage by supporting evidence-based choices, but limited observability and trialability—due to contextual gaps in reports—slow its adoption as a decisive tool in operational decisions.

The highest-rated indicator, "The RDC strengthens data-based decision-making onboard" (WM = 3.37), highlights the system's role in complementing officers' judgment with objective diagnostics. Likewise, consulting reports before major decisions and adjusting engine parameters based on RDC inputs (both WM = 3.36) indicate that officers recognize the value of RDC insights as credible, actionable data. However, the slightly lower ratings for verifying onboard readings and planning maintenance interventions (both WM = 3.32) suggest that experiential knowledge and direct inspections remain prioritized.

This pattern reflects Perera et al. (2019), who argued that decision-support systems are most effective when fully integrated into user workflows rather than treated as optional. Kristiansen (2022) likewise noted that diagnostic centers enhance fault detection and reduce error likelihood when officers are trained to interpret digital outputs alongside physical inspections. Similarly, the IMO (2021) promotes remote monitoring tools as enablers of timely, evidence-based decisions, but stresses the need to align them with established safety and performance protocols.

The lack of any indicator in the Strongly Influences range (≥ 3.50) illustrates why officers remain cautious about full reliance on shore-based diagnostics. This caution stems from their reliance on professional experience and contextual awareness, which they consider indispensable. As noted in Theotokatos et al. (2022) and Zhang et al. (2024), ambiguities in remote diagnostic reports, language barriers, and limited contextual annotations can also reduce trust in such systems. Officers' own enhancement suggestions — such as expanding equipment coverage (auxiliaries, LNG and gas monitoring), integrating navigation data, and maximizing Unmanned Machinery Space (UMS) features — reflect their view that the RDC must evolve to become a more comprehensive and indispensable decision-making tool.

RDC Contributions to Engine Operations Onboard

This section presents how the Remote Diagnostic Center (RDC) contributes to engine operations onboard NYK vessels, particularly in relation to troubleshooting and maintenance activities. Insights gathered from the respondents reveal the practical value of RDC-generated reports in identifying abnormalities, planning corrective actions, and supporting condition-based interventions. The results help determine the extent to which the RDC system enhances shipboard efficiency and operational responsiveness.

Troubleshooting

As presented in Table 8, all indicators related to troubleshooting were rated within the Moderately Helpful range, with weighted means between 3.30 and 3.37 and an overall weighted mean of 3.33. This indicates that respondents generally perceive the RDC as a supportive tool in addressing engine-related issues, though not yet at the level of being considered Extremely Helpful.

Table 8. Contribution of RDC to Engine Operations Onboard in terms of Troubleshooting

TROUBLESHOOTING	WM	Description	Interpretation
1. The RDC supports the identification of engine abnormalities.	3.37	*Agree*	*Moderately Helpful*
2. The RDC helps detect malfunctioning components quickly.	3.34	*Agree*	*Moderately Helpful*
3. The RDC aids in planning corrective actions.	3.34	*Agree*	*Moderately Helpful*
4. The RDC allows troubleshooting without the need for additional tests.	3.31	*Agree*	*Moderately Helpful*
5. The RDC shortens the time needed for issue investigation.	3.30	*Agree*	*Moderately Helpful*
OVERALL WEIGHTED MEAN	**3.33**	***Agree***	***Moderately Helpful***

Legend: 3.50 – 4.00 — Strongly Agree (Extremely Helpful); 2.50 – 3.49 — Agree (Moderately Helpful); 1.50 – 2.49 — Disagree (Slightly Helpful); 1.00 – 1.49 — Strongly Disagree (Not Helpful at All)

These findings directly answer Research Question 3.1 (Troubleshooting), confirming that the RDC assists in fault identification and guides corrective action, but has not yet reached the level of being indispensable for onboard troubleshooting.

Through the lens of the Technology Acceptance Model (TAM), officers recognize the RDC's usefulness in identifying abnormalities, but the need for manual verification weakens behavioural intent for full reliance. From the Diffusion of Innovations (DOI) viewpoint, the system demonstrates relative advantage in fault detection, yet its limited trialability and partial compatibility with existing troubleshooting practices slow its deeper adoption.

The highest-rated item, "The RDC supports the identification of engine abnormalities" (WM = 3.37), highlights its strength in early fault detection, a critical aspect of proactive maintenance. Similar ratings for detecting malfunctioning components and planning corrective actions (both WM = 3.34) reinforce its role in providing actionable data for initial responses to technical issues. By contrast, lower scores for troubleshooting without additional tests (WM = 3.31) and for shortening investigation time (WM = 3.30) suggest that engineers often still require manual verification and supplementary diagnostics, limiting the RDC's impact on efficiency.

These findings are consistent with Fischer et al. (2020), who noted that remote diagnostics reduce emergency repairs but depend heavily on reliability and crew confidence. Berg et al. (2023) similarly emphasized that RDC effectiveness in troubleshooting requires integration into existing maintenance protocols and two-way communication with onboard personnel. From NYK's perspective, RDC alerts are reviewed by experts before release to vessels, ensuring quality but reinforcing a collaborative rather than fully automated diagnostic model (NYK Line, 2022).

The "Moderately Helpful" ratings also echo broader concerns in the literature. Theotokatos et al. (2022) and Ahola et al. (2021) pointed out that inconsistent reporting formats, information overload, and lack of contextual detail can extend troubleshooting time. Zhang et al. (2024) further highlighted how ambiguity and linguistic inconsistencies reduce trust in digital diagnostics, particularly within multicultural crew environments such as those in NYK's global fleet.

Maintenance and Repair

Table 9 presents the respondents' evaluation of the RDC in terms of maintenance and repair, with an overall weighted mean of 3.34, interpreted as Moderately Supports Maintenance. All indicators fell within this category, indicating that while the RDC is considered helpful in managing maintenance tasks, it is not yet perceived as highly essential.

Table 9. Contribution of RDC to Engine Operations Onboard in terms of Maintenance and Repair

MAINTENANCE AND REPAIR	WM	Description	Interpretation
1. The RDC improves the scheduling of overhauls and inspections.	3.36	*Agree*	*Moderately Supports Maintenance*
2. The RDC encourages condition-based maintenance practices.	3.36	*Agree*	*Moderately Supports Maintenance*
3. The RDC supports my decisions in the Planned Maintenance System (PMS).	3.35	*Agree*	*Moderately Supports Maintenance*
4. The RDC helps verify the success of recent repairs.	3.32	*Agree*	*Moderately Supports Maintenance*
5. The RDC contributes to reducing emergency repair incidents.	3.31	*Agree*	*Moderately Supports Maintenance*
OVERALL WEIGHTED MEAN	**3.34**	***Agree***	***Moderately Supports Maintenance***

Legend: 3.50 – 4.00 — Strongly Agree (Strongly Supports Maintenance); 2.50 – 3.49 — Agree (Moderately Supports Maintenance); 1.50 – 2.49 — Disagree (Slightly Supports Maintenance); 1.00 – 1.49 — Strongly Disagree (Does Not Support Maintenance)

These findings directly answer Research Question 3.2 (Maintenance and Repair), confirming that while the RDC is perceived as valuable for maintenance planning, its contribution remains supplementary to traditional practices.

Applying the Technology Acceptance Model (TAM), these findings indicate that while the RDC is perceived as useful in supporting PMS and condition-based planning, this perception has not built strong behavioural intent to treat it as indispensable. From the Diffusion of Innovations (DOI) framework, the RDC offers relative advantage in optimizing maintenance, but limited observability of repair outcomes and partial compatibility with established routines hinder faster adoption.

The highest-rated indicators — "The RDC improves the scheduling of overhauls and inspections" and "The RDC encourages condition-based maintenance practices" (both WM = 3.36) — emphasize the RDC's role in shifting from time-based routines toward condition-based maintenance. This aligns with DNV (2023) and Fischer et al. (2020), who documented the efficiency and cost savings of condition-based approaches enabled by real-time diagnostics.

Similarly, "The RDC supports my decisions in the Planned Maintenance System (PMS)" (WM = 3.35) reflects its integration into structured maintenance programs. NYK Line (2022) reports that RDC insights have led to adjustments in PMS intervals and prioritization of equipment, enabling more efficient resource allocation.

Lower scores for "The RDC helps verify the success of recent repairs" (WM = 3.32) and "The RDC contributes to reducing emergency repair incidents" (WM = 3.31) indicate that engineers continue to rely more on direct inspection and onboard monitoring when confirming repair outcomes or preventing

failures. This mirrors the concerns of

Theotokatos et al. (2022) and Ahola et al. (2021), who noted that ambiguity, reporting delays, and lack of contextual clarity reduce confidence in remote diagnostics. Zhang et al. (2024) further cautioned that unless diagnostic systems are fully embedded into maintenance routines and reinforced by user training, they will remain supplementary rather than indispensable.

Challenges Experienced by the Respondents in Integrating RDC Information into Engine Department Operations

Table 10 shows the challenges encountered by engine management-level officers in integrating RDC information into shipboard operations. The overall weighted mean of 1.64 falls under the Disagree category, indicating that such challenges were rarely experienced onboard.

Table 10. Challenges Experienced in Integrating RDC to Engine Operations Onboard

Challenge Statements	WM	Description	Interpretation
1. I experience delays in receiving RDC reports.	1.69	*Disagree*	*The challenge is rarely experienced.*
2. I notice occasional mismatches between onboard readings and RDC data.	1.65	*Disagree*	*The challenge is rarely experienced.*
3. I find it difficult to apply RDC content to actual engine operations.	1.64	*Disagree*	*The challenge is rarely experienced.*
4. Some terms in the reports are overly technical.	1.63	*Disagree*	*The challenge is rarely experienced.*
5. Connectivity issues sometimes delay report delivery.	1.61	*Disagree*	*The challenge is rarely experienced.*

Legend: 3.50 – 4.00 — Strongly Agree (The challenge is frequently experienced); 2.50 – 3.49 — Agree (The challenge is occasionally experienced); 1.50 – 2.49 — Disagree (The challenge is rarely experienced); 1.00 – 1.49 — Strongly Disagree (The challenge is not experienced)

These findings directly answer Research Question 4, which asked about the challenges faced by officers in integrating RDC information into engine operations. Results confirm that challenges are minimal and only rarely encountered.

Within the Technology Acceptance Model (TAM), the rarity of reported challenges reflects high perceived ease of use, yet occasional issues still reduce behavioral intent for stronger reliance. From the Diffusion of Innovations (DOI) perspective, the RDC is largely compatible with workflows, but minor mismatches and technical jargon reveal weak trialability among diverse crews, which may slow uniform adoption

The two highest-rated items — delays in receiving RDC reports (WM = 1.69) and occasional mismatches with onboard readings (WM = 1.65) — hint at sporadic connectivity limitations or calibration issues, which are common in maritime digital systems. DNV (2023) and Fischer et al. (2020) emphasize that transmission quality and sensor reliability are critical for effective diagnostics. With the rollout of Starlink across NYK vessels, such delays are expected to be further minimized through faster, more stable data transmissions.

Meanwhile, "difficulty applying RDC content" (WM = 1.64) and "technical terms in reports" (WM = 1.63) suggest that while most officers easily interpret the reports, a minority still encounter cognitive or operational barriers. Ahola et al. (2021) described this as technostress, when users feel overwhelmed by complex digital outputs. Theotokatos et al. (2022) similarly warned that inconsistent formatting and technical jargon can hinder usability, especially for multinational crews.

The lowest-rated challenge, "connectivity issues" (WM = 1.61), reflects NYK's robust digital upgrades such as IoS-OP, SIMS, and Starlink integration (NYK Line, 2022; ClassNK, 2024), which ensure reliable remote monitoring.

Although these issues are rare, scholars caution against disregarding them. Fischer et al. (2020) and DNV (2023) highlight that even low-frequency mismatches or delays can affect decision-making if left unresolved. Ahola et al. (2021) and Theotokatos et al. (2022) likewise stress the importance of clear, standardized reporting to avoid hesitation in high-pressure conditions. Thus, while challenges appear minimal, continuous improvements remain essential for full integration.

Respondents' Proposed Enhancements to RDC

Respondents suggested the following improvements to expand the RDC's functionality and coverage:

The respondents suggested several improvements to expand the RDC's functionality and coverage. These recommendations were categorized into three key areas:

Expanded Equipment Scope

The study's finding of a moderate influence on decision-making suggests that officers still rely heavily on their own experience before finalizing actions. This reliance may partly stem from the system's current monitoring being limited to select machinery and parameters. Respondents recommended expanding coverage to include auxiliary machinery, LNG tanks, and gas monitoring, as well as integrating navigational systems for a more holistic view of vessel operations. The inclusion of Unmanned Machinery Space (UMS) data was also proposed to strengthen diagnostics and support proactive interventions. These enhancements reflect the view that RDC data will only become indispensable when it comprehensively captures the vessel's operational environment.

Broader Vessel Coverage

RDC monitoring is not yet applied to all NYK vessels, which limits its perceived necessity in fleet-wide decision-making. Respondents emphasized extending RDC services to the entire fleet, with particular attention to LNG-powered vessels. This aligns with global industry trends, as the International Gas Union (IGU, 2024) reports steady growth in LNG-fueled ship orders. NYK itself has expanded its LNG carrier fleet in recent years, positioning LNG as a key transitional fuel for decarbonization. Broader RDC coverage would ensure consistent operational oversight across vessel types and enhance NYK's ability to leverage remote diagnostics in this critical sector.

Operational Improvements

Despite RDC's proven reliability, the absence of round-the-clock monitoring was seen as limiting its integration into urgent operational decisions. Respondents recommended implementing 24/7 RDC watchkeeping to ensure continuous oversight and immediate feedback. Real-time responsiveness is particularly important for addressing machinery anomalies and safety-related events. This proposal is consistent with industry best practices in shore-based fleet monitoring, where uninterrupted diagnostics reduce response times and help prevent the escalation of technical issues.

These recommendations directly answer Research Question 5, which asked what enhancements to the RDC could be proposed. Collectively, they highlight the need to expand equipment scope, broaden vessel coverage, and strengthen real-time operational support so that the RDC can evolve from a supportive system to an indispensable decision-making tool.

Conclusion

This study concludes that while the Remote Diagnostic Center (RDC) is integrated into NYK's operational framework and regularly used by Chief Engineers and Second Engineers, it functions more as a supplementary tool than as the primary driver of shipboard decision-making. Despite RDC training and familiarity with the system, officers continue to rely heavily on their knowledge, judgment, and extensive sea experience—a reliance reinforced by the demographic profile showing long years of service, particularly among Chief Engineers.

Evaluation across usefulness, clarity, reliability, and ease of use produced consistent positive ratings, yet none reached the highest category. The RDC supports maintenance planning, trend detection, anomaly identification, and condition-based maintenance, but its moderate influence underscores that experiential decision-making still outweighs system-driven recommendations. From the Technology Acceptance Model (TAM) perspective, this reflects adequate perceived usefulness and ease of use, but insufficient behavioral intent for full reliance. Viewed through the Diffusion of Innovations (DOI) framework, the RDC demonstrates relative advantage and compatibility with existing practices, but adoption remains gradual due to limited observability, trialability, and entrenched reliance on traditional methods.

The study further concludes that enhancements—such as expanding equipment scope (auxiliary and LNG systems, UMS integration), broadening vessel coverage across NYK's fleet, and implementing 24/7 monitoring—would strengthen the RDC's real-time responsiveness and operational value. Coupled with structured change management and ongoing user training, these measures could shift the RDC from a supportive tool to an indispensable operational asset, enabling NYK to maximize remote diagnostics for safer, more efficient, and future-ready fleet performance.

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