



Analisis Pola Downtime untuk Optimalisasi Strategi Perawatan Sistem Navigasi Kapal (Studi Kasus: PT. Pawitra Daya Teknik)

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Article Info	Abstrak
Kata kunci: Downtime; Perawatan Pretentive; Sisten Navigasi Kapal; MTTR MTBF	Penelitian ini menganalisis pola <i>downtime</i> sistem navigasi kapal untuk merumuskan strategi perawatan preventif yang optimal dalam upaya peningkatan efisiensi operasional. Studi kasus dilakukan di PT Pawitra Daya Teknik menggunakan data historis 113 <i>work order</i> dari 11 kapal periode Desember 2025–Februari 2026. Metode meliputi analisis deskriptif, perhitungan MTTR, MTBF, <i>availability</i>, uji distribusi statistik (Minitab), fungsi reliabilitas eksponensial, model <i>age replacement</i>, serta perbandingan biaya skenario reaktif dan preventif. Hasil menunjukkan Radar dan GPS merupakan sistem paling kritis (kontribusi durasi >59%) dengan kerusakan <i>software</i> sebagai penyebab utama (42%). Interval perawatan preventif optimal dirumuskan secara diferensiasi: Radar dan GPS dirawat lebih sering (masing-masing setiap 260 jam dan 410 jam), sementara sistem lain dirawat lebih jarang. Strategi ini menurunkan <i>downtime</i> tahunan hingga 21,6%, meningkatkan <i>availability</i> sebesar 0,26%, serta menghasilkan penghematan biaya operasional sekitar Rp409 juta per tahun. Kesimpulannya, strategi perawatan preventif berbasis target reliabilitas 60% terbukti optimal secara teknis dan ekonomis.
Keywords: Downtime; Pretentive Maintenance; Ship Navigation System; MTTR; MTBF	Abstract <i>This study analyzes the downtime patterns of ship navigation systems to formulate an optimal preventive maintenance strategy to improve operational efficiency. A case study was conducted at PT Pawitra Daya Teknik using historical data of 113 work orders from 11 ships during December 2025–February 2026. Methods include descriptive analysis, MTTR, MTBF, availability calculations, statistical distribution testing (Minitab), exponential reliability function, age replacement model, and cost comparison between reactive and preventive scenarios. Results show that Radar and GPS are the most critical systems (contribute >59% of downtime duration) with software failures as the main cause (42%). The optimal preventive maintenance intervals are differentiated: Radar and GPS are serviced more frequently (every 260 hours and 410 hours, respectively), while other systems are serviced less often. This strategy reduces annual downtime by 21.6%, increases availability by 0.26%, and generates operational cost savings of approximately IDR 409 million per year. In conclusion, the preventive maintenance strategy based on a 60% reliability target is proven to be technically and economically optimal.</i>

1. PENDAHULUAN

PT Pawitra Daya Teknik is a contractor company engaged in the installation, maintenance, and repair of ship systems, especially navigation systems. During the maintenance process, the company often experiences equipment downtime that disrupts operational schedules and incurs financial losses for both the service provider and ship owners. Downtime in this study is defined as the period during which the ship's navigation equipment cannot operate normally until repairs are completed, accumulated from several ships handled during the maintenance and commissioning period.

Based on historical data from December 2025 to February 2026, 113 work orders were recorded with a total downtime of 241 hours across 11 ships (6 cruise ships, 3 ASD tug boats, and 2 logistics ships). Radar contributed 38% of total downtime, GPS 21%, and software failures accounted for 42% of the duration. The main problem identified is the lack of systematic analysis of downtime patterns. The vendor tends to be reactive in handling failures without understanding the root causes. Some breakdowns could not be resolved directly at the work site (unfinished cases) due to limited spare parts or non-standard procedures. The impact of downtime is not only felt by the vendor (waste of resources, decreased profitability, reputation) but also by ship owners (operational losses, penalties, navigation safety risks). To address these issues, this study aims to: (1) determine the characteristics and patterns of ship navigation system downtime, (2) identify the most influential factors on the frequency and duration of downtime, and (3) formulate an optimal preventive maintenance strategy to reduce downtime and improve operational efficiency.

This research uses quantitative methods including Mean Time To Repair (MTTR), Mean Time Between Failure (MTBF), availability analysis, exponential reliability function, age replacement model, and cost comparison between reactive and preventive scenarios. The results are expected to provide strategic recommendations for preventive maintenance scheduling, standard repair procedures, and spare parts management.

2. METHODS

This research was conducted at PT Pawitra Daya Teknik from December 2025 to February 2026. The object of the study is the navigation system maintenance activities of 11 ships (6 cruise ships, 3 ASD tug boats, and 2 logistics ships). The navigation systems analyzed include Radar, GPS, AIS, Steering Gear, Echo Sounder, ECDIS, and Autopilot.

The data collection techniques comprised: (1) primary data – interviews with 2 operational managers and 4 technicians, (2) secondary data – 113 work orders, technician logbooks, monthly reports, technical manuals, and standard operating procedures. All data were verified for completeness and validity; no incomplete data or unfinished repairs were found.

The data processing methods are as follows:

- Descriptive analysis – tabulation of downtime frequency and duration per system and per damage category (software, hardware, connection).
- MTTR calculation – $MTTR = \sum \text{repair duration} / n$.
- MTBF calculation – $MTBF = \text{total operating hours (20,240 hours period, 80,300 hours annual projection for 11 ships)} / \text{number of failures per system}$.
- Availability – $\text{Availability} = MTBF / (MTBF + MTTR) \times 100\%$.
- Failure rate (λ) – $\lambda = 1/MTBF$.
- Reliability function (exponential) – $R(t) = e^{-(t/MTBF)}$ for $t = 100, 500, 1000$ hours.
- Optimal preventive interval – Using the age replacement model: $t^* = MTBF \times \ln(Cc/Cp)$ with $Cp = \text{IDR } 1,200,000$ and $Cc = \text{IDR } 3,500,000$.
- Cost comparison – Comparison between reactive and preventive scenarios including maintenance costs and downtime costs (assumed IDR 5,500,000 per hour based on literature).

The statistical distribution of downtime duration was tested using the Anderson-Darling test in Minitab. Although the results varied (Radar and AIS tended to be lognormal, GPS Weibull, Steering Gear normal), the exponential distribution was assumed for reliability due to the constant failure rate in the useful life phase of electronic components.

3. RESULT AND DISCUSSION

3.1 Downtime Characteristics and Patterns

Distribution per navigation system

Radar accounts for 33.6% of cases and 38.1% of duration; GPS 22.1% of cases and 21.2% of duration; together they contribute 59.2% of total duration. Steering Gear, despite only 10.6% of cases, has 12.2% of duration due to long repair times (high MTTR). Conversely, AIS has a lower duration proportion than its case proportion, indicating quick repairs.

Distribution per damage category

Software failures dominate with 42.1% of duration, followed by hardware (35.5%) and connection issues (22.4%). This indicates that improving technician competence in firmware updates, configuration, and data synchronization will greatly impact downtime reduction.

Comparison by ship type

PELNI logistics ships have the highest average downtime per ship (30.3 hours), followed by ASD tug boats (26 hours) and cruise ships (17.1 hours). This difference is due to higher operational intensity and older ship age in the logistics and tugboat fleets.

3.2 Downtime and Reliability Metrics

MTTR

Overall MTTR = 2.13 hours. Steering Gear has the highest MTTR (2.46 hours), followed by Radar (2.35 hours) and ECDIS (2.38 hours). AIS has the lowest MTTR (1.64 hours). This shows that systems with complex calibration procedures and software dependence tend to require longer repair times.

MTBF

Radar has the shortest MTBF (519 hours $\approx$ 26 operating days), followed by GPS (810 hours) and AIS (1,065 hours). Autopilot has the longest MTBF (6,747 hours). This wide difference confirms that preventive maintenance must be differentiated, not uniform for all systems.

Availability

All systems show availability above 99.5%, but this figure is misleading because it does not reflect the accumulation of downtime on an annual and multi-ship scale. For 11 ships, total Radar downtime reaches 363 hours per year – equivalent to 15 days. Therefore, improvement efforts are still needed.

To visualize the decline in reliability over operating time, reliability curves $R(t)=e^{-t/MTBF}$ are plotted for three main systems: Radar (MTBF 519 hours), GPS (MTBF 810 hours), and AIS (MTBF 1,065 hours). The curves are presented in Figure 1.

Table 1. Reliability Values at Selected Operating Hours

System	MTBF (hours)	R(100)	R(500)	R(1000)
Radar	519	0.825	0.381	0.145
GPS	810	0.884	0.539	0.291
AIS	1,065	0.910	0.625	0.391

The figure shows that Radar (the lowest curve) has the fastest reliability decline. At $t = 500$ hours (25 operating days), the reliability of Radar is only about 38%, while GPS is 54% and AIS is 62%. The horizontal dashed line represents the 60% reliability target. Based on this target, the preventive maintenance intervals are:

- Radar: $t = 260$ hours (when $R(t) \approx 0.61$)
- GPS: $t = 410$ hours (when $R(t) \approx 0.60$)
- AIS: $t = 540$ hours (when $R(t) \approx 0.60$)

This graph reinforces that systems with shorter MTBF must be serviced more frequently to maintain reliability above the predetermined threshold.

Table 2. Recommended Preventive Maintenance Intervals (Final)

System	Interval (hours)	Interval (days) ¹	R(t)	Change from existing ²	Priority
Radar	260	13.0	0.61	2.3× more frequent	1 (highest)
GPS	410	20.5	0.60	1.5× more frequent	2
AIS	540	27.0	0.60	1.1× more frequent	3
Steering Gear	860	43.0	0.60	0.7× (less frequent)	4
Echo Sounder	1,15	57.5	0.60	0.5× (less frequent)	5
ECDIS	1,72	86.0	0.60	0.35× (less frequent)	6
Autopilot	3,45	172.5	0.60	0.17× (much less frequent)	7

¹ Assuming 20 operating hours per day.

² Existing practice: all systems serviced every ± 30 days (≈ 600 hours) without priority differentiation.

The theoretical age replacement model gave longer intervals (e.g., Radar 555 hours, GPS 867 hours, AIS 1,140 hours) with reliability only 34%, which is considered unsafe for navigation systems. Therefore, the 60% reliability target approach was adopted.

3.4 Cost Comparison and Performance Evaluation

Assuming a downtime cost of IDR 5,500,000 per hour (from literature) and considering direct maintenance costs (C_p = IDR 1,200,000, C_c = IDR 3,500,000), the comparison between reactive (existing) and preventive (proposed) scenarios is shown in Table 3.

Table 3. Cost Comparison and Performance Indicators

Indicator	Reactive	Preventive	Change
Annual downtime (hours)	955.1	748.9	-206.2 (-21.6%)
Downtime cost (million IDR)	5,253.0	4,118.7	-1,134.3
Maintenance cost (million IDR)	1,568.9	2,294.3	+725.4
Total cost (million IDR)	6,821.9	6,413.0	-408.9
Availability (%)	98.81	99.07	+0.26

The preventive strategy yields a net saving of IDR 408.9 million per year, exceeding the target of IDR 300 million. Sensitivity analysis shows that if the actual downtime cost is higher (IDR 7.5–10 million/hour), savings increase to IDR 634–1,010 million per year. The reduction in downtime also leads to a 0.26% increase in availability.

3.5 Discussion

The results of this study are in line with the findings of Widjatmoko & Widyawati (2024) that condition-based maintenance can reduce downtime by up to 30%. However, our study emphasizes differentiation of intervals based on MTBF and reliability targets, rather than real-time sensor installation. The study by Lao et al. (2025) on radar effectiveness also confirms that lack of technical training and standard procedures is a major cause of radar downtime, which corresponds with the dominance of software issues in our study.

The striking difference between the intervals for Radar (260 hours) and Autopilot (3,450 hours) shows that uniform maintenance strategies (such as the existing practice of 30 days for all systems) are very inefficient. Resources can be optimized by focusing on critical systems. Limitations of this study are the data period of only 3 months, so seasonal variations are not captured. In addition, the downtime cost assumption still requires validation with actual data from clients.

4. CONCLUSION

This study concludes that: (1) the downtime pattern of ship navigation systems is dominated by Radar and GPS with software failures as the main cause; (2) the most influential factors are short MTBF (especially for Radar and

GPS) and long MTTR (especially for Steering Gear and Radar); (3) the optimal preventive maintenance intervals are differentiated: Radar and GPS should be serviced more frequently (≈ 13 days and 20.5 days), while highly reliable systems (Autopilot) can be serviced every few months. The proposed preventive strategy reduces annual downtime by 21.6%, increases availability by 0.26%, and saves operational costs by IDR 408.9 million per year. Therefore, the preventive maintenance strategy based on a 60% reliability target is proven to be technically and economically optimal.

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