

Ship Telemetry in the Oil and Gas Industry: Architecture, Deployment Challenges, and Impacts on Operations and Efficiency

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Abstract:

Transpetro, the largest integrated hydrocarbon logistics company in Latin America, is implementing a ship telemetry program to increase operational visibility, improve maintenance planning, and support energy-performance management across its fleet. This paper presents the architecture, deployment challenges, and early applications of the program. The solution addresses the collection, standardization, transmission, historization, and use of real-time data from heterogeneous onboard systems. The architecture combines industrial gateways, OPC UA-based interoperability, edge buffering, secure satellite communications, IPsec VPN connectivity, and integration with the corporate Process Information Management System (InfoSCADA). The first implementation was carried out on the Suezmax tanker Henrique Dias and is being scaled to 25 additional vessels with different levels of instrumentation complexity. The resulting data environment supports dashboards for propulsive efficiency, main engine condition monitoring, vessel operational status, energy efficiency, and alarm management. By reducing dependence on manual data collection and improving the frequency, traceability, and quality of operational data, the project establishes a practical foundation for predictive maintenance, condition-based monitoring, and data-driven decision-making. Preliminary business-case estimates indicate relevant potential benefits in fuel efficiency, lubricant management, corrective maintenance reduction, and operational reliability, subject to progressive validation during fleet deployment.

Key words: ship telemetry, maritime automation, OPC UA, predictive maintenance, energy efficiency, decarbonization.

1. Introduction

Telemetry enables the acquisition and transmission of shipboard data in near real time and has become increasingly relevant to maritime transport. Modern vessels generate large volumes of information from navigation and machinery systems, including speed through water, depth, wind speed and direction, main engine variables, auxiliary engine data, boiler parameters, cargo-system information, and other process signals. However, these data are often distributed among independent onboard systems and are not always available for integrated onshore analysis.

When shipboard data are reliably collected, standardized, historized, and made available to shore-based teams, they improve operational monitoring, fault detection, and decision-making. Telemetry also supports logistics optimization by enabling voyage and route analysis, reducing avoidable delays, and improving the visibility of vessel status.

From a maintenance perspective, continuous monitoring of critical equipment creates the basis

for early diagnosis and timely intervention, reducing the probability and consequence of failures. When integrated with monitoring centers and corporate analytics platforms, telemetry improves service reliability, operational transparency, safety support, schedule adherence, performance follow-up, and business continuity.

2. Methodology and System Architecture

This work describes the design, development, and phased deployment of a telemetry and telecommunications infrastructure for Transpetro vessels. The implemented scope includes onboard industrial gateways, switches, servers, firewall rules, IPsec tunnels, cabling, local buffering, and integration of shipboard data with headquarters systems. The project also includes fleet-wide expansion to 26 vessels and the development of web-based dashboards for technical and managerial use.

2.1 Project Scope and Deployment

The telemetry system is based on onboard industrial gateways that collect and transmit data from main engines, auxiliary engines, navigation

systems, tank measurement systems, cargo-related systems, and other sensors associated with maintenance, operations, and energy-efficiency monitoring.

Phase I comprised the implementation on the pilot vessel Henrique Dias, a Suezmax tanker with high instrumentation complexity. This phase enabled near-real-time onboard data acquisition

and secure transmission to Transpetro headquarters in Rio de Janeiro. Phases II, III, and IV comprise the expansion of the solution to 25 additional vessels, including crude oil tankers, product carriers, and gas carriers with different levels of automation and instrumentation. These phases also include the progressive development of dashboards, data-governance routines, and operational-efficiency use cases.

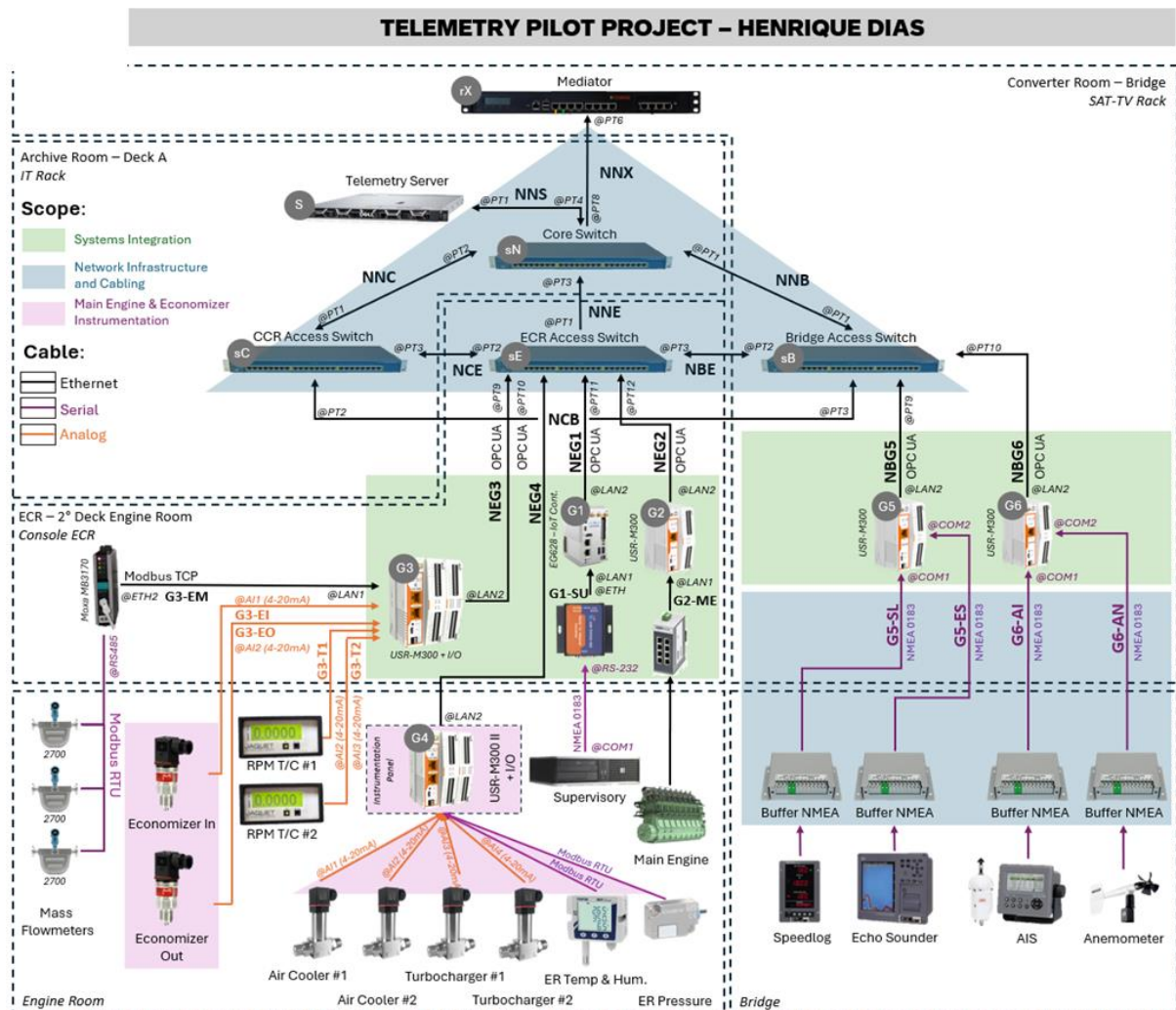


Fig. 1. Vessel telemetry system diagram.

2.2 Onboard Data Sources and Network Infrastructure

The onboard architecture integrates systems distributed across the bridge, engine control room, and cargo control room. Typical data sources include AIS, echo sounder, speed log, and anemometer on the bridge; main engine control system, supervisory system, fuel-flow metering, and auxiliary machinery signals in the engine control room; and level gauging and

cargo-handling systems in the cargo control room.

Programmable Automation Controllers (PACs) execute control logic and act as communication gateways, including protocol conversion from legacy or proprietary interfaces to OPC UA [4]. PACs interface with distributed I/O modules and sensors and provide data through a client-server architecture, typically acting as OPC UA servers while the telemetry server operates as an OPC UA client. Depending on the subsystem,

interfaces range from analog 4–20 mA loops to serial and Ethernet-based industrial communication protocols.

The onboard telemetry network topology is based on one core switch and three access switches installed in key operational areas of the vessel. This arrangement reduces cabling length, improves maintainability, and facilitates future expansion.

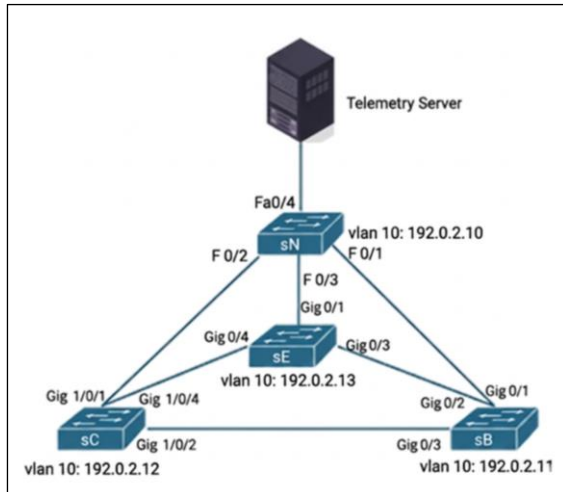


Fig. 2. Local network infrastructure.

Redundant-star topology principles are adopted to improve availability and fault tolerance, allowing rapid recovery in the event of a link or node failure. This reduces communication downtime, which is particularly relevant in maritime environments where physical access for maintenance may be limited.

CAT6A Ethernet cabling was selected to reduce the effects of electromagnetic interference (EMI), which is common in ship environments due to high-power equipment, machinery spaces, and long cable runs. The cabling choice also supports higher bandwidth and improved signal integrity.

To address the heterogeneous nature of onboard systems, the architecture prioritizes openness, flexibility, and scalability. The selected gateways support multiple physical interfaces, including 4–20 mA, RS-422, RS-485, and Ethernet, and a wide range of communication protocols, including OPC UA, MQTT, Modbus TCP, Modbus RTU, NMEA, BACnet, and native drivers for PLC platforms such as Siemens, Delta, Omron, and Mitsubishi. This design enables integration of legacy and modern systems while reducing vendor lock-in and facilitating future expansion.

Centralized tag management is enabled by normalizing incoming data into the OPC UA protocol. This unified data model simplifies

integration with the telemetry platform and improves maintainability, scalability, and consistency of the overall system. The approach is also aligned with broader maritime data-standardization principles [2,3].

2.3 Telemetry Server and Edge Buffering

The telemetry server hosts the Industrial Gateway Server (IGS), which interfaces with more than 100 industrial communication protocols. In this architecture, IGS operates primarily as an OPC UA client, selected for its security features, robustness, and suitability for structured industrial data exchange when compared with older OPC DA implementations.

In addition to protocol integration, the telemetry server hosts a GE Proficy Historian Collector responsible for acquiring real-time data from IGS, buffering them locally, and transmitting them to the central historian when communication is available. This store-and-forward strategy preserves data during temporary communication outages, a common condition in maritime satellite links, and reduces the risk of data loss.

The collector maintains a configurable local buffer that stores time-series data whenever connectivity to the central historian is unavailable. During such periods, acquisition continues, and buffered data retain their original timestamps. Once communication is restored, data are transmitted sequentially to the central historian, preserving consistency and temporal integrity.

The sampling rate of each tag is defined individually according to the dynamics and criticality of the monitored process. These parameters are configured from the onshore historian environment, allowing remote adjustment without onboard intervention.

To optimize bandwidth and storage, deadband or exception-based reporting is applied at tag level. Within the GE Proficy Historian architecture, compression is implemented at two levels: collector-level compression at the edge and archive-level compression in the central historian.

At collector level, compression acts as a deadband filter by discarding incoming values that do not exceed a configured magnitude threshold. This reduces the volume of data transmitted over constrained links, such as VSAT, while preserving relevant process variations.

At archive level, a second compression stage is applied after ingestion using a rate-of-change algorithm, commonly known as swinging-door

compression. This method evaluates signal trends and retains only the points that represent significant directional changes, reducing redundant data while maintaining time-series fidelity.

Together, these two compression stages provide a balance between data fidelity, bandwidth optimization, and storage efficiency, which is essential for large-scale maritime telemetry.

2.4 Communication and Cybersecurity Architecture

The vessel-to-shore communication layer includes a mediator implemented as a hybrid firewall-router solution for managing communication between two satellite links: VSAT and LSAT. The mediator performs traffic routing, load balancing, failover control, and Quality of Service (QoS) enforcement between the onboard LAN and external WAN links. VSAT

is currently the baseline path for telemetry traffic because this traffic must comply with applicable information-security requirements and contractual routing constraints. Under the current contract, the VSAT service uses gateways located in Brazil, presently in São Paulo State.

In telemetry applications, the predominant data flow is ship-to-shore, although all communication remains governed by network policies and segmentation rules. The mediator manages communication by application, service, protocol, IP address, and port, thereby supporting secure bandwidth allocation and efficient use of the hybrid communication infrastructure. Secure transfer to the corporate environment is provided through IPsec VPN tunnels and firewall security layers, consistent with industrial cybersecurity principles [5].

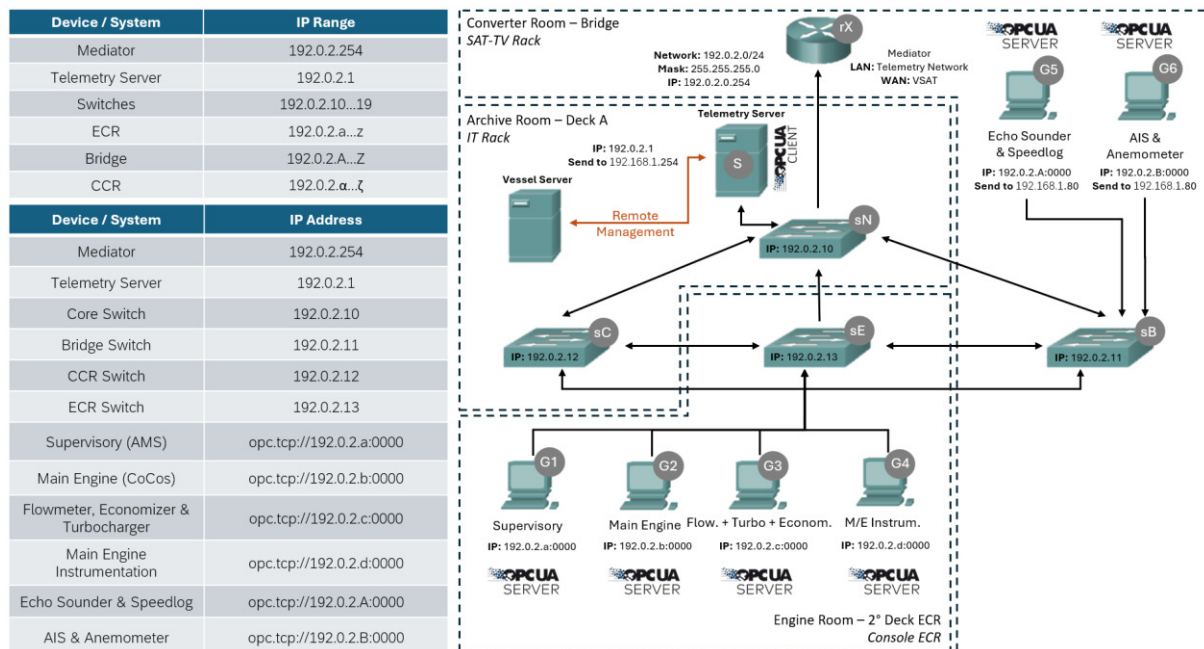


Fig. 3. Vessel telemetry system automation network.

2.5 Corporate Integration through PIMS

Given the wide geographic distribution of Transpetro's operations, the project required a centralized environment capable of aggregating process data from terminals and vessels and making them accessible to corporate users. This requirement is met through InfoSCADA, Transpetro's Process Information Management System (PIMS), which currently supports up to 320,000 tags and enables large-scale process-data acquisition and historization.

Maintenance is one of the areas expected to benefit most from this integration. Improved

access to process data and continuous monitoring of variables such as pressure, flow, temperature, and operating status strengthen the ability of maintenance teams to perform preventive and predictive analyses across onshore facilities and the maritime fleet. The data models are being progressively expanded to support advanced analytics, anomaly detection, and condition-based monitoring.

3. Results and Applications

Based on this infrastructure, real-time web dashboards have been developed and are being continuously improved to provide visibility of vessel performance and operational key

performance indicators. These dashboards combine live telemetry streams with historical data and are designed to support monitoring, analysis, anomaly identification, and decision-making in an accessible and scalable web environment.

The main analytical outputs currently associated with the project are:

- Propulsive efficiency: assessment of hydrodynamic and propulsive performance under environmental and operational conditions, aligned with ISO 15016 [1];
- Main engine condition monitoring: time-series analysis of fuel consumption, rotational speed,

cylinder performance, pressures, and temperatures.

- Vessel operational status: consolidated visualization of navigation data, auxiliary systems, boilers, pumps, and fuel-related conditions.
- Energy efficiency: monitoring of fuel consumption, lubricant usage, and emissions-related indicators.
- Alarm management: tracking of alarm frequency, duration, Mean Time to Repair (MTTR), and Mean Time Between Failures (MTBF).

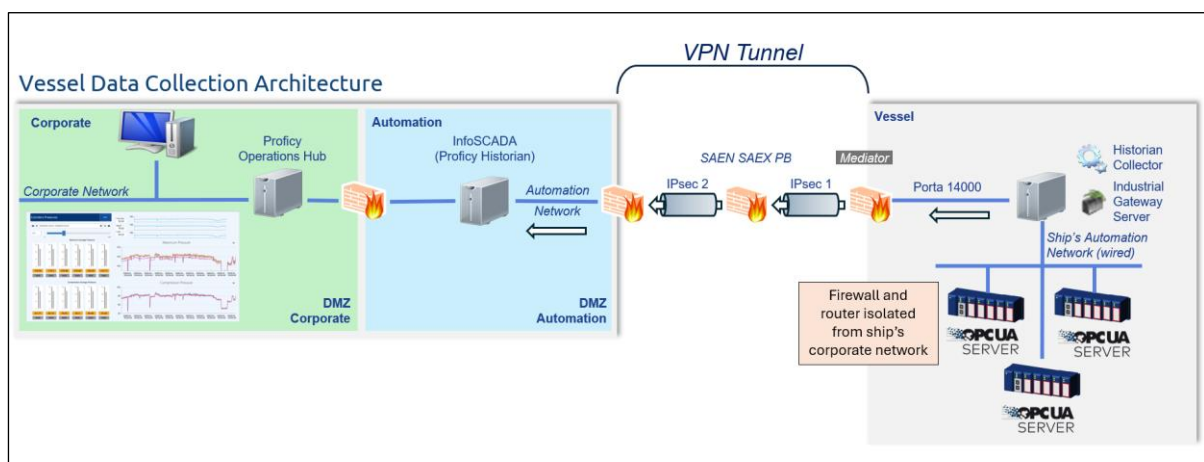


Fig. 4. Ship telemetry data acquisition and transmission architecture.

4. Discussion

The implementation of the telemetry system established an integrated data pipeline from onboard acquisition to onshore analysis, creating a practical foundation for data-driven maintenance and energy optimization. A major deployment challenge was that telemetry infrastructure had not been considered in the original vessel design. The solution therefore had to be retrofitted into mature operating assets with heterogeneous and historically isolated systems.

Interoperability was addressed through an OPC UA-oriented architecture supported by protocol-conversion gateways. Cybersecurity and communication reliability were addressed through segmented networks, IPsec VPN tunneling, local buffering, traffic control, and controlled transmission over satellite links. These elements are particularly important in maritime applications, where bandwidth constraints and intermittent connectivity are operational realities.

From a maintenance perspective, the solution increases the availability of trustworthy process data, reduces reliance on manual data collection, and accelerates the identification of anomalous operating patterns. From an operational perspective, the same architecture supports broader visibility of vessel performance and creates a foundation for future applications in advanced analytics, artificial intelligence, and decision-support systems.

5. Conclusion

Ship telemetry contributes to energy-efficiency and decarbonization objectives by enabling continuous monitoring of operational performance and more timely technical interventions. The proposed architecture also supports ESG-related initiatives and aligns with broader objectives of operational excellence, reliability, and digital transformation.

For the scaled deployment, the project business case indicates potential benefits, to be progressively validated during fleet implementation, including:

- up to 15% reduction in fuel consumption in targeted operating scenarios;
- approximately 3.6% reduction in lubricant usage;
- approximately 3.6% reduction in corrective maintenance costs;
- reduction or elimination of manual data collection, corresponding to about 4,992 hours per year;
- improved operational safety and reliability;
- longer equipment service life and fewer unplanned events;

- higher productivity and improved logistics planning;
- improved service reliability and customer satisfaction.

Overall, the initiative demonstrates that ship telemetry is not only a data-acquisition project but also a strategic enabler for predictive maintenance, energy management, and integrated fleet operations. The next phases should focus on validation of estimated benefits, standardization of data governance, expansion of condition-based monitoring models, and progressive integration with maintenance-management workflows.

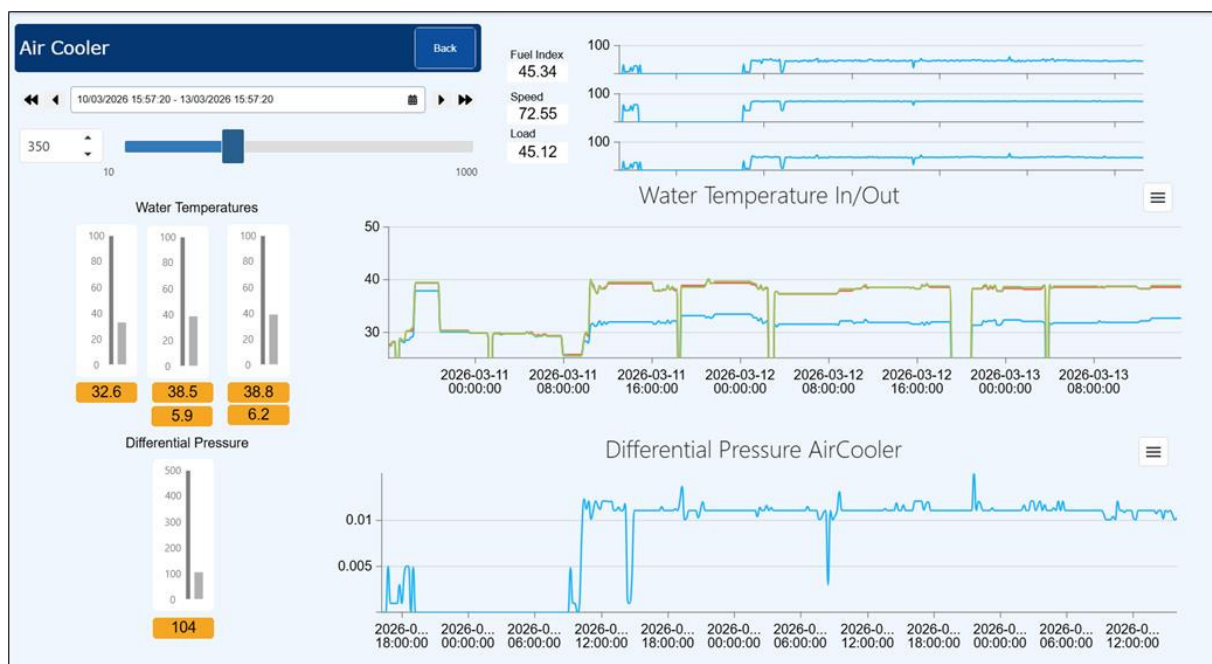


Fig. 5. Historical data obtained from a web-based dashboard.

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