A digital operations model for aligning subsea surveillance workflows with floating storage vessel schedules and offshore logistics

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Abstract

Offshore oil and gas operations rely heavily on two critical yet often disconnected domains: subsea surveillance and offshore logistics, particularly involving Floating Storage and Offloading (FSO/FPSO) vessels. These domains operate in silos, leading to delayed interventions, misaligned schedules, and significant inefficiencies. This paper proposes a digital operations model designed to align subsea surveillance workflows with floating vessel schedules and offshore logistics through real-time data integration, automated decision support, and intelligent orchestration. The model features a centralized digital platform that ingests data from ROVs, AUVs, and fixed sensors, integrates it with marine scheduling systems, and enables predictive planning through rule-based decision nodes. It emphasizes interoperability with legacy systems, hybrid automation with human-in-the-loop oversight, and robust cybersecurity to ensure operational integrity. By synchronizing maintenance needs with vessel movements, the model reduces downtime, improves resource utilization, and enhances the responsiveness of offshore operations. The proposed framework offers a scalable foundation for digital transformation in offshore environments and lays the groundwork for future integration with AI, digital twins, and industry-wide standardization initiatives.

Keywords: subsea surveillance, offshore logistics, Floating Storage and Offloading (FSO), digital operations model, predictive maintenance, data-driven coordination

1. Introduction

1.1 Context and Industry Challenge

Offshore oil and gas operations increasingly rely on subsea infrastructure to access reserves in deepwater environments. This infrastructure, which includes pipelines, risers, control systems, and wellheads, requires continuous surveillance to ensure integrity, optimize production, and prevent environmental incidents [1, 2]. Simultaneously, the logistics that support offshore activities, particularly those involving Floating Storage and Offloading (FSO) units or Floating Production Storage and Offloading (FPSO) vessels, operate on tight schedules dictated by weather conditions, fuel optimization, port availability, and production targets [3, 4]. These dual needs, subsea surveillance and floating vessel logistics, are deeply interconnected but traditionally managed through parallel, loosely coordinated systems [5, 6].

The complexity of aligning these operations stems from their inherently asynchronous natures. Subsea surveillance often runs on scheduled inspection campaigns or condition-based maintenance triggers that may not coincide with the availability of FSO vessels [7, 8]. Conversely, vessel scheduling is frequently reactive and must consider multiple constraints such as voyage time, demurrage costs, and berth availability [9, 10]. These constraints make it difficult to match inspection findings or urgent subsea anomalies with timely interventions, especially when vessel support is required. This lack of alignment can create significant operational risk, especially in aging fields where the margin for failure is narrower [11, 12].

Moreover, the growing adoption of remote and autonomous subsea systems, such as resident ROVs and AUVs, has increased the volume and frequency of surveillance data being generated. However, without digital synchronization with logistics systems, this data often cannot be acted upon in a timely fashion [13]. The disconnect means that even when problems are detected early, the delay in mobilizing support vessels or technicians undermines the effectiveness of proactive maintenance. This gap highlights the urgent need for a unifying operational model that integrates both sides of the offshore workflow [14].

In many current offshore assets, surveillance recommendations are reviewed periodically and translated into work orders or logistics requests through manual planning processes [15]. This decision-making latency increases the likelihood of deferred maintenance and creates inefficiencies in scheduling vessel support, leading to costly rescheduling, wasted fuel, or missed windows of opportunity [16, 17]. The resulting risk to safety, production uptime, and environmental performance underscores the critical challenge: how to seamlessly coordinate subsea intelligence with offshore logistics to enhance responsiveness and reduce operational friction [18, 19].

1.2 Motivation for Digital Alignment

Traditional approaches to coordinating offshore logistics and surveillance suffer from fragmented systems, legacy tools, and siloed organizational structures. Surveillance teams often rely on static inspection plans based on historical risk profiles or asset criticality, while logistics planners work from vessel availability schedules, weather forecasts, and supply chain constraints [20, 21]. Because these systems rarely share real-time data or communicate via integrated platforms, misalignment is not only common, but also expected. This creates an environment where critical information remains underutilized or arrives too late for operational decisions to be optimized [22, 23].

The motivation for a digital alignment model lies in bridging this persistent divide. Emerging technologies, such as integrated digital twins, cloud-based data lakes, and real-time analytics, offer the potential to create a shared operational picture that links the condition of subsea assets directly to vessel movement planning and resource allocation [24]. When surveillance workflows are digitally mapped to logistics triggers, operators can shift from reactive coordination to predictive planning, using data to anticipate needs and orchestrate workflows more effectively. This is especially valuable in offshore contexts where changes to one domain (e.g., inspection findings) can have immediate implications for another (e.g., cargo dispatching or maintenance vessel scheduling) [25, 26].

Digitization also allows for scalable automation of routine decisions and enhances human oversight of more complex tasks. For instance, real-time anomaly detection in subsea data can automatically flag maintenance requirements, which can be fed into a dynamic logistics dashboard that aligns vessel capacity, personnel availability, and offshore weather windows [27]. This level of orchestration is not achievable with legacy Excel-based or verbally coordinated systems. The digital model enables operators to capture efficiencies in vessel deployment, reduce downtime, and enhance offshore personnel safety by minimizing unnecessary exposure [28, 29].

Additionally, cost pressures and decarbonization targets are making vessel efficiency more important than ever. By reducing idle time, minimizing unscheduled trips, and enhancing planning accuracy, a digitally aligned model directly supports lower emissions and better financial outcomes. In a highly competitive offshore market, this advantage can translate to millions of dollars saved annually. Thus, the push for digital integration is not merely a technological upgrade; it is a strategic imperative for operational excellence and sustainability [30, 31].

1.3 Objective of the Study

The central objective of this study is to develop a robust digital operations model that synchronizes subsea surveillance workflows with the dynamic schedules of floating storage vessels and offshore logistics. By doing so, the study seeks to eliminate the inefficiencies and operational risks associated with siloed coordination methods and promote a more intelligent, responsive offshore asset management strategy. The proposed model serves as a blueprint for operators looking to integrate data streams from subsea infrastructure with vessel availability, real-time weather data, and logistical resource planning.

At its core, this paper advocates for a unified digital framework that can transform how offshore operations are executed. This model is designed not only to monitor and interpret data from subsea assets but also to translate that information into actionable logistics decisions. For instance, a detected anomaly in a riser system could trigger the automated scheduling of an inspection or repair window based on the closest available FSO unit, vessel fuel status, or crew availability. This approach reduces human latency, ensures timely response, and maximizes the value of surveillance data.

The study will present the architecture, data flow, and enabling technologies necessary for this digital coordination model. It will outline how such a system can be built using commercially available tools and infrastructure, avoiding the need for proprietary platforms or excessive customization. Special attention will be given to how the model maintains flexibility in the face of unpredictable offshore conditions while preserving operational discipline and regulatory compliance.

Ultimately, the aim is to provide industry stakeholders, ranging from operations managers to digital transformation leaders, with a comprehensive, scalable approach to aligning the physical and digital domains of offshore production. This includes not only the technical blueprint but also the operational philosophies that must underpin its successful implementation. By capturing the full value chain from subsea sensors to floating logistics support, the model aspires to redefine best practices in offshore coordination and pave the way for smarter, safer, and more efficient operations.

2. Operational Coordination Challenges in Offshore Environments

2.1 Disjointed Surveillance and Logistics Pipelines

In offshore production environments, subsea surveillance systems and logistics operations have historically evolved along separate trajectories. Surveillance workflows are typically managed by integrity teams focused on asset health, while logistics is coordinated by marine and operations departments concerned with vessel movement, cargo handling, and supply chain support [32, 33]. These functions often use different software tools, operate under different mandates, and report to different decision-makers. As a result, valuable data generated from subsea inspection campaigns frequently fails to reach logistics planners in a timely or actionable format [34, 35].

This siloed structure creates delays in response when issues are detected subsea. For instance, if a critical anomaly is observed in a pipeline or riser system, its remediation may require immediate mobilization of equipment or technical teams [36, 37]. However, if vessel scheduling is handled independently, without a direct digital link to surveillance findings, the necessary logistical response may be postponed or misaligned with vessel availability. This not only increases response time but can also incur significant standby costs or safety risks [38].

Further compounding the problem is the lack of unified planning dashboards. Surveillance data is often stored in specialized platforms used by subsea engineers, while logistics relies on legacy systems or manual scheduling spreadsheets. Without interoperability, it becomes difficult to create a shared operational picture, making it challenging to coordinate complex workflows or optimize offshore resources. This fragmentation introduces avoidable inefficiencies, particularly in time-critical scenarios such as leak detections or urgent maintenance windows [39, 40].

Moreover, there is often no feedback loop from logistics teams back to surveillance planners. If vessel schedules change due to external factors like weather or cargo reprioritization, the surveillance program may proceed based on outdated assumptions. This feedback gap leads to further mismatches, including wasted inspection efforts or underutilized vessel slots. In high-risk offshore settings, where every movement has cost and safety implications, these coordination failures can have severe operational consequences [41].

2.2 Vessel Scheduling Constraints and Impacts

Floating storage vessels operate under complex, high-stakes scheduling frameworks that must account for technical, environmental, and economic constraints. These vessels are central to offshore operations, serving as storage hubs for produced hydrocarbons and often supporting a variety of other functions, from crude offloading to bunkering and personnel transfers. However, their utility is tightly bound to precise scheduling, which can be disrupted by multiple external variables, including ocean conditions, berth availability, and geopolitical risks in port access regions [42, 43].

One major limitation is the narrow operational window for loading and offloading. These vessels must align with tanker rotations, port schedules, and production quotas. When these timelines shift, due to either upstream delays or market-driven changes, there is little flexibility to accommodate unexpected inspection or maintenance demands originating from subsea surveillance. The result is often a forced prioritization that sidelines integrity actions, pushing them to the next available slot, which may not be soon enough to prevent asset degradation [44, 45].

The weather is another major constraint. Harsh offshore environments make vessel navigation and positioning hazardous, especially during monsoon seasons or tropical storms. Even if subsea anomalies demand urgent attention, vessel redeployment may be physically impossible or prohibitively expensive under such conditions. These weather constraints compound scheduling rigidity and discourage dynamic adjustment in response to surveillance inputs [46, 47].

Fuel costs and crew availability also impact vessel flexibility. Long standby periods while awaiting alignment with inspection campaigns or delays due to manual rescheduling can dramatically increase operational expenditures [48, 49]. In many cases, vessels may need to return to port for regulatory reasons, such as safety certifications or crew changes, introducing further disruptions. Each of these logistical constraints amplifies the need for a more predictive and integrated coordination model, where data from subsea systems can proactively inform vessel movement rather than react to it [47, 50].

2.3 Consequences of Misalignment

When offshore surveillance and logistics systems are not digitally integrated, the consequences reverberate throughout the entire value chain. One of the most immediate impacts is the delay in resolving anomalies detected during subsea inspections. If a critical fault is identified, such as corrosion in a flowline or structural fatigue in a subsea template, but no vessel or support team is available within a reasonable timeframe, the risk of equipment failure escalates. This can lead to partial or total shutdown of production systems, especially if redundancy is not available [51, 52].

Downtime caused by misalignment has measurable financial and operational costs. In the oil and gas sector, each hour of production loss can equate to hundreds of thousands of dollars, depending on field maturity and output volume. When surveillance findings cannot be acted upon promptly, operators may resort to conservative strategies such as reducing flow rates or shutting down affected wells. While these actions protect asset integrity, they also reduce profitability and can affect long-term reservoir management plans [53, 54].

Another hidden cost is resource wastage. Uncoordinated workflows may result in vessels arriving on site without the required tools, specialists, or equipment because the logistics planning was disconnected from the technical findings [55]. Similarly, inspection teams may conduct surveys only to realize that their findings cannot be addressed in the same deployment cycle due to vessel unavailability or cargo conflicts. These inefficiencies lead to repeated mobilizations, increased carbon footprint, and fatigue among offshore personnel [56].

Finally, misalignment undermines confidence in operational reliability. Regulatory bodies and joint venture stakeholders expect timely responses to surveillance findings, especially in regions with strict environmental oversight. Repeated coordination failures can trigger penalties, damage corporate reputation, or lead to restrictions on operational licenses [57]. From a strategic perspective, this disconnection limits the organization's ability to implement advanced reliability-centered maintenance or transition toward predictive operations. Bridging this gap is no longer optional, it is critical for maintaining competitiveness and regulatory compliance in modern offshore operations [58, 59].

3. Proposed Digital Operations Model

3.1 Core Architecture of the Model

The proposed digital operations model is designed around a centralized, cloud-based integration hub that connects subsea surveillance systems with offshore logistics planning and vessel scheduling engines. At its core, this architecture functions as a modular platform, allowing for secure data acquisition, real-time visualization, and intelligent decision-making across multiple offshore domains. The system ingests structured and unstructured data from various subsea sources, including ROVs, autonomous underwater vehicles (AUVs), and fixed instrumentation, and integrates it with scheduling data from floating storage and logistics management systems [60, 61].

The architecture employs an event-driven framework, where surveillance triggers (such as anomaly detection or inspection alerts) serve as decision points that can automatically prompt logistics actions. For instance, a flagged inspection finding can initiate a request for vessel support, cross-validated against real-time vessel telemetry and cargo planning constraints. A unified dashboard offers operators and planners a consolidated view of asset health, vessel availability, weather windows, and supply chain status, all in a single interface [62].

Interoperability is a key architectural principle. The model is built to interact with existing enterprise systems such as CMMS (Computerized Maintenance Management Systems), ERP (Enterprise Resource Planning), and marine scheduling software. Through standardized APIs and data schemas, the platform ensures seamless communication and minimizes the need for custom integration efforts. This architecture empowers offshore teams to move from static planning cycles to dynamic, condition-based coordination, enabling operational decisions that are both timely and data-informeD [63].

3.2 Data Flow and Decision Nodes

The model's effectiveness hinges on the clarity and speed of its data flow. Subsea data enters the system through edge computing devices installed on ROVs, AUVs, and fixed sensors, capable of performing local preprocessing before transmitting critical insights to the cloud. These data streams are automatically tagged with spatial and temporal metadata and fed into an analytics layer that detects anomalies, assesses severity, and assigns recommended actions. Advanced pattern recognition and machine learning models further enhance anomaly classification and urgency scoring [64, 65].

Once insights are generated, decision nodes within the model determine the appropriate operational response. These nodes are built using a rules engine that evaluates various parameters: the type of anomaly, asset criticality, vessel proximity, crew readiness, and environmental conditions. For example, a moderate corrosion alert on a subsea tree may be queued for the next routine logistics cycle, whereas a high-severity pressure anomaly in a flowline could trigger immediate vessel dispatch, subject to confirmation of safe weather conditions and asset readiness [66].

Outputs from the decision nodes are relayed to human operators via an integrated dashboard and notification system. Each alert includes contextual information, suggested actions, and associated logistical implications. Operators retain the authority to accept, defer, or escalate these recommendations, maintaining a human-in-the-loop oversight mechanism. This hybrid decision framework, balancing automation and operator discretion, ensures responsiveness without compromising operational discipline or safety protocols [67].

3.3 Integration with Offshore Operations

True value is unlocked when the digital operations model is embedded into the daily rhythm of offshore activity. Integration with vessel logistics is achieved through continuous synchronization between the platform and marine management systems. Real-time AIS (Automatic Identification System) data, dynamic positioning metrics, and port rotation schedules are fed into the system, enabling it to match surveillance-driven tasks with optimal vessel deployment windows. This allows for intelligent bundling of inspection, repair, and supply operations to maximize voyage utility.

Operational alignment is further reinforced by integrating the model with offshore asset registries, work order management tools, and personnel-on-board (POB) tracking systems. When an inspection reveals the need for intervention, the model automatically checks for the availability of qualified personnel, necessary tools, and compatible vessel capacity, flagging any gaps for planners to resolve before execution. This not only speeds up response times but also minimizes the risk of aborted missions due to resource mismatches [68, 69].

To support field deployment, the system includes mobile and offline access capabilities, enabling offshore teams to receive synchronized updates even in low-connectivity environments. All field activity is logged back into the system for traceability and continuous learning. Over time, these records help refine the model's decision logic, improving its predictive accuracy and operational relevance. This tightly integrated approach transforms the model from a passive data aggregator into an active orchestration tool for offshore operations [70].

4. Key Enablers and Implementation Considerations

4.1 Interoperability and Standardization

For the digital operations model to function seamlessly across diverse offshore environments, interoperability must be a foundational design principle. Offshore facilities often rely on a patchwork of legacy systems, proprietary data formats, and bespoke protocols that make integration challenging. To overcome this, the model must support open standards such as OPC UA, MQTT, and ISO 14224 for equipment data. These standards enable consistent communication across different surveillance, logistics, and maintenance platforms [71].

Data normalization is critical to ensure comparability across assets and operational contexts. Surveillance data from ROVs, for example, must be harmonized with inspection reports from other sources and aligned with vessel telemetry in a shared ontology. The platform should include a metadata management layer that standardizes terms, units, and status codes, ensuring that analytics and automation can function reliably across datasets.

Equally important is standardizing the logic that connects surveillance findings with logistics actions. By encoding best practices into rule sets, such as urgency-based vessel allocation or inspection-to-workorder mapping, the model creates a predictable, repeatable coordination process. This consistency reduces operator workload, enhances auditability, and lays the groundwork for scalable deployment across different offshore fields. Ultimately, interoperability and standardization are not merely technical enablers, they are the backbone of operational trust and efficiency in digitally aligned offshore systems [72, 73].

4.2 Automation and Human-in-the-Loop Interfaces

While automation enhances speed and efficiency, offshore operations demand accountability and safety, both of which require human judgment. The proposed model is built on a hybrid approach where automation handles data collection, analysis, and recommendation generation, while human operators retain control over execution. This human-in-the-loop architecture ensures that critical decisions, such as emergency shutdowns or high-cost vessel mobilizations, are reviewed before implementation [74].

Automation is most effective in repetitive or time-sensitive tasks: flagging anomalies, ranking risk, and suggesting logistics plans. These functions reduce cognitive load on engineers and planners, allowing them to focus on higher-level problem-solving. For example, when a subsea inspection detects wall thinning beyond the threshold, the system can automatically calculate vessel proximity, send an alert, and suggest a time window based on environmental forecasts. The operator can then validate, modify, or escalate the recommendation [75].

The model's user interface is designed to support situational awareness. It offers role-based views, interactive maps, and real-time overlays of asset status, vessel movements, and pending work orders. This empowers decision-makers at all levels, onshore control rooms, offshore supervisors, and marine coordinators, with the information they need. By blending automation with intuitive interfaces, the model preserves operational oversight while accelerating offshore response capability.

4.3 Cybersecurity and Data Integrity

Given the strategic value and sensitivity of offshore data, cybersecurity is a critical enabler for model implementation. The digital operations model must be designed with a secure architecture that protects data in transit and at rest. This includes end-to-end encryption using protocols such as TLS 1.3, role-based access controls, and multi-factor authentication for user accounts. Additionally, secure APIs and firewall rules are essential to guard against unauthorized data flow between the platform and connected systems.

Data integrity is equally important. Offshore environments are often exposed to connectivity disruptions, which can result in corrupted or incomplete data. To mitigate this, the model incorporates redundancy protocols, time-stamped data packets, and automated validation checks that ensure only verified data is used in decision-making. For example, vessel telemetry must be cross-verified with AIS data and onboard logs to confirm authenticity before being used to trigger logistics decisions [76].

Operational security must also include audit trails and anomaly detection for the platform itself. Any unauthorized configuration changes, suspicious login attempts, or irregular data inputs must be logged and flagged for investigation. These controls are critical not only for compliance with industry regulations, such as NIST or ISO 27001, but also for maintaining confidence among operators, partners, and regulators. In a domain as risk-sensitive as offshore logistics, cybersecurity is not optional, it is foundational to trust, reliability, and long-term model adoption [77].

5. Conclusion

This paper has proposed a digital operations model designed to align subsea surveillance workflows with floating storage vessel schedules and offshore logistics. By integrating real-time data streams, automating decision support, and synchronizing disparate operational domains, the model addresses longstanding coordination inefficiencies in offshore asset management. The architecture, data flow, and operational logic outlined here represent a shift from fragmented planning to predictive, data-informed execution across the offshore ecosystem.

The model bridges three key areas: subsea surveillance, vessel logistics, and digital coordination. It enables rapid response to integrity threats, optimizes vessel deployment, and improves situational awareness across teams. Through its emphasis on interoperability, human oversight, and cybersecurity, the framework balances innovation with operational discipline, making it suitable for real-world offshore deployment.

Widespread implementation of this model has the potential to reshape offshore operations. Operators can reduce downtime, streamline inspection campaigns, and make more efficient use of vessel resources, delivering substantial cost savings and environmental benefits. The model also strengthens regulatory compliance by ensuring faster response to asset threats and maintaining comprehensive audit trails.

Furthermore, this integrated approach supports broader digital transformation initiatives across the oil and gas sector. As fields become increasingly automated and remote, the need for intelligent orchestration between assets, logistics, and human teams will only grow. The model offers a foundation on which these future-state operations can be built, agile, data-driven, and tightly coordinated.

To enhance the model's capabilities, future research should explore three key areas. First, integrating digital twin technology could improve predictive analytics by simulating asset behavior under various operational scenarios. Second, machine learning algorithms could be refined to anticipate vessel needs based on historical patterns and evolving inspection profiles. Third, standardizing policy frameworks across regions and operators would accelerate model adoption by reducing integration friction. By pursuing these advancements, the industry can move closer to a fully synchronized offshore environment, where decisions are made at the speed of data, and assets are managed with the precision of real-time intelligence.

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