

Review

## Environmental and Operational Implications of Dynamic Positioning Failures in Offshore Operations: A Review of IMCA Reports from 2018 to 2024

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### Abstract

Dynamic Positioning (DP) systems are widely used in offshore operations such as drilling, subsea construction, cable laying, offshore renewable energy support, and remotely operated vehicle (ROV) operations. As offshore activities become increasingly dependent on DP capability, failures in DP systems may result in operational disruption, safety concerns, and environmental exposure. Although advances in automation and redundancy have improved DP system reliability, the offshore industry continues to report DP incidents and undesired events. This paper reviews DP station-keeping events reported by the International Marine Contractors Association (IMCA) between 2018 and 2024. The reported percentages reflect descriptive compositions of voluntary submissions rather than incident rates or statistically generalizable temporal trends. The review focuses on recurring reported patterns related to thruster and propulsion failures, electrical faults, position reference problems, computer-related failures, and human factors. The review also discusses the operational and environmental implications of DP failures during offshore activities. Loss of position, reduced redundancy, and degraded vessel capability may increase the risk of collision, subsea equipment damage, operational downtime, and other offshore safety concerns. The paper also highlights the ongoing contribution of electrical and human factors to reported DP events. Finally, the paper discusses several approaches that may improve the resilience of future DP



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operations, including predictive maintenance, decision-support systems, and AI-based monitoring technologies. The findings suggest that DP failures should be considered not only as technical malfunctions, but also as part of a broader offshore operational and environmental risk management issue.

### Keywords

Dynamic positioning; offshore operations; DP incidents; operational resilience; environmental risk; human factors; maritime safety; offshore sustainability; predictive maintenance; IMCA reports

## 1. Introduction

Dynamic Positioning (DP) systems are essential to modern offshore operations. DP vessels are widely used in offshore drilling, subsea construction, cable laying, offshore renewable energy support, and remotely operated vehicle (ROV) operations requiring accurate vessel positioning without the use of anchors [1, 2]. As offshore operations expand into deeper waters and more complex environments, operational dependence on DP capability and redundancy management has steadily increased.

Recent developments in offshore renewable energy and subsea infrastructure projects have further increased the operational importance of DP-supported vessels [3]. Many offshore activities now occur in environmentally sensitive areas and congested subsea environments where the consequences of vessel position loss may extend beyond operational interruption. DP failures during offshore activities may contribute to collision risk, subsea equipment damage, interruption of offshore construction activities, and environmental exposure associated with offshore operations.

Although advances in automation, power management systems, and redundancy design have improved the technical reliability of DP systems, DP incidents and undesired events continue to be reported throughout the offshore industry. The International Marine Contractors Association (IMCA) has continuously collected and published DP station-keeping event reports to improve operational awareness and support lessons learned across the industry [4-10]. These reports include DP incidents, undesired events, and observations related to thruster and propulsion failures, electrical faults, computer-related failures, problems, environmental conditions, and human factors.

Several previous studies have discussed technical reliability, control system performance, and human factors associated with maritime operations and offshore safety [1, 11, 12]. Human and organizational factors have also been recognized as important contributors to maritime accidents and operational degradation [11, 12]. More recently, safety engineering and resilience-based approaches have received increasing attention in complex maritime and offshore systems [13, 14]. However, relatively limited attention has been given to longitudinal reporting patterns and environmental implications associated with DP station-keeping events reported across the offshore industry.

Recurring reports of electrical faults, thruster failures, reduced redundancy, and human operational errors suggest that DP failures should not be considered solely as isolated technical malfunctions. Instead, these events should also be understood in relation to offshore operational

resilience, environmental risk exposure, and sustainable offshore operations. Increasing levels of automation and system integration may also introduce additional operational challenges associated with human-system interaction and decision-making during degraded operating conditions.

Therefore, this paper reviews DP station-keeping events reported by IMCA between 2018 and 2024 to identify recurring patterns within the submitted reports and discuss their operational and environmental implications. Particular attention is given to the contribution of human and electrical factors, operational vulnerability during offshore activities, and future approaches for improving DP operational resilience. The paper also discusses emerging technologies, including predictive maintenance, decision-support systems, and AI-based monitoring technologies, from the perspective of sustainable offshore operations.

## **2. Background of DP Operations and Reporting System**

### **2.1 Dynamic Positioning Operations**

DP systems automatically maintain a vessel's position and heading by controlling thrusters and propulsion systems through an integrated control system [1, 2]. Modern DP vessels are widely used in offshore drilling, subsea construction, offshore renewable energy support, diving operations, cable laying, pipelay activities, and remotely operated vehicle (ROV) operations where precise vessel positioning is required.

Unlike conventional anchoring systems, DP operations rely on continuous interaction among propulsion systems, power management systems, position reference systems, environmental sensors, and operator decision-making processes. The operational reliability of DP systems therefore depends not only on technical redundancy, but also on the effectiveness of human-system interaction during normal and degraded operating conditions.

DP vessels are commonly classified according to redundancy capability and fault tolerance requirements. In offshore operations, redundancy management is particularly important because single failures may lead to loss of position, reduced operational capability, or operational interruption. Offshore activities involving subsea infrastructure, drilling equipment, or offshore renewable energy installations may be especially vulnerable to DP degradation because many operations are conducted in restricted operating environments with limited recovery margins.

The increasing complexity of offshore operations has also increased operational dependence on automated control systems and integrated vessel management technologies. As offshore operations expand into deeper waters and more congested subsea environments, maintaining operational resilience during degraded DP conditions has become an important safety and operational concern.

### **2.2 IMCA DP Reporting Framework**

The IMCA has continuously published Dynamic Positioning station-keeping event reports to support operational learning and improve DP safety awareness across the offshore industry [4-10]. These reports summarize operational events voluntarily reported by vessel operators and offshore organizations involved in DP-supported activities.

IMCA reports generally classify DP-related events into three categories: DP incidents, DP undesired events, and DP observations. DP incidents typically involve actual loss of position or loss

of heading affecting operational safety. DP undesired events refer to situations where the vessel experienced degraded DP capability without a complete loss of position. DP observations include operational findings, procedural concerns, and technical issues identified before escalation into more serious operational events.

The reporting framework also distinguishes between main and secondary causes for each event. Main causes generally describe the immediate operational failure affecting DP capability. In contrast, secondary causes are used to identify contributing technical, electrical, environmental, software-related, or human factors associated with the event. This structure allows recurring operational vulnerabilities and degradation patterns to be identified across multiple years of reported DP events.

Although IMCA reports are not intended to provide statistically representative accident data for the entire offshore industry, they provide valuable operational evidence regarding recurring DP vulnerabilities, technical degradation mechanisms, and operational challenges encountered during offshore activities [4-10]. The reports also show the ongoing contribution of electrical faults, thruster failures, computer-related problems, and human factors to degraded DP capability.

Because the reports draw on operational experience across different offshore sectors and vessel types, they provide a useful foundation for reviewing longitudinal reporting patterns and discussing resilience-related challenges associated with modern DP operations.

### **2.3 Main and Secondary Cause Classification**

The IMCA reporting framework classifies each Dynamic Positioning event according to main causes and secondary causes in order to improve the understanding of operational degradation mechanisms during DP operations [4-10]. This classification structure provides a consistent approach to identifying immediate failure events as well as contributing operational conditions associated with DP capability degradation.

Main causes generally represent the primary operational failure directly affecting Dynamic Positioning capability. These causes commonly include thruster and propulsion failures, power generation failures, electrical faults, position reference problems, computer-related failures, environmental influences, and operator actions. In many reported events, the main cause represents the operational condition that immediately contributed to reduced vessel position-keeping capability or operational interruption.

Secondary causes identify underlying or contributing factors associated with the reported event. These factors may include electrical system degradation, software-related problems, maintenance deficiencies, procedural weaknesses, communication failures, or human factors. In several reported cases, secondary causes contributed to escalating operational degradation following an initial technical failure.

The distinction between main causes and secondary causes is important because many Dynamic Positioning events involve multiple interacting failures rather than a single isolated malfunction. For example, a thruster shutdown reported as the main cause may be associated with electrical system instability, control system failure, or operational decision-making issues identified as secondary causes. This classification structure therefore supports a broader understanding of operational vulnerability and system interaction during degraded operating conditions.

Across the reviewed IMCA reports, recurring patterns associated with thruster and propulsion failures, electrical faults, computer-related failures, and human factors were repeatedly identified

as major contributors to Dynamic Positioning degradation [4-10]. These recurring patterns provide useful operational evidence for reviewing recurring reported patterns associated with offshore operational resilience and environmental risk exposure.

## **2.4 Ethics Statement**

This study was based exclusively on publicly available industry reports published by the International Marine Contractors Association (IMCA). This research involved no human participants, animal subjects, or personal identifying information. Therefore, ethical approval and informed consent were not required.

## **3. Review Methodology**

### **3.1 Data Collection**

This study was conducted using Dynamic Positioning station-keeping event reports published by the International Marine Contractors Association (IMCA) between 2018 and 2024 [4-10]. The reviewed reports include DP incidents, DP undesired events, and operational observations reported from offshore vessels engaged in drilling, subsea construction, offshore renewable energy support, cable laying, diving operations, and remotely operated vehicle (ROV) activities.

The IMCA reports were selected because they provide one of the most consistent industry-wide sources of operational evidence associated with Dynamic Positioning failures and degraded offshore operational conditions. Unlike isolated accident investigations or single-vessel case studies, the reports include recurring operational events collected across multiple offshore sectors and vessel types over several years.

The reviewed reports cover event categories, operational conditions, vessel activities, main causes, secondary causes, and operational consequences. The review paid particular attention to recurring operational patterns associated with thruster and propulsion failures, electrical faults, computer-related failures, position reference system problems, and human factors.

### **3.2 Review Approach**

This study adopted a narrative review approach focused on recurring reported patterns and resilience-related implications associated with Dynamic Positioning degradation. The review was not intended to provide statistical generalization or predictive risk modeling. Instead, the study focused on identifying recurring operational vulnerabilities and discussing their operational and environmental implications within offshore operations.

The reviewed events were examined to identify repeated patterns associated with technical degradation, operational interruption, reduced redundancy, and human-system interaction during DP-supported activities. In addition, the review considered how degraded Dynamic Positioning capability may contribute to operational vulnerability during offshore activities involving subsea infrastructure, offshore renewable energy support, and restricted operating environments.

Because IMCA reports rely on voluntary industry reporting and are not statistically representative datasets, the findings presented in this paper should be interpreted as descriptive observations within the submitted reports rather than quantitative risk predictions [4-10]. Nevertheless, the reports provide valuable operational evidence regarding recurring DP vulnerabilities and offshore

operational challenges observed across the industry. To improve consistency across annual reporting periods, similar operational categories reported under different terminology were manually grouped into unified analytical classifications during the review process. The reported percentages were retained solely as descriptive within-report compositions and were not used to infer year-to-year changes. The analytical process focused primarily on recurring operational patterns, degradation mechanisms, and resilience-related implications rather than isolated numerical comparison.

The unit of review was the annual IMCA DP station keeping review for each event year from 2018 through 2024. A report was included when it contained tabulated DP incidents, DP undesired events, or DP observations, along with corresponding annual cause summaries. Non-DP safety material, events outside the review period, and duplicated narrative case examples were excluded from numerical extraction.

All 1,129 records tabulated by IMCA across the three event classes were retained for the annual reporting-volume summary. For the cause distributions, only the main- and secondary-cause categories published by IMCA were extracted. Missing or unclassified items were not reassigned. Equivalent terminology used in different annual reports was grouped under consistent category labels to ensure comparability across reporting years. No events were reclassified between the original IMCA event classes.

Annual counts and percentages were used only to describe the composition of submissions within each IMCA report. These values were not normalized by fleet size or DP operating hours because consistent annual exposure denominators were not available. No statistical significance tests were performed because the voluntary, non-probability sample does not satisfy the assumptions required for population-level inference.

As a descriptive robustness check, a category was considered recurring only when it appeared in at least five of the seven annual reports. The term "dominant" was reserved for a category ranked first in every reporting year. Under this criterion, thruster and propulsion failures remained the dominant main-cause category, accounting for 33-41% of annual submissions, while electrical factors remained the first- or second-ranked secondary cause, accounting for 21-42%. No individual year-to-year percentage change was interpreted as statistically significant.

The published annual summaries do not provide consistent event-level cross-tabulations linking vessel activity, main cause, secondary cause, and consequence. Cross-correlation analysis and causal effect estimation were therefore not performed. Cause interactions identified from the narrative case descriptions were interpreted qualitatively and are not presented as statistically verified associations. The overall review procedure is summarized in Figure 1. The procedure consisted of report identification, eligibility screening, data extraction, category harmonization, and descriptive synthesis, with explicit safeguards concerning scope control, classification integrity, statistical restraint, and interpretive limitations.

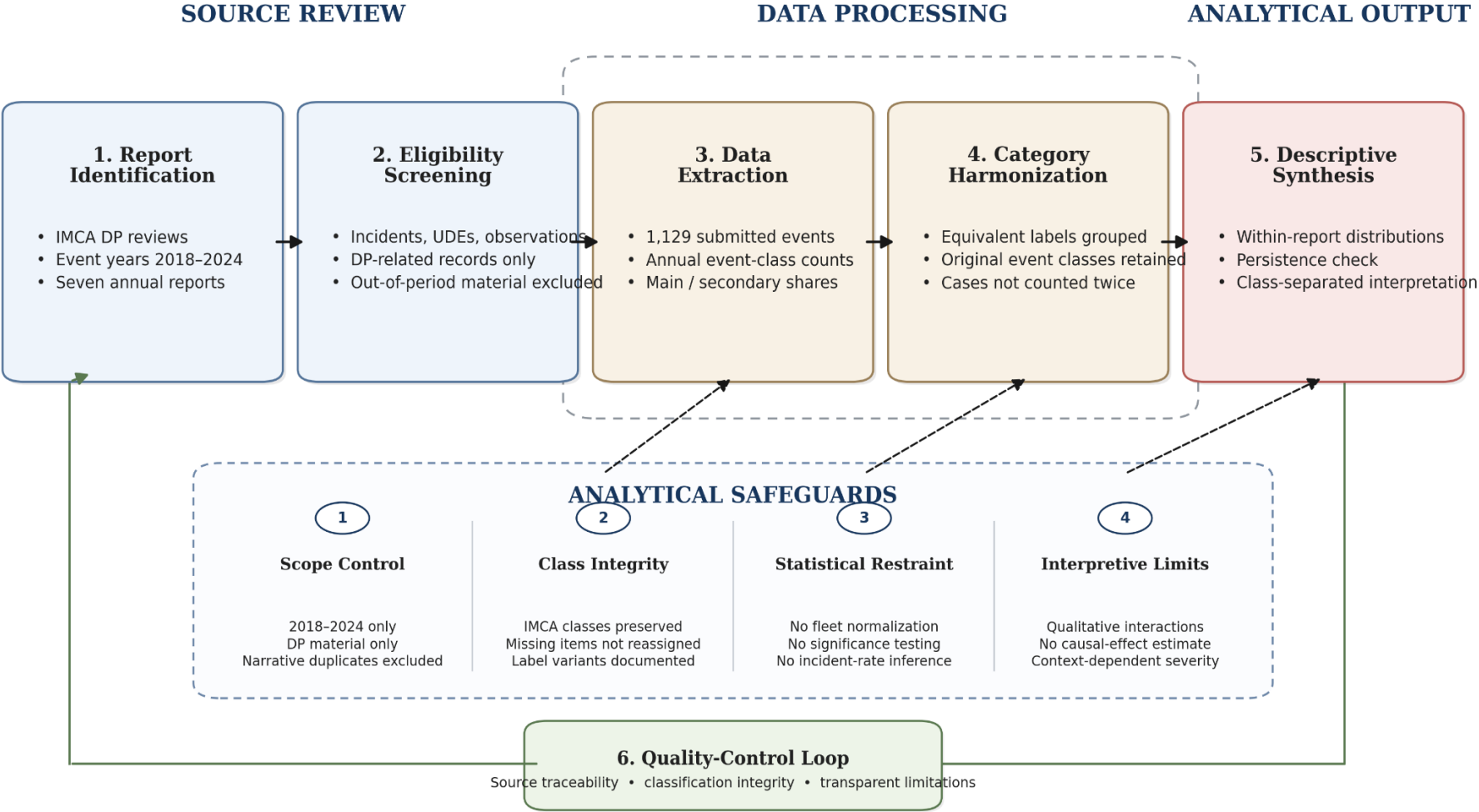


**Figure 1** Review selection, extraction, harmonization, and synthesis procedure. Narrative case examples were used for qualitative interpretation but were not counted again.

### **3.3 Analytical Categories**

To improve consistency during the review process, reported events were examined using several analytical categories derived from the IMCA reporting framework and recurring operational themes identified across the reviewed reports.

The primary analytical categories included:

- Main cause distributions;
- Secondary cause distributions;
- Thruster and propulsion failures;
- Electrical and computer-related failures;
- Human and operational factors;
- Reduced redundancy and degraded DP capability;
- Operational interruption during offshore activities; and
- Environmental and operational implications associated with DP degradation.

Special attention was given to recurring operational patterns involving electrical failures, human factors, and redundancy degradation because these factors repeatedly appeared throughout the reviewed reports [4-10]. The review also examined how these operational conditions may influence offshore operational resilience during activities involving subsea operations, offshore renewable energy support, and infrastructure-related operations.

Finally, the review considered several emerging approaches associated with improving Dynamic Positioning operational resilience, including predictive maintenance, decision-support systems, AI-based monitoring technologies, and resilience-oriented operational management concepts discussed in recent maritime safety literature [13, 14].

## **4. Reported Patterns of DP Station Keeping Events**

### **4.1 Annual Reporting Volume and Event Classes**

The three IMCA event classes were retained separately when interpreting operational consequences. Observations were treated as precursor or learning signals, undesired events as degraded DP capability without complete loss of position, and incidents as events involving actual loss of position or heading. Numerical severity weights were not assigned because these classifications do not consistently provide information on injury, physical damage, environmental release, distance to hazard, remaining redundancy, or activity criticality. Consequence potential was therefore interpreted conditionally, based on vessel activity, proximity to offshore assets, environmental loading, and remaining recovery capability. Consequently, an identical thruster failure may have relatively limited consequences during open-water station keeping but substantially greater consequence potential during diving, pipelay, drilling, or close-proximity operations.

DP incidents, undesired events, and DP observations were consistently reported across the offshore industry between 2018 and 2024 [4-10]. Although the number and distribution of reported events varied between reporting period, recurring operational vulnerabilities associated with DP degradation remained observable across multiple offshore sectors.

This reporting pattern indicates that undesired events and observations accounted for substantial proportions of the submitted records. However, because reporting participation and

reporting practices may have varied across years, no conclusions can be drawn regarding underlying changes in event frequency or safety culture.

Table 1 presents the annual distribution of DP station keeping events reported to IMCA between 2018 and 2024. The total number of submissions increased from 146 in 2018 to 217 in 2024. This increase in reporting volume within the IMCA scheme should not be interpreted as evidence of an increasing industry-wide DP incident rate. A consistent annual denominator for the worldwide DP-capable fleet, vessel-years, DP operating hours, or activity-specific exposure was not published with the reviewed IMCA reports [4-10]. Therefore, the annual report counts could not be reliably normalized. In addition, the submitted events originated from different operational sectors, including drilling, subsea construction, cable laying, offshore wind support, diving, and ROV operations, which may differ in both operational exposure and reporting propensity.

**Table 1** Annual Distribution of Reported DP Station Keeping Events (2018-2024).

| Year | DP Incident | DP Undesired Event | DP Observation | Total Reports |
|------|-------------|--------------------|----------------|---------------|
| 2018 | 24          | 81                 | 41             | 146           |
| 2019 | 19          | 75                 | 31             | 125           |
| 2020 | 41          | 79                 | 24             | 144           |
| 2021 | 52          | 78                 | 20             | 150           |
| 2022 | 46          | 89                 | 35             | 170           |
| 2023 | 51          | 111                | 15             | 177           |
| 2024 | 59          | 115                | 43             | 217           |

The reviewed reports also demonstrate that DP-related operational challenges continue to affect a wide range of offshore operations, including drilling support, subsea construction, cable laying, offshore renewable energy support, diving operations, and remotely operated vehicle (ROV) activities. Many of these operations are conducted in restricted operating environments where reduced DP capability may significantly affect operational continuity and vessel safety.

#### **4.2 Main Cause Distributions**

Thruster and propulsion-related failures were consistently identified as the dominant main cause category throughout the reviewed IMCA reports [4-10]. As shown in Table 2, propulsion-related events accounted for approximately 33-41% of all reported DP station keeping events between 2018 and 2024. These failures included thruster shutdowns, propulsion instability, reduced thrust availability, and propulsion control system failures. Because Dynamic Positioning capability depends heavily on continuous thrust allocation and vessel response capability, propulsion-related degradation may rapidly affect vessel stability during offshore operations. Table 2 summarizes the percentage distribution of main cause categories identified in IMCA DP events between 2018 and 2024. The percentages describe the within-year composition of voluntary IMCA submissions. They were not normalized to fleet exposure and were not used for statistical comparison between years.

**Table 2** Descriptive Distribution of Main Causes in Reported IMCA DP Events (2018-2024).

| Main Cause       | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|------------------|------|------|------|------|------|------|------|
| Thrusters        | 35%  | 34%  | 33%  | 41%  | 39%  | 37%  | 38%  |
| Power            | 11%  | 18%  | 27%  | 16%  | 19%  | 28%  | 24%  |
| Computer         | 21%  | 11%  | 16%  | 21%  | 30%  | 24%  | 11%  |
| References       | 13%  | 12%  | 8%   | 15%  | 6%   | 10%  | 11%  |
| Human Factor     | 8%   | 3%   | 5%   | 3%   | 0%   | 1%   | 1%   |
| Electrical       | 3%   | 3%   | 3%   | 2%   | 1%   | 0%   | 6%   |
| Sensors          | 8%   | 0%   | 2%   | 0%   | 3%   | 0%   | 4%   |
| Environmental    | 1%   | 4%   | 6%   | 1%   | 1%   | 0%   | 2%   |
| Mechanical       | 0%   | 0%   | 0%   | 0%   | 1%   | 0%   | 3%   |
| External Factors | 1%   | 0%   | 1%   | 1%   | 0%   | 0%   | 1%   |

Power-related failures represented 11-28% of annual IMCA submissions, with the highest share occurring in 2023. This year-to-year variation is presented descriptively and is not interpreted as a statistically established increase. Electrical instability, switchboard faults, generator failures, and power distribution problems frequently contributed to degraded DP capability and reduced redundancy conditions. In several reported cases, electrical failures affected multiple vessel systems simultaneously, increasing operational vulnerability during offshore operations.

Computer-related failures remained consistently observable across the reviewed reports. These events included software instability, network communication problems, degraded control system performance, and failures associated with integrated DP control systems. The continued presence of computer-related failures suggests increasing operational dependence on automated control systems and digital integration within modern DP-supported offshore operations.

Position reference problems also remained an important operational concern throughout the review period. Loss of position-reference signals, sensor degradation, and reference instability may significantly affect DP operational reliability, particularly during restricted offshore activities requiring precise vessel positioning.

Environmental conditions such as wind, current, and sea state were occasionally identified as contributing operational factors [4-10]. Although environmental factors rarely represented dominant primary causes, challenging operating environments may increase operational sensitivity when combined with technical failures or reduced redundancy conditions.

### 4.3 Secondary Cause Distributions

Recurring secondary causes identified throughout the reviewed IMCA reports included electrical failures, human-related operational issues, computer-related problems, mechanical deficiencies, and external operational factors [4-10]. Unlike the main cause categories, secondary causes were frequently associated with operational escalation, degraded redundancy, and reduced system resilience during abnormal DP operating conditions.

Table 3 summarizes the percentage distribution of secondary cause categories identified in IMCA DP events between 2018 and 2024. Because secondary cause classifications were not fully standardized across all reporting years, the percentages are presented as descriptive within-report

distributions. No statistical temporal trend was inferred because reporting participation, exposure, and classification practices may have varied across reporting years.

**Table 3** Descriptive Distribution of Secondary Causes in Reported IMCA DP Events (2018-2024).

| Secondary Cause  | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|------------------|------|------|------|------|------|------|------|
| Human Factor     | 23%  | 43%  | 26%  | 27%  | 18%  | 18%  | 14%  |
| Computer         | 11%  | 12%  | 10%  | 16%  | 21%  | 12%  | 12%  |
| Thrusters        | 6%   | 10%  | 2%   | 5%   | 5%   | 0%   | 3%   |
| Power            | 1%   | 4%   | 2%   | 8%   | 0%   | 0%   | 3%   |
| Electrical       | 42%  | 39%  | 41%  | 21%  | 27%  | 29%  | 27%  |
| External Factors | 13%  | 9%   | 2%   | 1%   | 2%   | 2%   | 7%   |
| References       | 3%   | 0%   | 2%   | 5%   | 7%   | 6%   | 4%   |
| Environmental    | 0%   | 1%   | 2%   | 1%   | 3%   | 10%  | 1%   |
| Mechanical       | 0%   | 0%   | 13%  | 12%  | 16%  | 18%  | 23%  |
| Sensors          | 1%   | 0%   | 1%   | 4%   | 3%   | 5%   | 6%   |

Electrical-related secondary causes were among the most consistently reported contributing factors throughout the review period. Electrical instability, switchboard failures, power management abnormalities, and control-system interaction problems frequently contributed to degraded redundancy conditions and operational escalation during DP operations. In several reported events, secondary electrical failures affected multiple vessel systems simultaneously, increasing operational vulnerability during offshore activities.

Human-related operational issues also remained recurrent throughout the reviewed reports. Reported factors included incorrect operator responses, procedural deviations, inadequate situational awareness, communication problems, and maintenance-related errors [4-10]. Human-system interaction therefore continued to influence escalation during degraded DP conditions, particularly when operators were required to respond to multiple simultaneous alarms or abnormal system conditions.

Computer-related secondary causes included software instability, network communication failures, degraded control system interfaces, and sensor integration problems. As modern DP systems become increasingly dependent on automation and integrated digital control systems, software-related abnormalities may increase operational uncertainty during degraded operating conditions.

The reported share of mechanical secondary causes was 13% in 2020 and 23% in 2024, with values of 12-18% in the intervening years. This descriptive pattern may reflect equipment condition, maintenance practices, reporting behavior, or classification differences and does not establish an underlying increase.

Overall, the reviewed reports suggest that DP degradation events frequently involve interaction between technical failures, operational decision-making, and redundancy management issues rather than isolated equipment malfunction alone. Maintaining DP operational resilience therefore requires not only technical redundancy, but also effective maintenance management, procedural

compliance, operational awareness, and human-system interaction during degraded operating conditions.

#### **4.4 Human and Operational Factors**

The reviewed IMCA reports indicate that many Dynamic Positioning events involved interactions among technical failures, degraded system conditions, and operational decision-making rather than isolated equipment malfunction alone [4-10]. As Figure 2 illustrates, DP degradation events may develop through progressive interactions among technical abnormalities, reduced redundancy conditions, operator perception, and operational response during offshore activities.

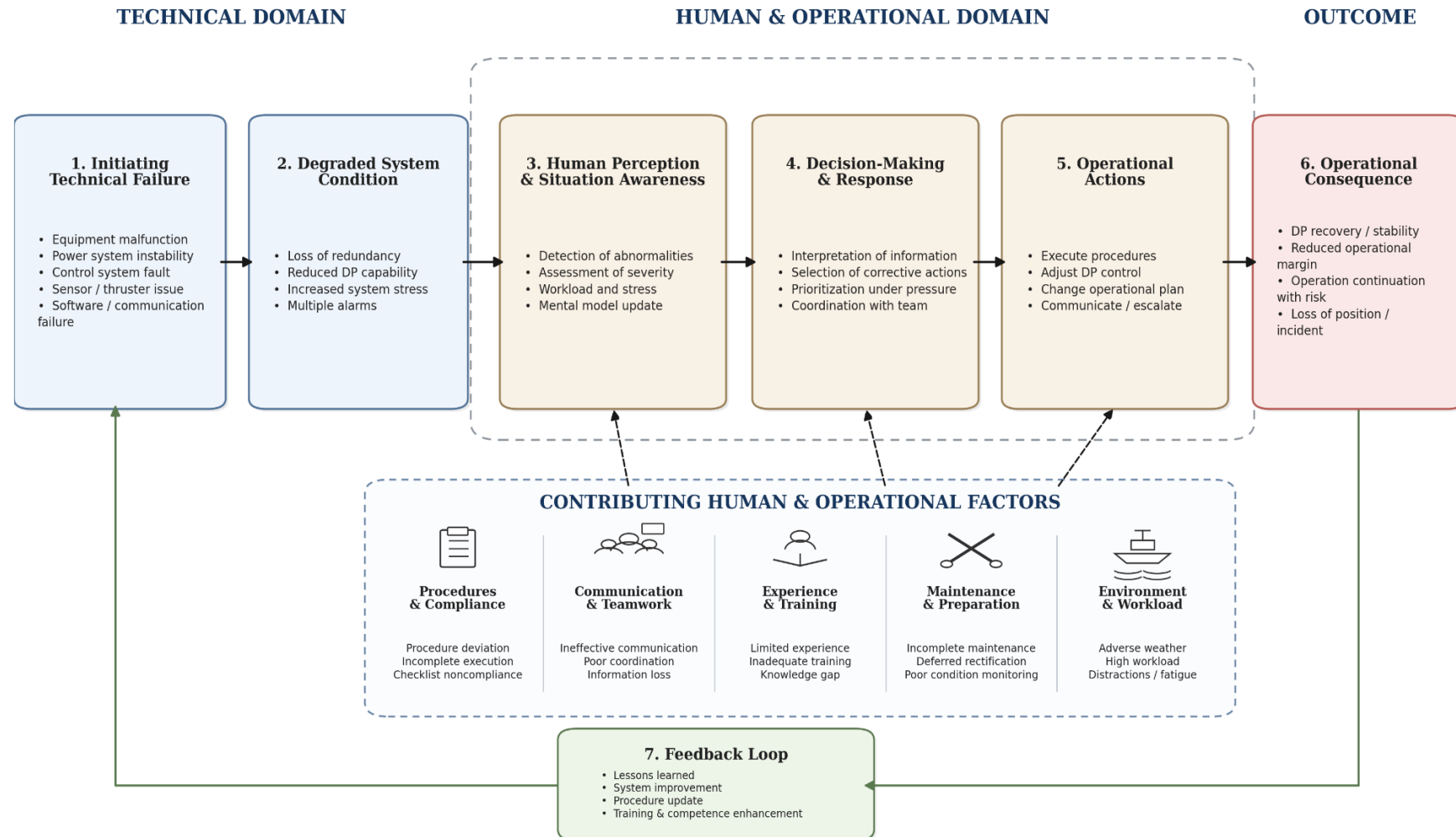


**Figure 2** Interpretive DP escalation framework integrating technical degradation, HFACS-related human and organizational factors, operational consequences, and learning feedback. Legend: Blue boxes represent technical conditions; beige boxes represent human and operational processes; red boxes represent operational consequences; green boxes represent organizational learning and feedback; dashed arrows indicate contributing influences rather than statistically verified causal relationships.

In several reported events, initial technical failures such as power instability, control system faults, sensor abnormalities, or propulsion-related failures degraded DP capability and increased operational stress. Under these conditions, operators were often required to respond to multiple simultaneous alarms, reduced redundancy conditions, and rapidly changing operational environments within limited decision-making timeframes. HFACS was applied as an interpretive lens rather than as a retrospective event-coding system. Operator responses and inappropriate corrective actions were considered at the unsafe-act level; workload, alarm burden, and incomplete situational awareness were interpreted as preconditions for unsafe acts; inadequate testing, maintenance preparation, and operational planning were associated with supervisory influences; and procedural weaknesses, communication arrangements, and organizational learning were interpreted as organizational influences [11].

Human and operational factors were frequently associated with escalation during degraded DP conditions. Reported operational issues included delayed operator response, incomplete situational awareness, procedural noncompliance, ineffective communication, and inappropriate corrective actions during abnormal operating conditions. In some cases, offshore activities continued despite unresolved technical deficiencies or reduced DP redundancy capability, increasing operational exposure during subsea and restricted offshore operations.

Figure 2 integrates these HFACS-related layers with technical initiating failures, degraded redundancy, operational outcomes, and organizational feedback. The framework extends the original IMCA main/secondary cause classification by illustrating how technical and human-organizational conditions may interact during escalation. The arrows represent an interpretive pathway derived from the reviewed narratives and do not indicate statistically demonstrated causation.

The reviewed reports further indicate that increasing automation and digital integration within modern DP systems may increase operational dependence on effective operator response and system interpretation during abnormal conditions. Failures associated with software interaction, alarm management, and integrated control systems may increase operator workload and decision-making complexity during degraded operations.

Overall, the reviewed events suggest that DP degradation is a system-level operational problem involving interactions among technical systems, human decision-making, operational procedures, and organizational preparation rather than isolated equipment failures alone. Maintaining long-term DP operational resilience may therefore require integrated approaches combining technical reliability, operational training, maintenance management, procedural compliance, and resilience-oriented safety management strategies.

## **5. Operational and Environmental Implications**

The reviewed IMCA reports indicate that Dynamic Positioning degradation remains a recurring operational challenge across offshore industries [4-10]. Although the reported events involved different vessel types, operational activities, and offshore environments, the review repeatedly identified these issues throughout the review period.

One prominent descriptive finding of this review is the continuing dominance of thruster and propulsion-related failures as primary contributors to DP degradation. As shown in Table 2, propulsion-related failures consistently represented the largest main cause category between 2018

and 2024. Because DP capability depends directly on continuous thrust allocation and vessel response performance, propulsion instability may rapidly reduce operational safety margins during offshore activities. These findings suggest that propulsion system reliability remains a critical component of long-term DP operational resilience.

The reviewed reports also demonstrate the recurring operational relevance of power-related and electrical failures. The reported annual shares fluctuated after 2020, but these variations do not establish a temporal increase in the underlying event rate. These patterns illustrate the dependence of modern offshore vessels on integrated electrical systems, automated control architectures, and complex power management configurations. Failures involving electrical instability, switchboard interactions, and power-distribution abnormalities may therefore cause cascading operational effects during degraded DP conditions.

Computer-related failures also remained consistently identifiable throughout the reviewed reports. Software instability, network communication failures, sensor integration problems, and degraded control system performance were repeatedly associated with both main and secondary causes. As offshore operations become increasingly dependent on automation and digital integration, maintaining reliable interaction between operators and automated control systems may become increasingly important during abnormal operating conditions.

Another important finding of this review is the continuing contribution of human and operational factors during DP degradation events. Although human-related issues were less frequently identified as direct main causes, human error and operational decision-making remained recurrent secondary contributing factors throughout the review period. Several reviewed events involved delayed operational response, inadequate situational awareness, ineffective communication, or procedural noncompliance during degraded DP capability. These findings suggest that operational escalation frequently develops through interaction between technical abnormalities and human-system interaction rather than isolated technical failure alone.

Mechanical secondary causes accounted for higher reported shares in several later annual reports. However, these values do not establish an underlying temporal increase. This reported pattern may indicate increasing operational concern regarding maintenance quality, equipment aging, machinery reliability, and long-term asset management within DP-supported offshore operations. Inadequate maintenance preparation and unresolved technical deficiencies may increase operational vulnerability prior to offshore activities, particularly during operations conducted in restricted environments with limited recovery capability.

DP degradation during offshore construction, drilling support, and subsea operations may also contribute to indirect environmental exposure. Loss of vessel position or reduced DP capability may increase the risk of subsea infrastructure interference, cable damage, hydrocarbon release, or operational interruption affecting offshore energy systems. In offshore renewable energy support operations, degraded DP performance may also affect installation accuracy and operational continuity within environmentally sensitive marine environments.

Although most reviewed IMCA events did not result in major environmental accidents, the reports demonstrate that degraded DP capability may increase environmental vulnerability during complex offshore operations involving subsea assets, restricted maneuvering conditions, and high-value offshore infrastructure.

The reviewed findings also support the importance of resilience-oriented operational management within modern DP operations. Traditional reliability approaches focus primarily on

preventing individual equipment failures; however, the reviewed reports suggest that many DP events involve interaction between technical degradation, operational workload, organizational preparation, and human decision-making under abnormal conditions. Maintaining operational resilience may therefore require integrated approaches combining technical redundancy, operational awareness, maintenance management, procedural compliance, and effective decision-support capability. Based on established DP assurance, annual trials, operational planning, and personnel competence guidance [15-18], Table 4 links the recurring cause groups to corresponding operational controls and emerging technologies.

**Table 4** Qualitative Cause-Interaction and Mitigation Matrix.

| Main reported cause            | Qualitative contributing pattern                                                                   | Targeted mitigation                                                                                                                       |
|--------------------------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Thruster and propulsion        | Electrical or control faults; mechanical degradation; delayed response under multiple alarms       | Condition monitoring and predictive maintenance; failure-isolation tests; capability and ASOG-based abort thresholds                      |
| Power and electrical           | Generator, switchboard, PMS, protection-system, and common-mode interactions                       | FMEA validation; annual proving trials; power-quality trending; verification of protective settings and load shedding                     |
| Computer and control           | Software instability; network failure; configuration errors; alarm overload                        | Configuration control; regression and change testing; network monitoring; alarm rationalization; independent backup modes                 |
| Position reference and sensors | Reference loss or disagreement; sensor degradation; communication or external interference         | Reference diversity and independence; weighting and voting monitoring; interference detection; cross-checking before close-proximity work |
| Human and operational          | Situational-awareness, communication, procedural, training, and maintenance-preparation weaknesses | Competence and familiarization; scenario-based drills; bridge-engine coordination; ASOG and stop-work criteria                            |

Note: The contributing patterns presented in this table are a qualitative synthesis of recurring narrative interactions. They do not represent event-level cross-correlations or frequency-ranked main-secondary cause combinations.

Several emerging technologies may improve future DP operational resilience. Predictive maintenance systems, condition monitoring technologies, AI-assisted anomaly detection, digital twin platforms, and integrated decision-support systems may improve early identification of degraded operating conditions before escalation into more serious operational events. However, increasing levels of automation may also add operational complexity associated with software reliability, alarm management, and human-system interaction. Future offshore operations may

therefore require balanced integration between automated technologies and operator-centered operational management.

This review has several limitations. IMCA reporting is voluntary and may under-represent unrecognized, commercially sensitive, minor, or non-member events, while organizations with mature reporting cultures may be over-represented. Reliance on a single self-reported source may therefore skew the observed category distributions. The IMCA data were not combined with external datasets because directly comparable data were unavailable. Maritime casualty databases generally capture higher-severity outcomes, while insurance claims data are largely proprietary. Furthermore, neither source consistently includes observations and undesired events comparable to those classified in the IMCA reports. Reporting structures and category definitions also varied slightly between annual reports. Accordingly, the results describe recurring patterns within the submitted IMCA records and should not be interpreted as population prevalence, incident rates, statistically significant temporal changes, or complete consequence distributions.

## **6. Conclusions**

This study reviewed DP station-keeping events reported by IMCA between 2018 and 2024 to identify recurring patterns within voluntary industry submissions. The analysis does not estimate industry-wide incident rates or statistically significant temporal changes. The reviewed reports indicate that DP-related operational challenges continue to involve complex interactions between technical failures, operational decision-making, and organizational safety management rather than isolated equipment malfunction alone.

The review identified thruster and propulsion-related failures as the dominant main cause category throughout the review period. Power-related failures, electrical instability, and computer-related abnormalities also remained consistently observable across multiple reporting periods. These findings illustrate the operational dependence of modern DP vessels on integrated electrical systems, automated control architectures, and digital system interaction.

Secondary cause analysis further demonstrated the continuing operational importance of electrical failures, human-related operational issues, and mechanical deficiencies during degraded DP conditions. In particular, the reviewed reports indicate that many DP events escalated due to delayed operational response, ineffective communication, inadequate situational awareness, procedural noncompliance, and unresolved technical deficiencies during offshore activities.

The reviewed findings also suggest that maintaining DP operational resilience requires more than technical redundancy alone. Effective maintenance planning, operational preparation, organizational safety management, and human-system interaction remain critical to safe DP operations, particularly during degraded operating conditions involving multiple simultaneous abnormalities and reduced operational margins.

As offshore operations become increasingly automated and technologically integrated, future DP operational resilience may depend on balanced integration between automated technologies and operator-centered decision-making processes. Emerging technologies such as predictive maintenance systems, AI-assisted anomaly detection, condition monitoring platforms, and digital twin technologies may help identify degraded operating conditions earlier and improve operational awareness during offshore activities.

Although this review was based on voluntary industry reporting and does not represent a complete statistical dataset of all DP-related events, the reviewed IMCA reports provide valuable long-term operational evidence regarding recurring vulnerabilities and resilience-related challenges within modern DP-supported offshore operations. Future research may further expand quantitative analysis of DP degradation mechanisms, human-system interaction, and predictive operational risk management within increasingly automated offshore environments. Additional research on environmental exposure during degraded DP operations may also support the development of more sustainable and resilience-oriented offshore operational management strategies. Future research will require event-level data linking vessel activity, operating exposure, main and secondary causes, event classification, and realized consequences before cross-correlation, numerical severity weighting, or predictive risk modelling can be justified.

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### **Author Contributions**

Jeongmin Kim conducted the conceptualization, literature review, data analysis, interpretation of results, manuscript preparation, and final review of the study.

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### **Competing Interests**

The author has declared that no competing interests exist.

### **Data Availability Statement**

The data supporting the findings of this study are publicly available through the International Marine Contractors Association (IMCA) Dynamic Positioning station keeping review reports published between 2018 and 2024. Additional information can be obtained from the IMCA official website: <https://www.imca-int.com/>.

### **AI-Assisted Technologies Statement**

Artificial intelligence (AI) tools were used for basic grammar correction, language refinement, and visual formatting of figures in the preparation of this manuscript. Specifically, OpenAI's ChatGPT was employed to improve the readability and linguistic clarity of the English text and to assist with the visual arrangement and presentation of figures. All scientific content, research data, analyses, interpretations, and conclusions were developed independently by the author. The author has thoroughly reviewed and verified all AI-assisted modifications to ensure their accuracy and accepts full responsibility for the content of the manuscript.

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