Abstract

The recent resurgence of interest in Integrated Operations (IO) and Integrity Management (IM) for the oil and gas industry has triggered necessary discussions of why revisiting these ideas and initiatives is important to the future of the industry. By implementing IO and IM programs and initiatives, operators gain an advantage in achieving increased recovery, reduction of operating expenses (OPEX), efficiency in execution, and optimization of asset availability. More than ever, the operator is held accountable by company stakeholders to determine rationalization when implementing any new program. This paper is to provide supportive rationale that the operator needs in choosing the subsea system provider as the best equipped to develop the intelligence engine driving its IO and IM programs.

The key to a successful IO and IM program design and implementation lies in the provider’s proven history of experience and competence in the areas of well completion, production flow management, power distribution (hydraulic and electrical), controls (subsea and topside), installation, intervention, and life of field services and support. On both the technical and logistical sides of IO, expertise in these areas lends to the provider a better comprehension and applicable tools essential to the successful and effective implementation of a real-time diagnostics system and the associated support services program, including:

- Risk identification
- Risk mitigation
- Performance attributes and trends (system and component)
- Preventative maintenance program enhancement
- Failure modes (system and component)
- Performance indicator algorithm development
- System integration
- Event response support and counsel
- Timely intervention planning
- Improved intervention execution

After being presented with this information, the IM program management of the operating company will understand why their program’s success is greatly increased when it is backed by a reliable partnership with a subsea system supplier. Additionally, the operator will possess a clear set of criteria to help them evaluate potential suppliers of this valuable support piece ensuring them continuous and reliable production operations over the life of the field.

Introduction

Offshore oil and gas operators are beginning to understand the importance of IO and IM programs to their offshore and subsea assets (Røed, 2005); and therefore, hold their implementation as internal initiatives for responsible stewardship of these valuable assets. However, the IM program appears to be a best business practice that struggles to get much support within the company, as it requires a large amount of work—especially when implementing retroactively—and has no obvious, immediate
return on investment. This investment can be quite substantial (ref: OLF, 2006), considering the fact that developing the concept and underlying deterministic algorithm requires fairly experienced engineering resources.

Post commissioning, the operator’s primary focus is maximizing the system uptime. Unfortunately, since the maintenance and optimization aspect of the installed base does not have the same level of funding as new developments and intervention activities, it is very susceptible to neglect. Hence, administering maintenance and optimization efforts must be as lean as possible, lest it be seen as a consistently costly investment. The fact is that the successful implementation of IM and IO programs requires technical expertise in the field-installed equipment, operational considerations, as well as functional knowledge of the underlying programs. Above all, however, unwavering dedication to the initiative and effective implementation of a developed solution is vital (Røed, 2005). If any of these elements is missing, the initiative fails to properly launch, and the program can be easily categorized as a “money pit”; and, subsequently, the most important aspects of continued productive operations are never effectively implemented. Avoiding such a pitfall comes through partnership with an agent that will keep the success of integrity management and integrated operations programs a primary focus and priority.

The subsea systems provider has the capability (inclusive of all the traits mentioned above) to effectively implement and administer, and successfully maintain IO and IM programs and their associated services. As an IO and IM program architect, the subsea systems provider brings along the extensive knowledge of the equipment, interfaces, and operations. Establishment of a small oversight organization within the operating company—to perform reviews, approvals, point-of-contact, etc.—maintains ultimate control for the operator, and to ensure that the company’s objectives are upheld and/or being met. These two groups, in association with a consortium of other product-service-specific vendors (for SME support), form an effective group for program implementation. The result is a mutually beneficial relationship between the companies to best support the life of the field.

Statement of Theory and Definitions

Programs

The focus of this paper is the successful implementation of two distinct, but—when properly employed—intertwined programs (or concepts), namely Integrated Operations (IO) and Integrity Management (IM). Therefore, perhaps it is best to first define these concepts.

Integrated Operations

IO Definition

Integrated operations is defined (by these authors) as the “the integration of people and resources across geographical distance (including onshore/offshore), company borders, and technical disciplines.” IO is the systematic assimilation of resources to promote—and yield—the maximum benefit of available, but otherwise diverse, operational programs for the overall objective of the organization—which is, in this industry’s case, subsea oil and gas production. The resources being integrated are those most readily available and utilized: people, processes, and data. A common theme in most IO-related papers and write-ups is that the last of these (i.e., data) is paramount in the program’s realization, whether it be real-time (a large focus) or historical. Accordingly, from the standpoint of offshore oil and gas production, IO essentially connects: (1) offshore to onshore, (2) the operations to the employee, and (3) the employee to subsea. The result is a connected microcosm that has the best possible potential to maintain and optimize production operations.

IO Uses

A typical IO program has three (3) functional uses: (1) recognize [problem] conditions, (2) provide solutions, and (3) facilitate actions.

Firstly, recognizing the current condition(s) requires crucial knowledge of the system configuration, the potential risks, intelligent identification of troubling conditions, and equally important, the ability to discern the severity of such. This sounds rather complex and involved—and rightfully so, as it takes incredible effort that is mostly customer- and asset-specific. However, with access to the right tools, this is a relatively painless process for educated and experienced personnel. The tools for executing this task are already well established and in use—e.g., risk analysis; engineering investigation; Failure Modes, Effects, and Criticality Analysis (FMECA); Key Performance Indicator (KPI) development; lessons learned; etc. Experience, being the most drawn upon, unfortunately almost always tends to be in clusters of tribal knowledge that varies quite widely depending on the personnel present during an event. IO provides the means of extracting, validating, and documenting the otherwise localized knowledge of system performance, to the extent that the underlying algorithms are updated to recognize
similar situations in the future, irrespective of the person on hand—this is increasingly important given the impending retirement of seasoned operators (Skytte af Sättra, et al, 2010).

Next, providing solutions has some key ingredients of its own; these include much of the data produced while completing the aforementioned condition recognition development tasks, operational knowledge, and operational experience. Fortunately, with proper implementation, the knowledge that goes into identifying problem conditions helps to recommend proven/known solutions that are archived in the IO infrastructure as a future troubleshooting aid.

Finally, the third application of the IO program is in facilitating actions to remedy the situation recognized. Hence, IO can guide and execute day-to-day operations and thereby serve as a vehicle to employ the solution in response to a recognized condition.

**Employment of IO**

The employment of the IO methodology across offshore operations has many features; however, at least three (3) primary manifestations are integral and characteristic of the operations of each implementation in today’s industry: (1) real-time monitoring systems, (2) 24/7 on-line global support, and (3) rapid response coordination. As will be emphasized later in this article, one IO concept is paramount: “Data is King!”

It is undeniable that access to proper (i.e., applicable, valid, reliable) data is needed to accurately establish the condition of a system and formulate the appropriate path forward. IO’s means of accomplishing this is via a “real-time” monitoring system. The term “real-time” must be cautiously used, however, as it requires the understanding that, in most cases, this includes data being polled from a sensor, handled in a control module, transmitted to the topside system, churned through an algorithm, inserted into a database, and retrieved for display in a Human-Machine Interface (HMI). Realistically, this is at best, three-second delayed data and more likely 30- to 60-second delayed data. Though, one must remember that condition monitoring systems are primarily intended to sense developing performance degradations—rather than immediate, catastrophic crashes, which are left to the devices of the system control software and on-site operators—and, therefore, these system-inherent delays are deemed acceptable.

Nevertheless, the [now historical] data is valuable in the response and resolution of immediate catastrophic crashes, as well—especially during the root cause analysis and related investigation. Despite the best monitoring technology and efforts, data is useless without knowledgeable resources to interpret it and provide support and counsel. Two aspects are imperative to effective support of offshore operations: (1) round-the-clock system availability and (2) global presence. The former attribute is generally accepted as common sense and a minimum requirement in the care of the now commonplace “24 hours a day, 7 days a week” support and service hotline. However, the latter is more topical and quite essential considering the global nature of the industry.

![Figure 1: Global Integrated Operations Landscape](image)

Figure 1: Global Integrated Operations Landscape
Figure 1 illustrates an example of the global landscape of integrated operations with development in Scotland, equipment coming from Houston, service support originating in Singapore, and offshore operations in Africa. The wide displacement of operating centers demands that the administrator of an IO program have a global presence and access to resources in all locations; the best knowledge- and experience-bases within an organization are too easily disbursed around the globe for any less.

Again, all best intentions and efforts are easily quashed into futility without a coordinated and timely response. As the old adage dictates, “time is money;” nothing is truer when continuing production is threatened. However, when response times are also closely tied to the safety of personnel and operations (as they are in offshore efforts), one can generalize to the similarly universal axiom “timing is everything.” Timing and effectiveness define the success of a service organization, and IO program administrators are no exception to this. Recall, the ultimate purpose of IO is to recognize suboptimal performances and address them early, so as to minimize the severity of impact (both monetarily and operationally) they might have on operations. Unfortunately, in the industry today, otherwise avoidable firefighting—with all of its waste in avoidable expediting fees and associated expense—is generally deemed a success or even celebrated. It remains an uphill battle to change this paradigm.

**Integrity Management**

**IM Definition**

Integrity Management, as a concept, aims to understand and maintain the covered systems in view of sustaining safe and productive operations. Along with its associated processes and tools, the IM program is focused on the complete understanding of the condition of systems and equipment to ensure proper operations throughout the life of the field. IM is, in all practicality, risk management. However, as with many tasks in the offshore world, it is not quite as easily done as it is stated. It is difficult to effectively manage risks without knowing how to identify, classify, mitigate, prevent, and recognize them.

**IM Uses**

Specifically from offshore asset standpoint, the IM program has three (3) primary applications: (1) it identifies concerns, (2) it establishes mitigation plans, and (3) it interprets performance data trends to evaluate effectiveness.

Risk identification is made possible through a deep understanding of the system (or equipment), the operations (including contingencies), and the environment (including interfaces, external forces, human error, etc.). Equipment manufacturers and system integrators are good sources for this knowledge; this is further enhanced when they are the same entity, since the success of their products relies on complete understanding of the design criteria parameters. Risk analysis results in firm understanding of likelihood (i.e., probability of occurrence) and the severity of impact (i.e., consequences) of the inherent risks. These analyses can be performed with respect to time and money, operations, safety, and per best business practice for all.

Whereas the entirety of the identification tasks along with mitigation planning are ideally upfront efforts, the actual implementation of mitigation tasks are further into the operations phase. Hence, while the methods of risk avoidance would have been confirmed prior to operational startup, the active practice of mitigation must be adhered to and maintained during operations throughout the life of the field (as applicable). Risk mitigation techniques may manifest as engineered barriers, but often times rely on several human-driven methodologies, such as procedural restrictions, safe practices and inspection schedules, and/or preventative maintenance programs.

The question then is: how does one assure and validate that mitigation efforts are not either insufficient or too much? The loop is closed with the interpretation of performance data trends. This aspect is essential for intelligent operations and to maximizing the benefit of an IM program. In essence, the KPIs are defined, developed, and implemented; and analysis of the resultant data—showing performance over time—is used to validate the risks and/or adjust the mitigation techniques. This can and indeed should be a two-pronged effort in which the KPI data is analyzed (1) in “real-time” to determine short-term responses—as discussed in IO above, and (2) offline—though still timely—to implement change in the operational plans to enhance efficiency and effectiveness.

**Employment of IM**

As a result of the above, we can witness the employment of IM methodology in several familiar manifestations within the regular practices of the industry. Risk identification, analysis, and mitigation documents are frequently found on the project side of a field with application to financial and schedule risks and impacts. However, as IM initiatives have received greater
focus within the industry, we find them to appear with focus on, and applicability to, assets and operations. The challenge remains procuring the services of an executor highly skilled with a wide breadth of the necessary knowledge and experience bases.

Preventative maintenance program and schedule development efforts are generally forced into a facilities focus due to the accessibility of subsea components. This is a good start; however, one of two paths must be followed with respect to the subsea portion, and both require funding and substantial effort: (1) development of inspection schedules and PM procedures or (2) real-time analysis of performance parameters. “Lean thinking” leads towards the latter, especially considering the CAPEX and incredible mobilization effort associated with the former that realistically draw too much of an inclination to put it off when OPEX is tight.

Implementing a system capable of such analysis additionally affords the possibility for intelligent development of maintenance schedules—i.e., refurbishing or replacing equipment when it is known to be necessary, rather than when it is suspected to be a prudent action. As a result, proper and effective administration of an IM program is not only a best business practice with respect to safety and operations over the life of the field, but also to all OPEX considerations as well.

How IO and IM Relate to One Another

Though defined and separated as distinct initiatives and programs, IO and IM are closely related to one another in several aspects through integral relationships. Ideally, a singular, capable entity administers both of these programs such that maximum benefit can be drawn from their pronounced congruencies to result in the best possible outcome with respect to operational advantage.

Figure 2 shows how IM transitions through six (6) distinct phases of operation. As discussed in the previous section, three of the phases—Identify, Mitigate, and Interpret—are exclusively IM-specific functions. The remainder of the six phases of the IM cycle of operations, IO facilitates the execution of the “Develop,” “Monitor,” and “Validate” stages.

First, the documents/analyses produced from IM efforts are used to define the scope of IO data services. Risk-based inspection (RBI) reports, risk analysis reports, and subsequent KPI and notification thresholds contain valuable data that provide the foundation for the functional design of a condition monitoring system.

Next, IO supports IM through enabling its effectiveness. IO programs execute the processes by which risks are mitigated. Though the fundamental theory of each KPI is determined as an IM deliverable, it is the deployment of a condition monitoring system that derives the algorithms that analyze system performance, builds the data trends, and makes the notifications. When system integrity has been compromised—or is indicating significant risk of doing so—the IO program is intended (by design) to devise and plan the proper response, and execute the actions to eliminate (or mitigate) the concern.

By design, as well, the IM program regularly utilizes the IO output data—e.g., real-time data trends, KPI values, non-conformance reports (NCR), test data, etc.—for process and program improvement. IM uses trends to validate the risk
analysis and preventative maintenance programs (including content and schedule). Learnings from the output of the IO data services can be applied to PM and inspection programs to justify modifications of practices, or to provide greater confidence in existing practices.

In general, IO makes IM effective. From the above, we can draw the conclusion that the two programs share a symbiotic relationship that is best handled as a partnership. IM defines the problem, and IO defines the solution. The IM program is the customer of the IO services. IO is the agent of IM to achieve programmatic success. Ultimately, IM is an indispensible part of IO… when operations are truly integrated.

Value and Importance to the Industry and the Operator

Having described each of the programs and how they relate to one another, the next set of questions is: what comprises each; how they can be used; and what does their implementation mean to an operator? Establishment of Integrity Management and Integrated Operations programs can have several distinct advantages for an operator.

Though the implementation of IO and IM programs require significant investment and effort, the potential for reduction of OPEX and increase in (and sustaninment of-) clearly justify the initial investment (Jeffrey, 2009). Open communication, sharing of knowledge and data, and programmatic relationships between different entities within the operating company and its service providers promotes efficiency in execution; and the trending of KPI enables (and justifies) modifications to PM practices that could help eliminate waste in ways such as not replacing components at frequencies greater than necessary, or increase system uptime by making repairs or changing components sooner. All with the end result of maximizing production uptime. In the end, the potential advantages are summarized as (1) increased efficiency in execution, (2) reduction of OPEX, and (3) optimization of asset availability.

However, the long-term advantages go even further. The lessons learned from the subsea data trends can provide the operator with insight, evidence, and justification for and into system modifications, retrofits and upgrades that would increase the production recovery and effectively increase the life of the field. The primary goal and benefit of IO and IM program implementation is to better understand and “be in tune with” your subsea assets such that the maximum value can be obtained from significant subsea developments.

Finally, offshore operations (from the broadest aspect) stand to benefit from the implementation of Integrated Operations and Integrity Management programs. Maximum insight to the health of systems and equipment, and the ability to remove operations from firefighting mode, increases safety at the end of the day by limiting exposure, reducing the pressure for rushed performance, and leaving more time for focus on quality and safety. Having the resources in place for early detection of equipment degradation and failures also provides operators with the opportunity to take action on erosion before it becomes a leak, a small leak before it becomes an unacceptable leak, and a non-compliance before it becomes an environmental disaster.

Key Elements of IO and IM

Successful Integrated Operations and Integrity Management programs have defined, indispensible characteristics that represent the operational philosophy of the asset owners and those entities helping to administer the programs. They include: skilful use of system data, supporting infrastructure, partnerships with vendors, global presence, and trust.

As stated previously in this paper: “Data is King!” Having it (and being able to trust it) provides enlightenment and facilitates deeper understanding of the applicable system(s); lacking it forces conservative predictions and assumptions, and ultimate blame for problems—since the evidence to prove otherwise is non-existent. Although, having data does not exclusively ensure success, it must be properly employed within the operations.

- One must consider how the data is being used—is it being monitored in real-time? Is it being aggregated into KPI algorithms? Are the KPI algorithms accurate and are all the remaining assumptions valid? Are the proper, knowledgeable personnel analyzing the results?
- Is the data trustworthy? Invalid, unreliable, corrupt, stale (i.e., out-dated) information from the subsea systems has a greater possibility to cause [more] problems rather than have no affect at all.
- Has a gap analysis of necessary data been performed? Missing vital data tags (or sensing instrumentation) can hinder the proper execution of a best-practice algorithm, and increase its evaluation assumptions and complexity.
- Can the missing data be obtained? Once a gap analysis has been performed and necessary data is identified, another analysis—this time focused on the value of work—must be performed to determine (1) how difficult it is to obtain the data and (2) what ultimate value that particular piece of information has on the system. Oftentimes, it is simply a matter of exporting data from the control system into a historian or increasing the sampling
frequency; conversely, obtaining the data can mean pulling equipment back from subsea and retrofitting it with expensive sensors. The latter case is rarely done (unless piggybacking on a planned refurbishment) due to the impact on production and the cost associated with a subsea intervention; however, all of the analysis efforts have not gone to waste. The value then comes with being equipped with these learnings when planning the next system design—i.e., when incorporation of precisely placed instrumentation is at its lowest cost and effort...before software has been written, before designs have been finalized, and avoiding the moment of regret for lack of foresight.

**Offshore Development Focus and Applicability**

Another quandary operators experience when considering establishment of an Integrated Operations program is the timing of implementation. As will be presented in the following section, subsea system owners can be put-off by the potential monumental effort (and associated development costs) for implementing IO in an existing (or, majority-) installation—i.e., “Brownfield.” More often than not, without previously established IO programs, asset planners question the benefit and are apprehensive to implement IO in new subsea development projects—i.e., “Greenfield.” This resistance is quite often echoed in operations personnel’s aversion to the cultural change associated with the introduction of IO. This section serves to justify the advantages of IO program implementation, regardless of the life-of-field phase; as well, the contrasts drawn will show that early life planning for such a program better serves the operations—at the front end, and through the life of the field.

**Brownfield Developments**

Implementing an IO program into Brownfield operations, the most important element is existing documentation. That is, the better documented a project is (especially when that documentation is maintained for as-built accuracy), in terms of being available and well organized—the less daunting the implementation effort is. It is necessary to understand what elements comprise the system to ensure effectiveness of the program. Doing so can entail a complete audit of the asset—i.e., topside to subsea—risk analysis, verification of the as-built configuration, and an assessment of the available data (both real-time and historical).

The next major task, though closely related, is identification and analysis of the existing gaps—in documentation, available sensor data, etc. Gap analysis includes not only the reporting of the gaps, but also: the depth to which the gap extends, feasible options for bridging the gaps, pros and cons associated with each option, and the value to operations yielded from filling the gap. As discussed in the previous section, equally important as the gap analysis is a complete understanding of the effort and impacts associated with bridging each of the gaps. Return on investment (ROI) must be considered on a case-by-case basis to avoid waste. Whereas the resultant insight of the addition of more data and documentation is likely deemed valuable and important, it has a tendency to appear less feasible when the necessary investment looks as if it will outweigh the benefit(s) (OLF, 2008).

It is important item to keep in mind that a baseline of the field’s health must be established early on in the implementation when developing IO for a Brownfield. Proper and accurate establishment of this footprint is essential to draw out actual reductions in system performance; failure to do so could result in excessive notification of existing/known conditions that amount to nothing more than nuisances, and divert attention from important notifications. Accordingly, one must understand that long-producing wells will likely not be performing at peak potential upon startup of the IO program. This includes known conditions of suboptimal performance (e.g., hydraulic leads, flow restrictions, fatiguing, erosion, etc.). Whereas, if designed properly, the condition monitoring system (an integral element of IO) will detect any existing concerns, operators may choose to overlook known conditions, due to low impact on system performance, and prefer to exclusively trend degradation progression. By doing so, operators can make more educated decisions concerning remediation efforts in response to event/problem notifications.

Furthermore, efforts should also be made to integrate historical data into new condition monitoring systems. The ultimate goal of such a system is early notification or prevention of developing failure conditions, but it can also assist in the root cause analysis (RCA) of sudden and/or catastrophic failures. While any installation (i.e., existing or new) with a condition monitoring system can benefit from utilizing its capabilities to review failures and/or catastrophic events as they occur, Brownfield installations can draw learning opportunities from applying more current evaluations to past events that may date as far back as the startup of the first well. Though it may be hindered by the lack of specific data, such analysis may provide insight previously unrecognized or conditions by which to evaluate future, developing events. Essentially, introspective understanding of historical data from past problems unable to be foreseen can be used to modify KPIs to include any critical characteristics.

Once a keen understanding of the development’s system performance is achieved, asset owners and operators can use the data as justification for system upgrades and equipment retrofits to support increased oil recovery (IOR). This begins with
identifying new and/or current technology that can eliminate existing performance concerns. Through IO, asset stewards can strategize on how to best capitalize on equipment pullbacks such that more high value gaps can be filled. Real-time trending and analysis of production supports equipment health, and promotes appropriately timed upgrades and/or modifications to the system through prudently planned interventions. Making the most of these opportunities, and employing gradual but progressive disbursement of technological advances, the assets can advance towards newer, safer, and more reliable system technology. All ultimately supporting boosts in production that could not have otherwise been realized.

Greenfield Developments

Planning for Integrated Operations in the Front-End Engineering and Design (FEED) phase of a Greenfield development has distinct advantages over a retroactive, Brownfield deployment in addition to the previously mentioned benefits applicable to Brownfield development. Those benefits include the application of new condition monitoring and analysis tools to historical data via now well-documented lessons learned concerning the recognition of certain critical performance characteristics. Early on, asset owners can recognize the advantages of Greenfield implementation of IO. Establishing an environment of integrating all operations in the fetal stages of the project promotes early, collaborative communication and development across all stakeholders. This greatly facilitates the IO program development (OLF, 2008), and the specifics of the program are developed effectively as the subsea systems are designed.

Additionally, IO’s early inclusion in the life of field services allows proper planning for the condition monitoring system and critical, data-retention strategy. Considering the relatively recent introduction of subsea processing systems, the need for real-time monitoring and precise troubleshooting becomes exceedingly important when subsea rotating machinery is present. Gaps in the monitoring instrumentation can be identified and filled upfront when the cost is at its minimum with respect to impacts on operations and production. That is not to say that, as time goes on technology advances and new discoveries will not create additional gaps; however, this strategy places the operators in the best situation for fewer post-commissioning gaps.

Another item of consideration for upfront planning is the communication strategy; this includes organizational structure, notification protocol, data transfers, and the physical system that supports them all. Having a clear understanding of and firm strategy for the operational goals of the IO program facilitates the definition of programmatic needs; and can help drive decisions on aspects, such as: networked logistics and inventory systems, video conferencing capabilities, data server sizing, data-retention policies, document management systems, media for “on-shoring” data (e.g., satellite or fiber optics), necessary bandwidth, redundancy, and global access. Proper planning and design of a communications system is important especially when considering the impact a “communications breakdown” (in all senses of the term) can have on IO.

Finally, early involvement of IOs into Greenfield development projects can positively affect the planning and support with respect to the life of the field. As data is produced and trends are developed, subsea asset owners and operators can resourcefully implement the strategy for phased deployment of IOR equipment and systems—e.g., water injection and gas lift wells, sidetrack drilling, and mudline and downhole production boosting. The subsea oil and gas industry is one that regularly breaks records (e.g., depth and capacities), consistently meets production challenges (e.g., pressure and temperature), and continually strives to advance its technologies (e.g., subsea separation and processing). The information gathered, lessons learned, and insights gained from the implementation of integrated operations programs can be used as drivers for new technology—allowing us to build on these pro-innovation industry advancement initiatives.

The Subsea System Provider

The subsea system and equipment provider is already a close and effective partner to the subsea asset owner(s) and operator(s) through technology development, system integration, installation and service, and life of field support. When the offered and provided services go beyond simply manufacturing and selling equipment, a transition is made from vendor to partner. A valuable partner in subsea is a vital element of success for operators implementing IM and IO programs.

As the designer and manufacturer of subsea systems (and the equipment that comprises them), the provider has profound knowledge of each individual component’s characteristics and performance. Additionally, the provider has the best source of expertise when those components are assembled and integrated into a working system. By professional obligation and best business practice, the subsea system provider maintains all equipment data (initial, present, and every version in between); and, especially valuable, it maintains all test data—from component manufacturing acceptance to systems integration. All things considered, the system provider is the most knowledgeable source on subsea systems.

The customer support and service organization within the subsea system provider’s businesses is a further value contributor to IO and IM programs. The service organization has engineering and technical experience in a variety of areas—including installations, commissioning, interventions and workovers, maintenance, refurbishment, preservation, and storage. Supporting all these fields gives it keen insight to the associated risks and appropriate recognition and remediation of such.
Regular operation of a service hotline and a structured rapid response plan—coupled with support of normal operations—sustains the service organization’s proficiency in the management and logistics of this wide breadth of skill-sets. Additionally, because it resides within the subsea system provider’s core businesses, it has the full support of global technical and logistical resources. However, perhaps the customer support organization’s most valuable contribution is that its knowledge base spans the full history of the operators’ installed base (i.e., complete product support…not just the latest technologies); as a result, it is capable of supporting IO and IM implementations for both Greenfield and Brownfield assets. Access to early benchmark and baseline data for all equipment and the familiarity of how the data was obtained is an added advantage during RCA or similar analysis.

Many aspects of IO and IM programs already exist within the provider’s businesses; however, they are traditionally, individually parsed-out according to customer request. Consequentially, integration of all of these services by the provider for deployment as an entire program, as already discussed in this paper, stands to provide significant mutual benefit to the system owners, operators, and providers. The subsea system provider has the knowledge, skills and expertise to effectively and successfully develop, implement, administer, and maintain IM and IO programs through close cooperation and partnership with, and for the benefit of, the subsea system owner/operator.

Description and Application of Tools and Processes

As we have seen above, the successful establishment of IM and IO programs has several key components; however, there are some chief contributing aspects of the programs. As an agent of the subsea system operator, the subsea system provider employs its knowledge base and expertise to ensure these functional characteristics are properly implemented in the IO and IM programs—ultimately, ensuring success. As we continue to discuss these portions, one must keep in mind that their successful completion and incorporation relies on two (2) vital ingredients: expertise and partnership. The provider’s expertise must adequately cover the subsea systems and the processes by which the life of the field is maintained. Partnership must extend beyond the simple vendor-customer relationship; this partnership should include qualities, such as trust, open and frequent communication, transparency, and commitment to common purpose.

Risk Assessment and Analysis

Risk assessment and analysis are fundamental elements of successful integrity management—and ultimately, the condition monitoring system employed within the IO program. When identifying risks, one is required to completely understand the equipment, systems, operations, and the operating environment(s). Comprehensive risk analysis entails consideration of the individual units in each of these categories with respect to the other categories. Once risks are identified, a mitigation plan must be devised for each risk that can be mitigated. Mitigation techniques may include engineered or procedural solutions, and allow risks to either be lessened in severity or eliminated completely.

An appropriate follow-up plan for risk identification and analysis is two-fold: RBI and KPIs. The former includes the establishment of an inspection plan (i.e., scope and frequency), but can be greatly inhibited—especially with respect to subsea systems—by accessibility of installation locations and the availability as well as cost of inspection resources (i.e., divers and remotely-operated vehicles). The establishment of KPI utilizes the talent of knowledgeable engineering resources to derive algorithms that accurately evaluate the health of subsea equipment and systems. Oftentimes, this can be as simple as the trending of a single instrument’s data; though, almost as frequently, sensing for the likelihood or actual onset of a particular risk can include the derivation of a complex algorithm that aggregates the readings of multiple sensors within a system, operating conditions, and the current state of a possibly changing system configuration (e.g., power distribution). This can quite often require innovation such as extrapolation and other analytical methodologies when the ideal sensor data is not available within the system.

When evaluating risks for employment of one of the aforementioned trending techniques (i.e., RBI, KPI, or both), it’s important to perform an impact analysis and understand the required investment of effort, and the return operations (with respect to risk avoidance or early identification) will see on that investment. Regular trending, reporting, and consultation of KPI results in the operator closing the risk analysis loop; however, this is a continual task for the life of the field.

Key Performance Indicators

Having identified the need as well as the uses of KPIs in the previous section, there is a need to understand the different types of KPIs that can be developed. Generally, there are two types: (1) leading and (2) lagging. Leading indicators address the [possible] causes of a specific condition or event, and are the basis for the development of preventative maintenance programs. They provide indication—based on measurements and algorithm-based evaluation of the conditions of the system or specific component—that the probability for concerns (i.e., sub-optimal performance, damage, failure, etc.) is high enough that such an event is imminent but has not yet been realized as actual. Conversely, lagging indicators address the [possible]
consequences; such theory recognizes that the condition has already onset, or that the event has already begun or occurred to some extent. Though they utilize data and calculations to verify inception of the one of the aforementioned conditions, lagging indicators do not necessarily signify that total failure is imminent or that interventional action cannot be initiated to prevent progression of the condition.

![Figure 3: Remediation Cost as Compared to the Timeline of Progressively Deteriorating Conditions](image)

Figure 3 illustrates how remediation costs—manifesting in these early stages as preventative maintenance (PM) costs—are high as compared to those associated with initial onset of suboptimal performance conditions. This is due to the PM modus operandi that equipment is serviced based on historical data rather than concrete evidence. As actions are spaced-out to occur closer to the point of initial deterioration, the cost lowers (and the value of waiting reaches its peak); however, such an approach is a gamble that requires two key elements: (1) immense understanding of the equipment and operations, and (2) luck. Likewise, a post-failure, reactive mindset causes a sharp rise in remediation costs as a result of operating in “firefighting” mode. This increase is a consequence of system downtime, loss of production, operation expediting fees, and similarly associated costs. Real-time indication strikes a balance between truly leading and truly lagging by not taking action until confirmation of the condition is made, but prior to a failure event.

Oftentimes in their development, algorithms can result in KPI that are lagging in the initial onset of problems; but, simultaneously, are leading indicators for severe concern and/or total failure. This is where real-time KPIs (as in a real-time condition monitoring systems) fit in. They use “current” condition data to determine the health of a system—even though this means it has already deteriorated to some extent. However, provided the uncertainty (no matter how small) that exists in truly leading indicators, this tends to still be the preferred method of indication for many operators.

Although leading indicators are traditionally preferred, due to their capability of “true” foresight—promoting earlier preventative intervention—lagging indicators are not without merit. If properly designed, the latter holds the potential to provide adequate warning for intervention planning, and reports solely on verified problem conditions—whereas the former alerts users that the probability of problem conditions is high, which could still leave doubt as to whether or not the condition will actually occur. Additionally, lagging indicators can be valuable in the investigation of sudden, unforeseeable catastrophic failures.

On a final note concerning KPIs, their development, usage, and results can identify gaps in a system’s instrumentation and opportunities for improvement in this area. As previously mentioned, these learnings can lead operators and IO administrators to take action, such as modification of data sampling frequency, addition of sensors, and investment of new technologies. However, perhaps it is placement reconfiguration that is ultimately necessary. Though sensor placement within a system has been accepted as norm per prior requirements, new insights through IO may lead to a more proper (and intelligent) placement of instruments, changing them from traditional jewelry to valuable harbingers.
Global Access

The effectiveness of an IO program is significantly increased when it reaches everywhere the operators are located. In today’s subsea oil and gas industry that modus operandi demands global access. Whereas accomplishing such a technological convenience is not insurmountable, several essential considerations are required for this wide-reaching communications network to be realized. The goal should be identical presence regardless of location.

The first hurdle to overcome is the “on-shoring” of data since practically all of the assets are rather remotely located. The key issues with respect to network communications are (1) desired functionality, (2) transmission medium, and (3) bandwidth. The majority of offshore assets have established communications circuits (primarily for remote operations centers); however, institution of a program with expanded purpose and capabilities, such as IO, may require a review of the established infrastructure from a capacity standpoint.

Secondly, the value of data cannot be ignored. When providing access to employees, operations centers, and partners, asset owners and IO program administrators must protect production and operational data as the asset it is. Protection can be accomplished many ways: secured, dedicated networks; access limitations; non-disclosure agreements; etc. It may seem an impossible oxymoron especially when partnering with an external organization and providing web access to trusted resources; nevertheless, it is not…it simply requires careful handling. This is where properly a crafted partnership between the asset owner/operator and the IO program administrator is absolutely vital.

Another consideration for effectiveness is a structured notification system. Just as operations continue around the clock, so does condition monitoring. Notification of events should be made within the operating company and the program administration organization—from there, other essential and value-added entities can be contacted, as needed. However, notification overload will likely lead to de-sensitization to any event; therefore, the protocol for notification should be carefully structured. Protocol deliberation points will include features, such as threshold of notification, appropriate personnel to contact, repeat notifications, and updates. Thought must also be put into methods of notification (e.g., email, mobile device, telephone, etc.) to extract maximum responsiveness of resources. The point is that even letting resources know of status changes requires careful planning and structure.

Finally, establishment of an operations command center can have a deep impact on the success of IO. Not only does it provide a single point of contact during event response; a command center serves as a central source for technical resources, documentation, data, analysis, and coordination. An IO command center must be designed to take full advantage of the resources available within the administering organization for the benefit of their operations and that of the assets. The key elements include uninhibited access to technical resources (via a functional communication plan and an approved response plan), documentation, data, and logistics utilities.

System Integration

Recall the definition for Integrated Operations: the systematic assimilation of resources to promote and yield the maximum benefit from available operational programs for the common purpose of the asset and its operations. However, simply considering each word in the term holds the fundamental intent to integrate operations. Operators and program administrators have a variety of tools at their disposal to accomplish this goal; it is the proper application and use of these different systems that will facilitate the final integration. The aim of this section is to identify the systems within those operations that should be integrated for successful implementation of an IO program. Ultimately, these information systems should, at a minimum, be readily at hand in an IO command center.

- **Condition Monitoring System [GUI]**: This graphical user interface (GUI) is likely the single most interfaced system for the average user. This is the face of the program through which personnel can view summaries and details of asset health, receive notifications, trend KPI, and link to other documentation. This face should be available through a secure web interface allowing local access and global, remote access. However, the GUI is simply the appealing “user-friendly” front of the real work occurring behind the scenes. It displays data from the historian which stores information from the controls systems and KPI algorithm calculator(s).
- **Engineering Document Management System**: An important reservoir of documentation including: specifications, design basis documents, test procedure, drawings (e.g., schematics, assembly diagrams, system layouts, etc.), reports, technical data sheets, operational procedures, etc. Life of field support demands that the system not only have access to the most current information, but historical “code of record” as well—enabling a transfer of knowledge and understanding of original to future generations.
- **Equipment Functional Location Database**: If properly administered, this is quite possibly one of the most vital wells of information for the installed base. This enables operators and administrators to identify the exact
components (down to the serial number) included in an installed system. As a result, when equipment or systems show trouble, responding personnel can access documentation and information, such as: installed configuration, part revisions, bills of material, test data, installation procedures, applicable non-conformance reports (on that or similar equipment), performance characteristics, material tracking, etc.

- **Service Notification (SN)/Field Non-Conformance Report (FNCR) Database(s):** As previously indicated, integration of this data system can aid in the investigation of events during root cause analysis. This information can provide insight not only to the history of a specific piece of equipment or system, but to similar parts as well.

- **As-Built Data:** These files contain the documented history of subsea systems. Ideally, they should be inclusive of test reports—e.g., factory acceptance testing (FAT), extended FAT, systems integration testing, completion, and commissioning—well log files, master equipment lists, master document registers, and operation and maintenance manuals (a.k.a. “rig books”).

- **Shop Schedule:** Visibility and “write” access to onshore maintenance resource and facility space scheduling can be one of the most valuable features of IO when condition/event remediation efforts threaten operations and/or production. Entry into a shop’s brick wall facilitated by authorized agents within the IO command center can be considered, perhaps, a marquis advantage of partnering with a subsea system provider for an IO program. Not only does the asset owner/operator have hard scheduling data with which to plan operations, but the provider can more accurately forecast work through maintenance and refurbishment work centers.

- **Service Coordinator:** Quite analogous to the shop schedule (above), visibility and write access to the offshore service schedule provides the operator with a means of planning continued operations based on the service center’s availability of technical resources. Loading the resources with skill sets, experience, and credentials allows the administrator’s IO command center to schedule work with the most appropriate resource(s), and the operator to make informed decisions based on the available and/or preferred personnel.

- **Logistics, Shipping, and Receiving:** These functions become exponentially easier to execute as through involvement with an IO program, they have instant access to the latest shop schedules, equipment statuses, severity of asset health (for purposes of prioritizing), mobilization dates, etc. Logistical planning becomes the model example of how IO facilitates communication within operations, provides transparency, and aids in the success of operations from the day-to-day to the most critical rapid responses. The ability for the IO command center to access all applicable data and inform the operator of the exact status of every aspect of an on-going operation is truly a sign of success.

Proper and successful integration relies on a bonding agent authorized and prepared to interface with all necessary people, organizations, processes, and operations. That agent is the partnership between the provider and the operator, and its primary instrument for effectiveness is the IO command center. The crucial component of success to the integration is dedication—dedication of resources, -to the commitment, -to the program, -to the partnership, -to the continuance of operations, -to the common purpose. When rapid response firefighting is indistinguishable from day-to-day operations, maximum effectiveness has been achieved.

**Expected Results of Enhanced Collaboration**

The implementation of Integrated Operations into offshore assets is widely accepted as the digital future of oilfield operations, with defined benefits of: accelerated production, increased recovery, reduced operating costs, and improved safety through exposure reduction (OLF, 2008).

Provided the cost of rig and vessel day rates, expedited equipment mobilizations, executing operations on a short notice, and production downtime, the general belief amongst operators is that the ability to track the health of a system (or component)—and identify suboptimal performance prior to resulting in [even just one] sudden/catastrophic failure and shut-in—would result in savings that exceed the cost of the entire IO program. Having this forecasting data allows operators and their collaborative partners the time to employ mitigation plans and execute remediation activities off of the critical path and at a pace that allows implementation of the best solution. Partnership with the subsea systems provider in the IO and IM programs not only eases this process, but also affords the best opportunity for the experience to be rolled-into the solution for future avoidance.
There is a cycle of learning and system improvement (refer to Figure 4), which exists and repeats throughout the life of a field. The cycle sees four major phases: design; install; monitor, predict, and resolve; and improve. Consider the case of traditional subsea installation and operations: A system is designed on best [known] practices and life of field (LOF) predictions/assumptions; however, each installation is unique—quite literally by nature. As the field produces, operators analyze performance data to understand how baselines have changed, and coordinate work-over activities in response to system failures. Years, and recurring events, may pass before the breakdowns are understood to the point of being ready develop a resolution that adequately addresses the root cause. But at what cost has the temporary bandage come in the meantime? Additionally, after such a negatively perceived venture, it is unlikely that further learnings will be developed into funded solutions. Though, perhaps, newer installations will stand to benefit from the learnings.

Typically, that it ever finds closure can be view as a negatively-motivated process laden with service notifications that drive re-design on the basis of inadequacy of, or failure in, purpose. However, when integrity management and integrated operations programs are in place and effective, it becomes a more frequently cycling process that finds its drivers in experience, greater insight, and the commitment to improvement. Subsequently, the fact that the process repeats more often should not be viewed negatively as identification of system flaws and oversights in the FEED phase of the project. Rather, the on-going execution of this sequence indicates: (1) deeper understanding of the systems and installation, (2) commitment to continuous improvement, (3) application of lessons learned for system optimization, and (4) efficiency in processes and operations.

Hence, consider the case that is converse from the previously discussed: With IO effectively employed, a system is still designed on the basis of LOF assumption; however, now well-documented experiences and actual performance data are major contributors, as well. As the asset settles-in, and the field produces, conditions are noticed early—prior to complete failure—and remediation activities and system improvements can begin immediately with all condition and performance data present. Global subject matter experts have ready access to all pertinent data; the subsea system provider is immediately aware of the concern and devises short- and long-term recommendations; and the remediation process is set in motion. The optimized solution is designed, built, and installed with efficiency enabled by streamlined processes and the condition of the existing system known throughout the process. Newer installations benefit from the experiences more readily because evolved and justified precedence has been adopted.

As the cycle of constant improvement executes, integrated operations contributes to each stage. More importantly, the IO and IM programs adapt to the new methods, configurations, processes, and learnings. The result is efficient, collaborative operations that learn from process data to improve performance.

Conclusions

The concepts of Integrated Operations and Integrity Management have only, relatively recently gained acceptance across the offshore oil and gas industry as meaningful programs that, if properly implemented, are an effective tool actively contributing to LOF operational objectives that maximize the value of a subsea asset: accelerated production, increased recovery, reduction
of operating costs, and improved safety. However, today it remains that only a small percentage of operators have employed such programs; and, even then, they have not implemented them across their complete portfolios of subsea assets. This could be due to perceived risk in development, implementation, and administration (OLF, 2008). Risk in the magnitude of scope; risk in the costly investment of qualified service providers; risk in following a path that has been blazed, but is not yet well-beaten.

The established subsea system provider, with whom operators have previously relied on for the delivery of equipment and services to last the life of the field, has the knowledge and experience to be positioned as an exceptional partner in the creation and operational direction of IO and IM programs on behalf of the operator. Without an effective partner, the programs risk years of inefficiency, wasted effort and lost funding. Implementation success relies on:

1. Properly identifying risks—requiring the investigators to completely comprehend the systems and included equipment;
2. Development of insightful and telling key performance indicators for implementation in risk-based inspection programs and real-time condition monitoring systems—requiring that developers are familiar with all failure modes and are able to recognize their onset
3. The ability to respond to trouble notifications and plan and execute short- and long-term remedies prior to complete failure—requiring a structured rapid response program that draws from the best available talent…regardless of physical location
4. A culture of continuous improvement that understands that as our knowledge of the asset changes, so must the way in which it is analyzed—requiring innovative technology development and the knowledge necessary to appropriately upgrade systems.

Therefore, a strong partner in subsea is the most vital element of success for operators implementing IO and IM programs. The subsea system provider is a value-added partner for IO and IM programs. It already provides all of the individual services—including design, analysis, systems integration, LOF servicing (e.g., maintenance, expansion, and upgrades), etc.—and, along with the operator, benefits from the integration of all of its resources and operations for the common purpose of the asset: extended, productive, and safe operation.

Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CAPEX</td>
<td>Capital Expenses</td>
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<tr>
<td>FEED</td>
<td>Front-End Engineering and Design</td>
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<tr>
<td>FMECA</td>
<td>Failure Modes, Effects, and Criticality Analysis</td>
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<td>FNCR</td>
<td>Field Non-Conformance Report</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HMI</td>
<td>Human-Machine Interface</td>
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<td>IM</td>
<td>Integrity Management</td>
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<td>IO</td>
<td>Integrated Operations</td>
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<td>IOR</td>
<td>Increased Oil Recovery</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<td>LOF</td>
<td>Life of Field</td>
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<td>OPEX</td>
<td>Operational Expenses</td>
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<td>Preventative Maintenance</td>
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<td>RBI</td>
<td>Risk-Based Inspection</td>
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<td>ROI</td>
<td>Return On Investment</td>
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<td>SN</td>
<td>Service Notification</td>
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References


